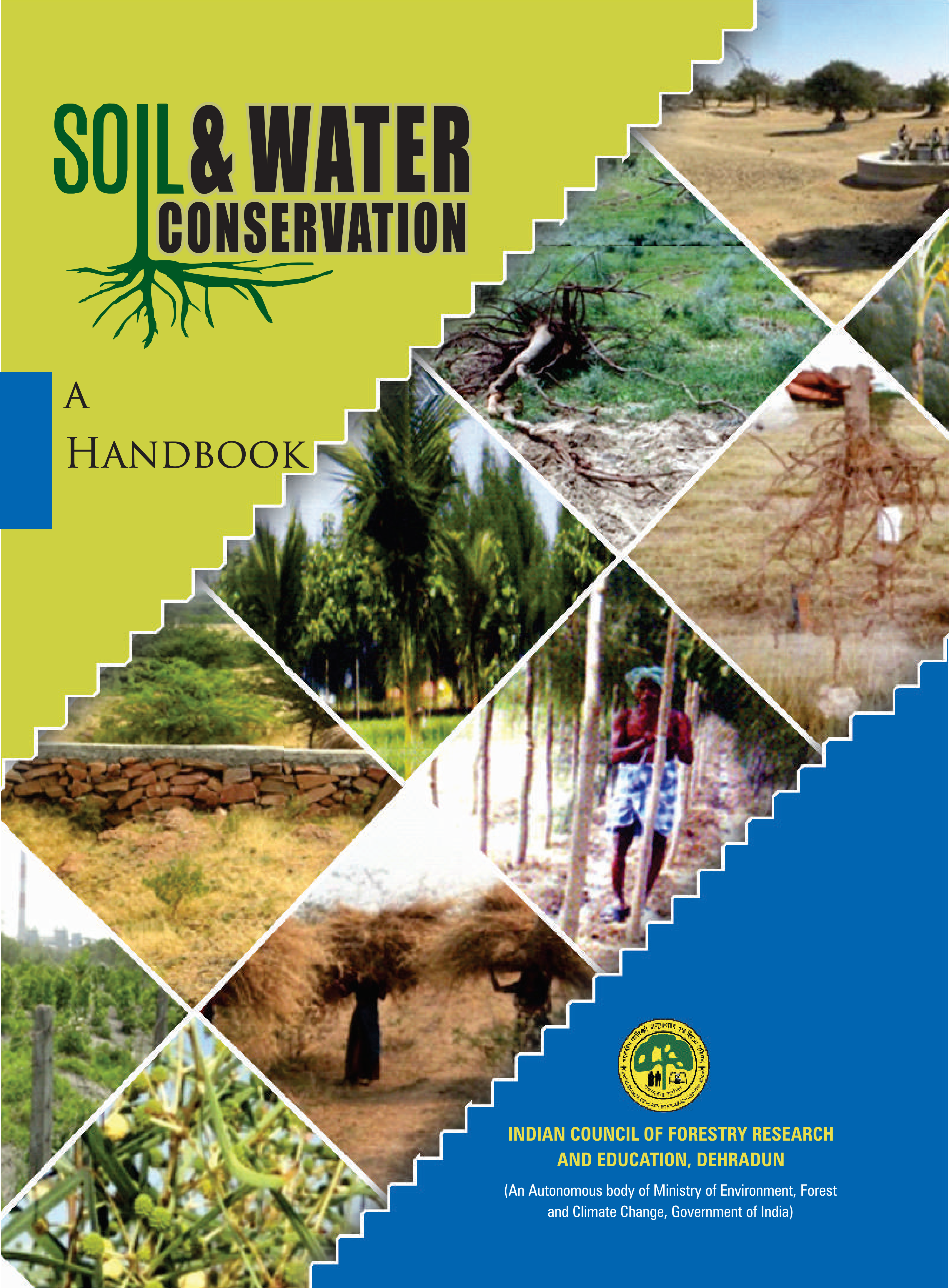
SOIL & WATER CONSERVATION

A HANDBOOK



INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION, DEHRADUN

(An Autonomous body of Ministry of Environment, Forest and Climate Change, Government of India)

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A HANDBOOK

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
P.O. New Forest, Dehradun - 248 006

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Foreword

Dr. Suresh Gairola, IFS
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ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need to present its research findings to the stakeholders in a simple and lucid manner, to improve the visibility and relevance of ICFRE. Therefore it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE be published in the form of operational manuals/user manuals. It is also desirable that the manual should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

The manual 'Soil and Water Conservation in Forestry', focuses on detailed knowledge and understanding on various processes of soil loss, problems generated through such processes and control measures developed at ICFRE's Institutes that are serving as an important step in reducing soil and water losses and improving forestlands productivity. The key theme of this compiled information is to reflect research evidences based on specific field treatments and observation recordings in afforestation/reforestation programmes implemented for controlling soil losses caused by wind and water erosion and developing protection forests over mine overburdens, ash ponds and saline-alkaline lands rehabilitation. The inclusion of many working examples in this manual is of great assistance to the readers and project implementing agencies working in this direction.

I hope this manual would be useful in implementation of different programmes of afforestation/reforestation in combinations with soil and water conservation measures ensuring livelihood related options and enhancing green over in the region. This altogether will strengthen capacity to conserve these valuable resources, reduce forest degradation, increase green cover, protect habitats, sequester carbon and favour societal benefits.

I congratulate the efforts made by the authors and I am sure that this publication will prove effective to all the people working towards the conservation and sustainable management of native biodiversity in the country.

Dr. Suresh Gairola

Preface

Problems originated by soil erosion and lowland flooding are more frequent now a days that provides evidence of ecological instability. Loss of soils either through wind or water erosion affects useful land resources and environmental quality, and creates threat to all facets of land productivity. There are growing evidences that an agricultural revolution is based on principles of better soil management that can have a significant positive impact on the sustainability and productivity of degrading lands. Increased human and livestock population densities are leading to rapidly increasing use of cultivable lands and overexploitation of natural resources like soil and water. In absence of adequate protective measures these degrading lands are too fragile to be disturbed easily. As large areas in India are threatened by land degradation due to wind and water erosion, both short and long-term actions are required to ensure optimal land use, sustain productivity, and maintain the quality of land resources. While windblown sands are indicators of low vegetation cover and increased fragility of lands, the increasing surface runoff means that the soil has become unreceptive and less porous. The challenge is to increase vegetation cover and enable the entry of as much rainfall into the soil as possible by promoting conditions that stimulate an absorptive capacity of the lands. Such conditions will stabilize the landscape, limit erosion and maximize the usefulness of the rainfall.

Although there is a complex set of interactions among weather, plants, soils, water and landscape, promoting soil and water conservation and rainwater infiltration into the soil will be useful in enhancing plant establishment and growth. This manual reflects the research evidences and field works on soil and water conservation and rainwater harvesting measures applied by researchers of different institutes of Indian Council of Forestry Research and Education (ICFRE) to control soil and water erosion, enhance vegetation cover area under protection forests and enhance land productivity. In this Chapters 1 deals with the general introduction to soil erosion and factors that influence this process like amount and intensity of rainfall, topography, physical and chemical properties of the soil, nature and extent of soil vegetation cover, tillage activity, soil moisture, and wind velocity. Chapter 2 focuses on wind erosion and control measures for stabilization of sand dunes and erections of wind breaks and shelterbelts and their importance in increasing vegetation cover and plantation/agricultural productivity. Chapter 3 describes soil and water losses through water erosion, conservation measures including rainwater harvesting and drainage line treatments and their benefits in afforestation/reforestation and enhancing green cover and biological diversity and carbon sequestration. The 4th chapter covers aspects of soil and water conservation in developing protection forests and rehabilitating mine overburdens, ash ponds and saline-alkaline lands. It is followed by bibliography.

This documentation has only been possible by supports of Directorate of Extensions and the scientists and staffs of different institute of ICFRE, Dehradun, for which we are grateful. We would also like to thanks the staff and scientists of Forest Ecology and Climate Change Division, AFRI, Jodhpur. It will not be justifiable if not mentioned the name of Dr. R.K. Verma, Scientist G from HFRI, Shimla, Sh. N. Bala, Scientist F and Sh. B.M. Dimri, Scientist E from FRI, Dehra Dun, Dr. P.K. Das, Scientist D from IFP, Ranchi and Dr. A.C. Suryaprabha, Scientist C from IFGTB, Coimbatore for their contributions in this compilation.

Thus I hope that this documentation will be useful to both filed level planners, non-government organizations and researchers equally and help in effective planning and transferring the knowledge in protecting and conserving natural resources, i.e. soil and water for restoring degraded forest lands, increasing green cover and promoting ecological values of these resources for rural livelihood.

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Contents

1 GENERAL INTRODUCTION

Soil and water are important natural resources for sustainability of agriculture and our surrounding environment. These resources however, are under immense pressure because of ever increasing human and livestock population thereby ensuing growing demand for food, fiber and shelter. Soils are formed through a diverse interaction among a number of forces, including climate, relief, parent material, organisms, all acting over time. Thousands of years are taken for a soil to form and most soils are still developing following changes in some of these soil forming factors, particularly climate and vegetation (Karmakar et al., 2016). In contrast, about 147 million hectares (mha) of land in India is under varying processes of degradation. This includes water erosion in 94 mha, acidification in 16 mha, flooding in 14 mha, wind erosion in 9 mha, salinity in 6 mha and a combination of factors in 7 mha. This is extremely serious because India supports 18% of the world's human population and 15% of the world's livestock population, but has only 2.4% of the world's land area. Despite its low proportional land area, India ranks second worldwide in farm output. Agriculture, forestry, and fisheries account for 17% of the gross domestic product and employs about 50% of the total workforce of the country. Soil and water conservation are adopted to obtain the maximum sustained level of production from a given area of land by preventing soil degradation and environmental pollution. Thus soil and water conservation are indispensable ways of keeping these resources in place and maintaining the functions of the soil in sustaining plant growth and agricultural production. Soil and water conservation practices involve managing soil erosion and its counterpart process of sedimentation, reducing its negative impacts and exploiting the new opportunities created by it. Young (1989) defined soil conservation as a combination of controlling erosion and maintaining soil fertility. Earlier, the focus of soil and water conservation has often been on trying to keep the soil at its place by plot-level activities only, but the attention has been diverted to landscape level approaches recently where sedimentation is studied along with erosion, and the role of channels (footpaths, roads and streams) is included as well as the 'filters' that restrict the overland flow of water and/or suspended sediment (Dumaski and Peireti, 2013).

SOIL EROSION

Erosion is the action of earth surface processes that removes soil, rock, or dissolved material from one location on the Earth's crust, and then transports it to another location. This natural process is caused by the dynamic activity of erosive agents, i.e. wind, water, ice (glaciers), snow, plants, animals, and humans. In accordance with these agents, erosion is sometimes divided into wind (aeolian) erosion, water erosion, glacial erosion, snow erosion, zoogenic erosion, and anthropogenic erosion. Because of these anthropogenic and natural factors soil and water resources are being deteriorated. Soil erosion is one of the several major deteriorative processes affecting soil quality (loss of organic matter and mineral contents) and hampering agricultural productivity because of excessive surface runoff or wind action. Soil erosion is a naturally occurring dynamic process which affects all type of landforms. While erosion is a natural process, anthropogenic activities have increased by 10-40 times the rate at which erosion is occurring at global level (Dotterweich, 2013). According to an estimate, soil erosion is taking place at the rate of 16.35 tons/ha/year which is more than the permissible value of 4.5–11.2 ton/ha in India (Narayan and Babu, 1983). About 29% of the total eroded soil is lost permanently to the sea, 10% of it is deposited in reservoirs and the remaining 61% is dislocated from one place to another place (Narayan and Babu, 1983). Soil erosion may be a slow process at some places and remain unnoticed but at some of the sites it may be at an alarming stage resulting in reduction in crop production potential and damaged drainage system. Human activities have raised the rate of erosion by 10-40 times the rate at which the erosion is occurring at global level. Erosion causes both land degradation and reductions in agricultural productivity resulting in environmental problems worldwide. Sea water also washes off soils along the coastline. It washes away farming areas along the coast and also creates problems for fishermen who use beaches to go into the sea instead of fishing harbours.

SOIL EROSION FACTORS

Soil erosion is the wearing away, detachment and transportation of soil from one place and its deposition at other place by moving water, blowing wind or any other cause including gravity force. Over-grazing, deforestation, wind action, water, glacier, etc. topography *viz.* steep slopes and heavy rainfall, faulty methods of agriculture, over – irrigation, shifting agriculture etc; Other anthropogenic factors *viz.* mining, industrial activities etc lead to loss of fertile top soil, lowering of the underground water table and decreasing soil moisture, drying of vegetation and extension of arid lands, Increase in the frequency of droughts and floods, silting of river and canal beds and recurrence of landslides. Mass movement is the downward and outward movement of rock and sediments on a sloped surface, mainly due to the force of gravity. Mass movement is an important part of the erosion process, and is often the first stage in the breakdown and transport of weathered materials in mountainous areas. Mass-movement processes are always occurring continuously on all slopes. Some mass-movement processes act very slowly, whereas others occur very suddenly but with disastrous results. Any perceptible down-slope movement of rock or sediment is often referred to in general terms as a landslide. Slumping happens on steep hillside areas and occurs along distinct fracture zones, mostly within materials like clay that, once released, may move quite rapidly in downhill areas. The area often shows a spoon-shaped depression from where the material begins to slide down slope of the hill. In some cases, the slump is caused by water beneath the slope weakening it. Surface creep is the slow movement of soil and rock debris by gravity which is usually not perceptible except through extended observation. However, the term can also describe the rolling of dislodged soil particles of 0.5 to 1.0 mm in diameter by wind along the soil surface. Thus most important factors that influence erosion are:

- The amount and intensity of rainfall in the region
- topography with special reference to slope of area
- physical and chemical properties of the soil
- nature and extent of soil vegetation cover
- tillage activity
- soil moisture
- wind velocity

Amount and Intensity of Rainfall

Rainfall is the most important factor causing soil erosion through splash and excessive run off from an area. Erosion by rain drop is splash, which is a result from the impact of water drops falling directly on the soil surface. Although the impact of rain drops on water in shallow streams may not splash soil, but it cause turbulence and provides a greater sediment carrying capacity. Large drop may increase the sediment carrying capacity of run off as much as 12-folds (Mohr *et al.,* 2013). Morgan (2005) observed that particles between 0.063-0.250 mm are the most detachable by raindrop impact, whereas Thomaz (2012) recorded distribution of particle sizes detached by splash like 42.3% macro-aggregates of >0.250 mm and 57.7 % micro-aggregates of <0.250 mm. Measurements show that rain splash mobilizes approximately 45.3% of the total material transported under rill system (Thomaz, 2012). Under gentle rainfall, water will enter the soil where it strikes and some will slowly run off, but if it occurs in torrents, as the chances is, there is not enough time for the water to infilter through the soil and it runs off from the site resulting in erosion. Run off that causes erosion, therefore, depends upon intensity, duration, amount and frequency of rainfall. It is observed that rains in excess of 5 cm per day always causes run off whereas those below 1.25 cm usually do not cause run-off.

- Topography/slope of lands: Increased slope gradient accelerates erosion as it increases the velocity of flowing water (Singh, 2011; Sun *et al.,* 2014). Rate of soil erosion also increases with increasing in the length of the slope. The greater accumulation of run-off on longer slopes of terrain increases its soil detachment and transport capacities (Mahapatra *et al.,* 2018). Midslopes and valleys are the major topographical contributors to soil erosion unless influenced by other factors like vegetation cover and tillage activities. Small differences in land slope make a big difference in soil damage and loss. The law of hydraulics indicates that four - time increase in slope gradient doubles the velocity of flowing water. This doubled velocity can increase the erosive power four times and the carrying capacity of eroded soil by 32 times. In one of the experiments in United States of America, it was observed that the loss of soil per hectare due to erosion in a maize plot was 12 tons when the slope was 5%, but it was as high as 44.5 tons under 9% slope. Often consolidation of small fields by removing the field bunds into larger ones results in longer slope lengths that increase the erosion potential due to accumulated water and increased velocity of run-off water. Increased slope gradient significantly increases soil erosion significantly even under the same land use type, however, but differences in soil erosion responding to slope gradients differ between land use types.

- Soil physical and chemical properties: Soils with faster infiltration rates, higher levels of organic matter and improved soil structure generally have greater resistance to erosion processes. There are many characteristics and indicators of soil quality like soil bulk density, good soil pores and water-holding capacity, infiltration rates and high levels of soil organic carbon and beneficial soil organisms too (Jankauskas *et al.,* 2008). The erodibility of the soil is also influenced by soil texture, structure, soil surface features, particularly stoniness (i.e., size of rock fragments like gravel, pebbles, stones and/or blocks), and environmental condition and the amount and kind of salts present in the soils (Descroix *et al.,* 2001; Singh, 2011). Energy require to detach one kilogram of sediments by raindrop impact is minimum for particles of 0.125 mm. Particles ranging between 0.063 to 0.250 mm sizes are the most vulnerable to detachment. This means that soils with high content of particles falls into vulnerable range, for example silty loam, loamy, fine sandy and sandy loam are the most susceptible soils to detachment. Thus soil detachability increases as the size of the particle increases but soil transportability increases with the decrease in particle size. Clay particles are more difficult to detach than sand, but are easily transported on a level land and much more rapidly on slopes. Further, there is less erosion in sandy soil because water is absorbed readily due to high permeability. More organic manure in the soil improves granular structure and water holding capacity as well. As organic matter decreases in the soil, the erodibility of soil increases. Fine textured and alkaline soils are more erodible as compared to the other soils.

- Vegetation cover: Potential of soil erosion usually increases if the soil has no or very little vegetative cover. Plant and its residue protect the soil significantly from the impact of raindrops or wind action. Existing vegetation helps to slow down the movement of surface run-off and allows excess surface water to infiltrate in the soils. The erosion-reducing capacity of plant and/or residue vegetation cover depends on the type, extent and quantity of vegetation cover. Vegetation and residue in combinations completely cover the soil and act as the most efficient system in controlling soil loss. Presence of vegetation as ground cover retards soil erosion and soil loss even in sloppy areas (Singh, 2011). Observations of Shit *et al.* (2014) indicates that highest spatial coverage of vegetation (73.5%) yield very low amount of soil, whereas, the lowest spatial vegetation coverage (5.9%) leads to severe soil loss. Forests and grasses are more effective in providing soil cover than cultivated crops. Vegetation intercepts the erosive beating action of falling raindrops and retards the amount and velocity of surface fun off, permits more water flow into the soil and creates more storage capacity in the soil. Thus forest, shrub and dense grassland provides the best protection from erosion, but the decadal trend of reduced soil erosion is greater for the lower vegetation cover of woodland and moderate and sparse grassland. Soil erosion by wind is also caused by lack of vegetation cover, dry pulverized soils, strong wind velocities, and poor land management practices such as continuous tillage and over-grazing. Hata *et al.* (2018) recorded extremely large quantity of soil loss from bare ground areas and exposure of sub-soils at the soil surface after vegetation degradation also increase soil loss, which alter soil chemical properties and such alteration for a longer period limit the establishment of plant species.

- Tillage Activity: Tillage activity has a large effect on soil surface micro-topography and consequently on soil degradation process that is accounted for while assessing the erosion impacts on soil productivity, environmental quality or landscape evolution (Zhao *et al.,* 2018). Changes in tillage depth and tillage direction cause the largest variations in soil redistribution rates, although other factors like tillage speed and implement characteristics, also play an important role in it. Decreasing tillage depth and ploughing along the contour lines reduces tillage erosion rates significantly and can be considered as effective soil conservation strategies. Erosivity is characterized by the tillage transport coefficient and are very consistent and range in the order of 400–800 kg $m^{-1}yr^{-1}$ and 70–260 kg $m^{-1}yr^{-1}$ for mechanized and non-mechanized agriculture, respectively (Van-Oost *et al.,* 2006). A comparison of tillage erosion rates and water erosion rates indicates that tillage erosion rates are at least in the same magnitude or higher than water erosion rates in most of the cases. High redistribution rates of tillage practices are associated with various processes and its direct effect on soil properties. Tillage negatively impacts almost every one of those characteristics, though some soils erode more readily than other under the same environmental conditions. Tillage and winter fallow cause degradation in soil quality resulting from the decomposition of biological nutrient reserves. The conservation and soil quality benefits derived from conventional practices may rapidly decline once an area is tilled and left fallow during non-cropped period. Overall, the results indicated that NT has greater potential to reduce runoff and soil losses in temperate regions where soils of peri-glacial influence are relatively young, moderately weathered and fragile compared to the heavily weathered clayey tropical soils that are well aggregated and less erodible (Mhazo *et al.,* 2016). The infiltration and permeability of the soil is improved by the practice of proper tillage and thereby reducing the chances of erosion. But excess tilling exposes the soil to erosion, especially by wind. A small change like contour tillage and reservoir tillage reduces surface run-off by 60% compared with a smooth slope during overland flow, whereas only a small reduction in run-off occurs during rill flow (Zhou *et al.,* 2018).

- Soil Moisture: Soil strength and thus stability concerning wind and water erosion are also controlled by the soil water content. The study of Bolte *et al.* (2011) indicates that reduction of soil critical water content and soil water matric potential- a component of water potential due to the adhesion of water molecules to undissolved structures of the system, leads to a steeply significant, almost 20-fold increase in soil losses under wind erosion, i.e. projected at 0.56 up to 11.00 Mg ha^{-1} h^{-1}. An experimental evidence indicates that soil erosion is significant when the wind velocity at a height of 0.4 m is over 6.0 m s^{-1} (which corresponds to 14 m s^{-1} at a height of 10.0 m) and the volumetric water content decreases to <0.17 cubic meter per m^3 (Yuge and Anan, 2019). Variations in initial water content is associated with large changes in soil erodibility, particularly for the initially wet soils of higher strength, and rates of runoff erosion are controlled by rates of detachment of the sediment. The presence of high water table checks the infiltration and permeability, thus allowing more flow of water on the surface, and greater erosion. At the same time, long continuous rainless periods cause loosening of soil and thus expose the soil to erosion by wind. Furthermore, soil moisture content at the time of compaction has a significant influence on soil erosion resistance, because at constant moisture content, the erosion resistance increased as the dry unit weight of the soil increases (Hanson and Robinson, 2013).

- Wind Velocity: Erosion of soil by the action of wind is generally known as wind erosion. Wind erosion is the serious problems in the arid and semi-arid regions where forest cover is very less and mainly in lands devoid of vegetation (Gurjar *et al.,* 2017). Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. Soil movement is initiated as a result of windforces exerted against the surface of the ground. For each specific soil type and surface condition there is a minimum velocity required to move soil particles. Arid deserts and semiarid steppe are also influenced by wind action, which causes erosion and deposition in environments where sediments have been recently deposited or disturbed. Wind speed of >4 km/hr is required for sand transport. However, soil particle size also affects wind erosion and sand drift as heavy particles creep on the soil surface, while fine and very fine sand (0.25 to 0.05 mm) fly in suspension. Wind erosion is a natural process where the soil is moved, carried, and transported by the force of the wind from one place to another. In order to be transported, threshold velocity of the wind is needed. However, this depends on the size, weight, and wetness of the soil particles. Soils are composed of different-sized particles: silt, clay, and sand. In order to be moved by the wind, each soil must need to be less than 1mm. The size of the silt particle ranges from 0.05-0.002 mm, sand particle ranges from 2.00-0.05 mm and clay are less than 0.002 mm. The clay which has the least size, however, makes itself hard to be carried by the wind because of its ability to clump together with other particles. This makes the silt and sand be more susceptible to wind erosion. In order for erosion to occur, a wind velocity must be 20 to 30 kilometers per hour. When threshold velocity is met, the particles are moved to the other place at a different height and transported at different distances. There are three ways at which the particles are being moved: suspension, saltation, and surface creep.

CONSERVATION MEASURES

Soil and Water Conservation are strategies that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion. It is a worldwide strategy in the context of a sustainable and poverty-orientated natural resource management and is an integral part of Watershed Management - a concept recognizing judicious management of soils, water and vegetation. Although watershed Management was formerly considered to be nearly synonymous with soil and water conservation, comprises a variety of further activities that attempt to improve the living conditions of the people living within the respective watershed. There are many scientific ways and practices that can reduce and limit erosion of vulnerable soil. For proper management of the land and water resources and prevention, reduction and control of soil erosion the simplest and most natural ways are plantations and developing vegetation cover. Plantations or forests have important protective as well as productive roles. They not only supply timber, fuel, fodder and a variety of other products but also have a moderating influence against floods and erosion and help maintain soil fertility. Plants establish root systems, which stabilizes soil and prevents soil erosion. Adopting engineering measures for soil and water conservation measures include all mechanical or structural structures that control the velocity of surface runoff and thus minimize soil erosion and retain water where it is needed. Such structures are designed either to conserve water or to safely discharge it away wherever required. A variety of soil and water conservation measures are known to us. These technologies can be differentiated either by their main purpose or by types as many of them fulfill several functions simultaneously. There classifications are as below:

Biological Measures

These are agronomic practices which utilize the role of vegetation and help in minimizing the soil erosion by increasing soil surface cover, surface roughness, surface depression storage and soil infiltration. Some of them are:

- strip cropping/alley cropping/hedgerow,
- diversified cropping system involving annuals and perennial in rotations, sequences and association;
- Improved fallow systems or maintenance of soil cover with crop residues and green manure crops, particularly legumes;
- natural vegetative strips of grasses,
- planting tree and afforestation (Kasam *et al.,* 2014) etc.

Soil Managements

Soil management is related to the ways of preparing the soil to promote dense vegetative growth and improve the soil structure so that it is more resistant to soil erosion either by wind or water. Some techniques included in this group are: minimum tillage, crop rotation (food/cover crops), manure, sub-soiling and drainage. Mulch of plant residues or other material is also applied on the surface of the soil with the object of moisture conservation, temperature control, prevention of surface compaction or crust formation, reduction of run-off and erosion, improvement in soil structure and even weed control (Dabi *et al.,* 2017).

Mechanical Measures

Mechanical or physical methods are viewed as an attempt to control the energy available for erosion (rain splash, runoff or wind velocity). These mechanical measures play a vital role in controlling and preventing soil erosion. They are adopted to supplement the agricultural or forestry practices and include bandings (i.e., contour bund, graded bund etc.), terracing (either channel type or ridge type) and contour stonewall, diversion drains, drainage line treatments etc. Various mechanical measures can be used for gully erosion control and diversion of flowing water and air to reduce run off and impound water for longer time to help infiltration into the soil.

2 WIND EROSION AND CONTROL MEASURES

Wind erosion is a major geomorphologic force especially in dry areas, where Aeolian landforms are common throughout the world shaping the face of the landscape. In coastal area also, wind shows several effects on the processes influencing coastal geomorphology that include wind stress on the water surface during storms, such as tsunami, hurricanes or typhoons, inducing short-term above normal sea elevations or storm surge (Healy, 2005). A considerable mass transport is taking place along the sea surface waters in the wind direction, so that onshore storm winds force the seawater up against the land. Wind causes erosion and deposition in environments where sediments have been recently deposited or disturbed. These environments include lake and ocean coastline beaches, alluvial fans, and agricultural fields where topsoil is being disturbed by cultivation. Wind and water erosion are the widest spread problems of environmental degradation since the second half of the nineteenth century, specifically in the areas with contrasting seasonal climate and increased human activities (Bakker *et al.,* 2007; McTainsh *et al.,* 2011). Wind erosion is the phenomenon of transportation of worn-out soils and their accumulation in any other place by the action of wind (Acar and Dursun, 2010). He *et al.* (2011) observed highest climate factor index of annual wind erosion in summer and lowest in winter, where climate factor index has a very good exponential relationship with the wind speed.

This process is a major source of land degradation, evaporation, desertification, harmful airborne dust, and crop damage especially after being increased far above natural rates by human activities such as deforestation, urbanization, and agriculture.

WIND EROSION PROCESS

Wind erosion is very severe in arid areas and severity increases during droughts. For example, in the arid plains, it is estimated that soil loss due to wind erosion can be as much as 6100 times greater in drought years than in wet years.

Wind Erosion Types

The loss of soil by wind action involves two processes like soil detachments and transportation.

- Abrasion: The abrasive action of the wind results in detachment of tiny soil particles from the granules or clods of which they are a part. When the wind is laden with soil particles, however, its abrasive action is greatly increased. The impact of these rapidly moving grains extricates other particles from soil clods and aggregates.
- Deflation: It is the process where the wind picks up and carries away loose particles or movement of sand grains. It is further divided into three categories such as surface creep, saltation and suspension based on their grain sizes. In surface creep, larger and heavier particles slide or roll along the ground. Under saltation process, the particles are lifted to a short height into the air, and bounce and saltate across the surface of the soil. In their fall sand particles bombard other particles to move in definite trajectories to hit other grains to move. Sand grains may escape the dune bodies and move between dunes as drifting sand. Under suspension, very small and light particles are lifted into the air by the wind, and are often carried for long distances. Saltation is responsible for

about 50–70% of wind erosion, followed by suspension (30–40%), and then surface creep (5–25%). Silt soils tend to be the most affected by wind erosion as silt particles are relatively easily to detach and carry away.

Wind Erosion Factors

The ability of the wind to erode the soil surface is governed by two main factors, i.e. air density and wind velocity. The erosive power (i.e., capacity of wind to cause erosion) of the wind (E) is given as:

$E = V^3 p$

Where V is wind p velocity, and is air density. The density has relatively little impact on the power of the wind. The erosive force of the wind is primarily related to its velocity. Its importance is seen as erosive power varies with the third power of wind velocity. It means doubling of the wind velocity increases the erosive power by 8-fold while a tripling of wind velocity produces a 27-fold increase in erosive power of the wind. However, a wind speed of >4 km/hr is needed for sand transport, whereas sand particle size, as heavy particles creep on the soil surface, while fine and very fine sand (0.25 to 0.05 mm) fly in suspension.

The speed of the moving sand depends on several factors including the textural sand characteristics, grain size and shape, wind characteristics, and topography. Increased wind speed, direction, cohesionless soils, large exposed area and lack of soil protection lead to wind erosion. Thus sand drift and types of dune forms are influenced by topography, roughness, soil types, soil particle size, lacking of vegetation and low soil moisture content. Landscapes created from wind erosion and depositions consist of loose sand and various forms of sand dunes. This process occurs throughout the world, even in the wet and humid areas and creates serious impacts. The risk of wind erosion is lower than water erosion but greatness and aspects of wind erosion is higher than water erosion throughout the world. Loss of soils and nutrients increases with increase in wind velocity and for every 1000 kg soil eroded by wind action, there is loss of 15 kg organic matter, 227 g available nitrogen, 262 g available phosphorus and 120 g available potassium (Gao *et al.,* 2014). Important characteristics of dune sands are extremely low natural moisture content ranging between 0 and 3–4%, because of the infrequent rainfall, deep water table and high capacity of evaporation in the region. The coefficient of permeability is in the range of 3.4×10^{-4} to 1 x 10-2 cm/s indicates a predominant free draining soil, i.e. water can permeate down directly into the sand bed because of low moisture holding capacity of these sands. The maximum water absorption value of these soils does not reach more than 1% (Al-Ansary *et al.,* 2012). The particle size for Aeolian sands has been found in the range 0.08–0.80 mm or even between 0.08 and 0.40 mm.

SAND DUNES

The accumulation of windblown sand marks the beginning of one of nature's most interesting and beautiful phenomena, the sand dunes. Sand dunes are found throughout the world. The most famous are in Africa, along the coasts of Chile, France, Belgium and the Netherlands, and in Australia, the Middle East and the ‘Thar’ in India. The largest sand area is the Sahara Desert, which covers 3.5 million square miles. In addition to the remarkable structure and patterns of sand dunes, they also provide habitats for a variety of life, which is marvelously adapted to this unique environment. About 48% area of arid districts of Rajasthan is occupied by sand dunes.

Process of Sand Dune Formation

Sand dunes form an important and unique ecosystem that can be mobile or fixed by vegetation The origin of sand dunes is very complex, but three essential prerequisites for dune formation are: i) an abundant supply of loose sand in a region generally devoid of vegetation, i.e. ancient lake bed or river delta; ii) a wind energy source sufficient to move the sand grains; and iii) a topography whereby the sand particles lose their momentum and settle down (Singh, 1982). Sand dunes first begin their life as a stationary mound of sand that forms behind some vertical obstacles of barriers. When the dunes reach a certain size threshold they continue growth with active surface migration. In a migrating dune, grains of sand are transported by wind from the windward to the leeward side and begin accumulating just over the crest portion of the dune. In this process, the dune migrates over the ground because sand is eroded from one side and deposited on the other side leading to cause the appearance of the dune to take on a wave shape. Active movement of sand particles across the dune causes windward slope to become shallow, while the leeward slope maintains a steep slope known as slip-face. Sand movement is highly affected by geomorphology, vegetation, shapes and height of the terrains and the grain sizes of the sand and wind energy.

Types of Dunes

Worldwide inventories of deserts define five types of dunes: crescentic, linear, star, dome and parabolic (Schad, 1979). Crescentic dunes are the most common dunes and the crescent is generally wide than long. It is also known as barchans or transverse dune. Straight or slightly sinuous sand ridges, which are much longer than wide are called linear dune. The linear dunes may occur as isolated ridges, which are separated by miles of sand, gravel or rocky interdune corridors. Star dunes are radially symmetrical and pyramidal sand mound with slip faces on three or more arms that radiate from the high centre of the mound. Dome dunes are rare but are oval or circular mounds in shape that generally lack a slipface and occur at the far wind margins of sand seas. Parabolic dunes are U-shaped mound of sand with convex noses trailed by elongated back arms. Such dunes are also called as blowout or hairpin dunes and are well known in coastal desert. In Indian desert, the total area affected by sand drift is about 88,078 sq km (Kaul, 1996). The aeolian processes in arid zone of India are mostly restricted to the period of strong summer monsoon wind that results in various types of dunes in the desert depending upon age and structure of the dune. The earlier studies defined only four types of old dune in Indian desert, e.g. parabolic, linear or longitudinal, transverse and major obstacle dunes. However, recent studies described compound parabolic (Shergarh area), linear or longitudinal (Drishadavati in the north east Thar), transverse (Indo-Pak border), star like (Mohangarh and Suratgarh area), barchans or megabarchanoids and network dunes with height ranging from about 2 m to 50 m or more.

Obstacle dunes are developed at many places where the wind velocity decreases and the sand carried by wind gets deposited due to obstruction, particularly hills, buildings and bushes. These are present on either side of the hill or obstacles and are generated by low sand deposition by winds. The best sand streak zones are seen north and northeast of Sambhar Lake. However, about 48% of the total area of 12 arid districts of western Rajasthan is covered by sand dunes as compared to 52% and 58% reported earlier. Such decrease in sand dune area appeared to be due to leveling of dunes for cultivation in Ganganagar, Hanumangarh and other irrigated areas, transport of sands as building materials and fillings etc. However, the ultimate results of these bed forms are sand encroachment of productive agricultural fields, human habitations, canal, road and railway tracts and the existing water ponds.

Difference in Coastal and Arid Zone Dunes

Coastal dunes are a ridge, or a series of ridges, that are formed at the rear of a beach and differ from most other constructional coastal landforms in that they are formed by the movement of air (Aeolian transport) rather than by tidal, wave, or current action. These coastal dunes, particularly foredunes, which are formed by the continuous accumulation of wind-blown beach sand, which is trapped by burial-tolerant vegetation, support a resilient ecosystem and reduce coastal vulnerability to storms (Duran and Moore, 2013). In contrast to dry desert dunes, coastal dunes arise from interactions between biological and physical processes. The coastal dunes have relatively similar morphology, and in many cases similar wind regime and vegetation pattern. However, both ecosystems have conditions quite similar like extreme conditions of exposure to air and the sun, and poor moisture retention that inhibit plant growth. These dune systems have several physical and chemical parameters typical of the ecosystem influencing distribution of flora and fauna. These parameters are poor nutrient levels, soil salinity, salt spray, changes in organic matter and pH. In order to cope with these harsh environments, plants should have mechanisms that enable these plants to establish successfully in such environmental conditions. Moreover, the results obtained from coastal dune may not be applicable to the arid zone dune. Because coastal dunes often have shallow water table, salty sand, limited sand supply and a wind regime unlike that of most arid zone dunes. In addition, some coastal dunes sands are calcareous rather than siliceous in arid zone dunes.

SAND DRIFT CONTROL MEASURES

Regular strong winds and low precipitation (P) to potential evaporation (PE) ratios allow destabilization of soil erosion, particularly through anthropogenic activities. Tillage activity parallel to wind direction is much erosion prone leading to soil loss up to 2837 tons ha^{-1} from ploughed area as compared to only 207 tons ha^{-1} from the long fallow (Kar *et al.,* 2009). Reduction in tilling seems to be beneficial in controlling soil loss and land degradation. Remote sensing data covering various dune regions of the world however, indicates no major changes in desert dune orientations since last three decades (Varma *et al.,* 2014). The problems of wind-blown sand can be dealt by four different ways such as:

- Enhancing sand deposition by use of ditches, fences or shelterbelts,
- Enhancing sand transport, using streamlining techniques like creation of smooth texture over the land surface, or by erecting panels to deflect the air flow,
- Reducing the supply of sand upwind using surface stabilizing techniques like fences or vegetation
- Deflecting the moving sand to other side using fences or tree belts (Singh *et al.,* 2017).

The movements of sand dunes can be controlled by adopting three approaches such as:

- By removing the sands mechanically, which is relatively difficult
- By dissipating them using reshaping, trenching or surface stabilization techniques
- By immobilizing them through altering their aerodynamic form by surface stabilization or by using fences

Sand Dune Stabilization

Sand dunes have been a problem throughout the world for centuries. The earliest modern reference to dune control was in 1316 in Germany. Stabilization or control of sand drift includes the activities like reduction in wind velocity and availability of sand prone to erosion. A number of physical, chemical and biological methods have been tried during the last four to five decades, in which the most effective method was the control through a careful plantation of trees, shrubs and grasses. The importance of surface vegetation are such that as little as 4% vegetation cover could reduce soil loss by 15% compared to bare ground in an area with 356-915 mm mean rainfall (Fryrear,1995). Success of biological sand dune fixation largely depends upon the delicate balance between the availability of soil nutrients/ moisture and their use for biomass production.

Traditionally checkerboard windbreaks are constructed of plant remains (straw), locally available bushes or plastic nets in a rectangular pattern similar to the checkerboard. A typical checkerboard system is 30-70 cm high forming 4 x 5 m rectangles to avoid primary sand drift and seedlings burial. This system can withstand weather conditions for few years, and is long enough to implement the permanent solution of sand drift control. For example semi-buried straw checkerboard barriers and porous upright fences show better sand drift control effects. However, introduction of undershrubs and grasses along with the tree species provides beneficial effects in controlling sand reactivation and drift, particularly, at the time when planted seedlings attain the size of a tree facilitating free air movement under the canopy that results in reactivation of sand drift as observed at many sand dunes. In absence of surface cover, planting only *Acacia tortilis* leads to reactivation of sand drift from the exposed soil surface and exposure of tree roots causes tree to fall down and increases the canopy gap size and wind actions (G. Singh, personal observations). Sometimes tree also benefits undercanopy vegetation through i) shading effect during hot summer influencing water status of under canopy vegetation, ii) enrichment of soil nutrients for the vegetation, and iii) protection from adverse climatic condition and browse (Singh and Shukla, 2012). Growth and development of *Aloe vera* around the rootstock and under the canopy of *P. julflora* along the coastal dune of Hathab village near Bhavnagar in Gujarat is the best example (Fig 2.1). Here, *P. juliflora* is not only nourishing the under canopy *Aloe vera* stock but is also providing shelter to the farmlands along the coastal belt that otherwise have been covered by the sand blowing from the seabed (Singh, 2003 a).

Fig 2.1. *Aloe vera* in association with *P. juliflora* in coastal dune of Hathab near Bhavnagar in Gujarat

Importance of Cover Crops

Sowing of leguminous and or non-leguminous under shrubs or grasses improves the nitrogen and organic matter status in dunes, control sand drift effectively and provide fodder for livestock. Introduction of sand dune legumes or other vegetation like *Ipomoea biloba, I. pes-caprae, Spinifex sericeus* etc., as cover crops serve as nitrogen fixers, and provide green manure and mulch in coastal areas particularly in coconut (*Cocos nucifera*) basins (Namboothri *et al.,* 2017). Likewise, introduction of *Cassia angustifolia* (Sonamukhi or Senna) provide income to the desert dwellers by harvesting leaves of Senna for its medicinal value in addition to improve soil conditions by enhancing soil organic carbon and nutrients. It occurs as a perennial shrub in northern Africa and south-western Asia and is valued for its laxative and cathartic effects. The main ingredient 'sennosides' (a hydroxyanthracene glycosides) are generally extracted to the amount of 2.5% to 4% in leaf and 3 to 5% in pods. Being a perennial shrub in nature, if cultivated once, *C. angustifolia* may give a regular crop for the next four to five years. This species was considered as the perfect crop for restoring barren and infertile lands of dry regions.

Cenchrus ciliaris is important grass of Indian dry zone and used as fodder for the milching animals. Furthermore, surface vegetation influence tree seedling roots to penetrate deeper soil layers through root competition and therefore protects the tree from exposure of roots and uprooting during the high wind velocity (Singh, 2004; Singh and Rathod, 2002).

Experiments and Findings

A field experiment was conducted on a sand dune near Shekhala village, situated 90 km from Jodhpur on Jodhpur-Jaisalmer Highway to screen tree/shrub species for effective stabilization of sand dune and increase green cover on such degraded lands (Gupta *et al.,* 1997). The dune was longitudinal type and varied between 10 and 30 m height, spanning over several kilometers in extent. The soil of the site was fine sandy in texture having 9% water holding capacity and 0.057% soil organic carbon. Five tree species namely *Prosopis juliflora, Acacia tortilis, Acacia planifrons, Tecomella undulata* and *Prosopis cineraria* and a shrub *Ziziphus nummularia* were planted as the main treatments, whereas no mulching and mulching with locally available undershrubs were sub-main treatments. The mulching material was of *Crotolaria burhia* (Sinia) which was spread around each plant in a circle of 1 m diameter and 10-15 cm thick mat to prevent evaporative loss of soil water and to moderate the soil thermal regimes in the root zone of the plants. There were 12 plants per plot (i.e., 36 plants per treatment). Growth improvements as a result of mulching (with vegetation residue) were dramatic in case of *Z. nummularia, T.*

Table 2.1 Growth of two-year old different species on a sand dune at Shekhala in the Indian Desert (Source: Gupta and Singh, 1997).

Species	**Height(cm)**			**Collar circumference (cm)**			**Crown diameter (cm)**		
	-M	**+M**	**Mean**	**-M**	**+M**	**Mean**	**-M**	**+M**	**Mean**
Tecomella undulata	55	78	67	3.0	8.3	5.7	25	65	45
Acacta planifrorns	128	127	129	9.0	9.1	9.1	174	176	175
Prosopis juliflora	268	274	271	18.0	18.1	18.1	335	342	339
Acacia tortilis	214	259	237	12.4	15.9	14.2	246	233	240
Ziziphus nummularia	86	123	105	4.6	8.4	6.5	58	83	72
Prosopis cineraria	30	50	40	2.0	4.0	3.0	25	40	33
Mean	130	153		8.2	10.2		144	157	

-M : Without mulch +M: With mulch

The mulched plants exhibited healthier appearance having darker foliage, indicating better availability of water and nutrients in mulched plots. *Prosopis juliflora* and *Acacia tortilis* were the fast growing species attaining highest height growth and continued to accumulate height and collar circumference throughout the year. Initial studies revealed that species like *Acacia planifrons* (an introduction from Tamil Nadu) hold fairly good promise in sand dune stabilisation in Thar region also. The order of all growth variables *viz.* height, collar circumference and crown diameter for these species are: *P. juliflora* > *A. tortilis* > *A. planifrons* > *Z. nummularia* > *T. undulata* > *P. cineraria*.

Another study was carried out to find out suitable species and its combined surface vegetation with aim of fast stabilization of dune and production of fuel and fodder from a highly stressed site (Singh and Rathod, 2002). Seedlings of *Acacia tortilis, Prosopis juliflora* and *Calligonum polygonoides* species were planted on shifting dune in September 1996 at 5 x 5 m spacing near Bikaner, Rajasthan and micro-windbreaks were erected to protect the seedlings from the drifting sand. *Cassia angustifolia* and *Cenchrus ciliaris* were sown as treatment (vegetation type) to develop under canopy vegetation for effective control of sand drift and to provide the product of medicinal value the fodder for the livestock. Live saving irrigation to the tree seedlings was done four times in first year @ 30 liters per irrigation in September, November, February and April provided with sand mulching) and three times in second year (November, February and April). Vegetation types had no significant ($P > 0.05$) effect on the growth of the species. However, growth of species differed significantly ($P < 0.001$) and *Prosopis juliflora* was the best performer to cover soil the best (Fig 2.2). *C. polygonoides* produced the highest biomass in form of fuelwood utilizing minimum amount of soil water. There was an increase in SOM and soil available NH4-N due to plantation and vegetation type treatments. *C. polygonoides* with *C. ciliaris* was the best combination for fuel and fodder production where as combination with *C. angustifolia* was best to control sand drift.

Fig 2.2. Surface vegetation. Left) *Cassia angustifolia* with *Calligonum polygonoides*, and Right) *Cenchrus ciliaris* root stock with *C. Polygonoides.*

Product from Trees: At the age of 50 months, A. tortilis produced 5.2 tons ha^{-1} fuel wood as compared to 7.00 tons ha^{-1} from *P. juliflora* and 7.15 tons ha^{-1} from *Calligonum polygonoides. C. polygonoides* produced the highest biomass in form of fuel wood utilizing minimum amount of soil water in the experiment carried out at Bikaner under sand dune stabilization (Table 2.2).

Table 2.2. Dry biomass (kg plant^{-1}) of the 50 months old tree seedlings (kg seedling-1) on a shifting dune. CA: *Cassia angustifolia*; CC: *Cenchurus ciliaris;* CL: control. Source: Singh and Rathod (2002).

Tree species	**Above biomass**			**Root biomass**			**Total biomass**		
Vegetation	**CA**	**CC**	**CL**	**CA**	**CC**	**CL**	**CA**	**CC**	**CL**
A. tortilis	13.3	13.0	13.2	4.1	4.0	3.8	17.4	17.0	17.0
P. juliflora	18.1	16.6	17.8	8.0	6.6	6.6	26.1	23.2	24.4
C. polygonoides	18.0	18.7	16.9	9.8	8.9	7.8	27.8	23.6	24.7

Performance and Productivity of Surface Vegetation

Seeds of *C. angustifolia* germinate within five days of sowing. However, regeneration from the naturally dispersed seeds occurs immediately after rain (during monsoon period of July to September) when sufficient soil water availability is there in the soils. The phenological expressions occur twice in a year. *C. angustifolia* plants attain maturity during September. Low temperature in middle of January to first week of February results in drying (mortality of shoots) of *C. angustifolia* plants due to frost effect-indicating *C. angustifolia* as a frost sensitive plant. Rootstock however re-sprouts during favourable environmental condition of February and March resulting in start of the life cycle in the next season i.e., February to June. Flowering starts in October and again in April. Fruiting occurred during November to December and again in May to June. Seed dispersal observed in December and again in May-June. *Cassia angustifolia* plants attained height of 70-80 cm and crown diameter of 50-60 cm within a period of 5-6 months. Beneficial effect of *C. angustifolia* are its phenology – takes maturity and remains green during summer when maximum sand drift takes place, and its fast root growth that facilitates its adaptability in such harsh environmental condition at faster rate.

Regeneration and survival of *Cassia angustifolia* seedlings have also been studied in relation to different adult neighbours and soil water content with a view to developing effective surface vegetation and control of sand drift (Singh *et al.,* 2003a). *Acacia tortilis, Prosopis juliflora* and *Calligonum polygonoides* were the experimental adult neighbours under the study. Observations were recorded at distances of 0-1.0 m (IC zone), 1.0-1.5 m (OC zone) and 1.5–2.5 m (OS zone) from the neighbours. Seeds and regenerated seedling densities were higher in the *C. polygonoides* plot than the other two neighbours and the control plots with *C. angustifolia* plants only. The density of regenerated seedlings was higher in the OC zone of the *C. polygonoides* and *P. juliflora* plots, the OS zone of the *A. tortilis* plot and the IC zone of the control plot. Both inter- and intraspecific competition resulted in high mortality in the seedlings during July to October in *A. tortilis* and *P. juliflora* plots. Seedling survival decreased in February and June, but the density, which was greater in the IC zone, was positively correlated with that in July and with the soil water content (SWC). The ultimate survival was higher in the neighbour inclusion than in the control plots. The soil water content (SWC) was generally higher in the *Calligonum polygonoides* plot than that in the *A. tortilis* and *P. juliflora* plots. With distance from the adult neighbours, the SWC increased in the 25-50 and 50-75 cm and decreased in the 0-25 cm (June 2000) soil depth layers. Shoot height and biomass of one year old *C. angustifolia* seedlings were higher in the *C. polygonoides* plot than in the plots of other neighbours. A negative relative neighbour effect for most of the growth variables suggests that the adult neighbours facilitated regeneration, survival, growth and biomass of *C. angustifolia* seedlings. *C. polygonoides* was the best neighbour with better soil water regime underneath and highest facilitating influences on the associated vegetation than *P. juliflora* and *A.*

tortilis; therefore, suitable for increasing the population of *C. angustifolia* in effective stabilization of dunes and control of further reactivation of sand drift.

Growth and productivity of *Cassia angustifolia* was also studied during 1997 to 2000 in presence of adult neighbours like *Acacia tortilis, Prosopis juliflora* and *Calligonum polygonoides* (Singh *et al.,* 2003b). Growth of woody perennials, growth, phenology, biomass productivity and root study of *C. angustifolia* and soil water content were recorded. *C. angustifolia* flowers twice in a year and remains green during peak summer of May and June and therefore it will be beneficial in sand drift control effectively. It shows deep penetrating roots to extract limiting resources in this low productive land. Production of *C. angustifolia* produces higher biomass with *C. polygonoides* as compared to those with *P. juliflora* and *A. tortilis* (Table 2.3). For example, fresh leaves production varied from 1.47 to 2.86 tons ha^{-1} to 1.25 to 2.15 tons ha^{-1} with *A. tortilis* and *C. pollygonoides*, respectively in 1998. Contribution of leaves was comparatively less in summer (May 1998) as compared to that in November and decreased with age of the plants. *Cenchrus ciliaris* produced green fodder of 1.22 tons ha^{-1} year^{-1} with *A. tortilis*, 1.58 tons ha^{-1} year^{-1} with *P. juliflora* and 2.23 tons ha^{-1} year^{-1} with *C. polygonoides*. Soil water content was higher under *C. polygonoides* than that under other two species and suggested to be due to spreading type of canopy. Fresh weight of stem + twigs and leaves of *C. angustifolia* ranged from 61.9 % to 66.7% and 33.3 % to 38.1%, respectively with total above ground biomass production of 3.70 to 7.35 tones ha^{-1}. There was no difference between biomass of summer and autumn harvesting, though the production decreased with age of the plants.

Table 2.3. Fresh biomass (tones ha^{-1}) from surface vegetation in association with tree plants on a shifting dune.

Tree species	*C. angustifolia*			*C. ciliaris*			Control		
	1998	1999	2000	1998	1999	2000	1998	1999	2000
A. tortilis	3.97	3.80	3.70	0.97	1.40	1.29	-	0.30	0.46
P. juliflora	5.17	4.98	4.06	1.42	1.77	1.56	-	0.35	0.49
C. polygonoides	7.28	7.35	6.46	1.93	2.57	2.19	-	0.58	0.60

Income from *C. angustifolia*

Under sand dune stabilization activity, *Cassia angustifolia* produced dry leaves of 0.76 tons ha^{-1} year^{-1} with *A. tortilis,* 0.96 tons ha^{-1} year^{-1} with *P. juliflora* and 1.39 tons ha^{-1} year^{-1} with *C. polygonoides*. Considering the economic return from *C. angustifolia* leaves, Rs 16720 ha^{-1} year^{-1} could be obtained from the plots in which *C. polygonoides* are integrated with *C. angustifolia* as compared to 9120 ha^{-1} year^{-1} from the plots in which *A. tortilis* was integrated (Table 2.4).

Table 2.4. Dry mass (tons ha-1) of leaf of *Cassia angustifolia* and the economic benefits (Rs ha-1 @ Rs 12 kg-1) under different tree species in a shifting dune.

Tree species	Nov 1998	May 199	Nov 2000	Mean	Income (Rs ha^{-1})
A. tortilis	0.76	0.80	0.71	0.76	9120
P. juliflora	0.97	1.04	0.87	0.96	11520
C. polygonoides	1.39	1.56	1.23	1.39	16720

Species Suitability

Species with spreading canopy appears better as compared to the species with canopy well above the soil surface. For example *Calligonum polygonoides* appeared best followed by *P. juliflora* in our experimentations (Singh and Rathod, 2002). Species like *Leptadenia pyrotechnica* and *Calligonum polygonoides* provide good protection and establishes well with medium irrigation and when protected from sand blasting at early establishment. *Lasiurus sindicus* and *Panicum turgidum* grasses are difficult to establish, but are extremely efficient in settling drifting sand when found in a cluster. *Prosopis juliflora* has reasonable establishment potential and good sand settling properties making it a good choice, whereas *Acacia tortilis* tolerates well hard conditions and is aerodynamically very successful on large scale. *Acacia jacquemontii, Calotropis procera, Clerodendrum phlomidis, Lycium barbarum, Aerva pseudotomentosa* are easy I establishment. Besides, *Prosopis cineraria, Tecomella undulata, Ziziphus mauritiana, Z. nummularia, Citrullus colosynthesis, Cenchrus ciliaris, Dactyloctenium sindicum, Ochthochloa compressa* etc. are other important species for sand dune stabilizations (Singh *et al.*, 2017).

Rooting Patterns

Rooting pattern of a species also make the species more adaptable under harsh environmental conditions. Root of *C. angustifolia* penetrates >30 cm within two days and >1 m in dune sand within a year giving them better chances of survival and sand drift control. The other property of this species is its phenology as it remains green during summer months, when maximum sand drift takes place (Singh *et al.*, 2003b). Likewise, *Hardwickia binata* and *Colophospermum mopane* shows deeper roots penetrating even the hard layer of $CaCO_3$ (Singh and Singh, 2015). This type of rooting is more pronounced in seed sown 9 months old plants of 18 cm height and extended its root to 121 cm penetrating the hard layer of calcium carbonate available at 70 cm soil depth (Singh and Rathod, 2006a). *Aerva pseudotomentosa* – a shrub of sandy area of Indian Desert extends its roots up to 43 feet horizontally demonstrating its capability in resource mobilization for its survival and control of wind erosion. Likewise roots of other species viz., *Calligonum polygonoides, Leptadenia pyrotechnica, Acacia jacquemontii, Prosopis cineraria* etc mines the area many more times than their canopy and deeper soil layers as well (Fig 2.3). *C. polygonoides* plant of average growth parameter spreads its root horizontally in about >25 m diameter and

Fig 2.3. Rooting pattern (urface spreading and anchoring roots) of *P. cineraria* (left) and *Calligonum polygonoides* (right).

0.9-1.2 m deep penetrating, thus mining and protecting about 164 cubic meter soil (considering a cone like mining volume) and produce about 10-15 kg dry biomass (i.e. average 12 kg per plant).

The extent and intensity of available surface vegetation also influence the root growth pattern of the planted seedlings under competitive interaction for the best fit survival. Availability of tap root as well as surface spreading roots (> crown spread) in *Acacia tortilis* depend on the existing natural conditions, i.e. only surface spreading roots were observed when grown in a bare dune to exploit surface available moisture in this low rainfall region. In semi-stabilized dunes, where availability of natural vegetations are relatively less, both tap root and surface spreading roots were observed because of lesser amount of competition imposed by the existing sparse vegetation (Singh *et al.*, 2017). In flatland where competitive effect from surface vegetation, i.e. *Dactyloctenium sindicum,* was very high the planted *A. tortilis* showed deep penetrating roots for better access to the deep available soil resources (Fig 2.4). Thus surface vegetation provides an opportunity for the planted seedlings also to adjust in such a way for better survival in harsh condition.

Fig 2.4. Rooting pattern of *Acacia tortilis* planted in bare dune (left), semi-stabilised dune (middle) and flatland (right). Courtesy: Singh *et al*. (2017).

LIVING FENCES AND SHELTERBELT PLANTATION

Living Fences

Living fences or barriers are more commonly called as hedgerows and are in practice since ages. Living barriers are promoted to protect crops against livestock, sand drift and modifying the micro-climate. Small farmers cannot afford costly barbed wire and other fencing to protect their plantation or agricultural crops. Live hedge, therefore is one of the cheaper alternative and offer a more sustainable, longer-lasting fencing option with additional benefits of micro-climate modification and crop yield variations (Fig 2.5). However, the hedge plants also require protection in early stages and therefore before planting of such living fences a trench of 1m wide and 75 cm deep can be dug along the boundary. Species selection for living fences should be such that extra income could be generated from the hedge and they are adaptable to the local climate, besides their primary function of protection from biotic interferences and boundary demarcation (Singh and Gupta, 2000). When the row of trees and shrubs or shrubs alone, planted together to form a barrier, are beneficial for crops and animals (domestic livestock and wildlife). It is a form of traditional agroforestry which can fulfil the ever increasing demand of fuel and fodder from the same land which is used for agricultural production. Leaves and litter from these hedges provide mulch for conserving soil moisture, decreasing weed growth and increasing nutrient status. It also protects agricultural crops and houses/huts from the dusty and warm wind and animals both domestic and wild, where browsing and grazing are restricted and provide shelter too for livestock on farmlands.

Table 2.5. Various species used under living fences in dry areas of western Rajasthan and Gujarat. Modified from Singh and Gupta (2000).

S.No.	Species	Local Name	Density (nos. per 100 running meter)
1	*Euphorbia caducifolia*	Danda Thor	80-90
2	*E. tiruculli*	Danda Thor	80-90
3	*Caesalpinnea bonduc*	Kathkaranj	30-35
4	*Acacia senegal*	Kumath	38-80
5	*Prosopis juliflora*	Vilayati babul	120-180
6	*Lycium bararum*	Murali	80-90
7	*Opuntia dillenii*	Nagfani	80-90
8	*Z. nummularia*	Jhad Ber	10-15
9	*Jatropha curcas*	Jatropha	20-50
10	*Balanites aegyptiaca*	Hingota	40-50
11	*Clerodendum phlomidis*	Irna	40-50
12	*Leptadenia pyrotechnica*	Khimp	20-30
13	*Calligonum polygonoides*	Fog	20-30
14	*Ipomoea carnea*	Besharm	150-200

Fig 2.5. Effect of live hedge (east-west direction) on growth and productivity of agricultural crop in south facing (left) and north facing (right) fields.

Hedge Improvements

Living fences shares a border and its effects are also used to describe the various upshots on vegetation and wildlife residing in the area. In such areas, edge improvement technique increase available food and cover by providing a variety of vegetation types and layers, from the shortest herbaceous vegetation to the tallest trees. As many wild animals use edge habitat for nesting, feeding, and travelling, edges can be modified by re-vegetation of the areas with local native species and planting the inner zone around edges to develop multilayer system and to increase the size of the habitat and to reduce edge effects generated by vehicle tracks, roads etc. Further, multiple layers available in vegetation provide more places where wildlife can feed and find nesting, resting, or escape cover. Methods used to enhance hedge habitat are planting, letting natural succession to occur and cutting or removal of unwanted vegetations (Singh, 2018).

Growing a Living Hedge

The first thing one will require to develop a living fence is patience because plants require some time to grow in full height and in providing effective protective roles.

- Choice of plant species: A right plant species is one that has capacity of growing in a local climatic condition. This is the number one consideration. The key here is taking some time to study each plant, and select the best one that will suit to a particular land and beneficial to wildlife also. The trees and shrubs under release should be those that provide quality food or cover for wildlife, such as fruiting shrubs like *Z. nummularia, L. barbarum, G. tenax, C. decidua* etc (Singh, 2018).
- Sowing or planting: Seed sowing or planting of the species should be closed enough to one another means their branches and leaves will interlock densely to ensure that there are no noticeable gaps in the living fence. For example seed (seeds socked in warm water overnight) sowing of Acacia senegal are done in two rows and at 15-30 cm intervals during onset of monsoon to facilitate seed germination.
- Plantation management: There will be a need to cultivate the soil under hedge planting using fertilizer or compost. Frequent watering (weekly) and protecting them from extreme weather and other harmful elements are also essential requirements. Training of plants is also required to lay out the branches of the plants so that they naturally grow wide and outward. This will promote the interlocking pattern to take place later on when the branches start getting longer and stronger. Furthermore, removing dead and overgrown branches through regular pruning is also important, as it stimulates growth. The more the plants grow, the denser the leaves and branches of the hedgerows will be there under developing an effective living fence of hedge.

Windbreak/Shelterbelt Plantation

A shelterbelt (windbreak) is a planting usually made up of one or more rows of trees or shrubs planted in such a manner as to provide shelter from the hot or chilled wind, ameliorate microclimate and to protect soil from wind erosion (Singh and Tripathi,1998). They are also planted in hedgerows around the edges of fields on farms. If designed properly, windbreaks around a home can reduce the cost of heating and cooling and save energy. Shelterbelt prevents the soil erosion, arrest the desert and protect the agricultural and residential lands from dust-storms. A row of trees and shrubs planted across the winds-direction is the most effective and reduces the wind speed up to 60-80% on leeward side. The height of tall tree and length of wind break determine the extent of protection provided to the sheltered area. It provides a protective shelter against desiccating winds to extent of 5-10 times the height of the shelterbelt on windward side and up to 30 times on leeward side of the belt. For example, a 10-11 m tall shelterbelt when encountered by 45-50 km /hr wind, its velocity reduces on windward side to 20-30 km /hr and to 10 km / hr on just leeward side Likewise, the belt reduces the wind speed on the leeward side at 200 m away up to 20% only and in the area as at 300 m away, there is no effect at all. It means that such shelterbelts should be repeated at an interval of 300 m. Thus the amount of air pressure difference is determined by the structure of the shelterbelt. The denser the shelter is the greater is the difference in the air pressure. The structure of a shelterbelt can be altered by modifying the:

- Height
- Density
- Number of rows
- Species composition
- Spacing between the trees or shrubs.

To control wind erosion, the capacity of shelterbelt depends upon the speed and direction of the wind as well as species composition and growth (Mertia and Upadhyay, 1993). In case of high wind speed, the protective area is reduced and in such areas, the interval between two shelterbelts is to be reduced. To counter winds direction, it is necessary to be long length of windbreak so that wind blows across the wind break. Depending upon the porosity of shelterbelt, certain amount of wind passes through it and some deflects and crosses over it. Thus, it does not produce turbulence of air. Reducing the wind speed reduces the evaporation losses and makes available more water to crops enhancing agricultural production (Gajja *et al.*, 2008). According to planting pattern of trees and shrubs as shelterbelt, the grasses and shrubs are planted on the outer rows which train the wind to rise much above the ground surface (Singh, 2012). The inner rows are of small trees which further raise the wind level. Relatively better performing species in Indira Gandhi Canal Area are *Eucalyptus camaldulensis, Dalbergia sissoo* and *Acacia nilotica* (11.38, 9.0 and 6.80 m in height, respectively at 4 years of age) and *Acacia tortilis, Prosopis juliflora* and *Colophospermum mopane* (3.10, 2.30 and 2.10 m in height, respectively) at Chandhan area in Jaisalmer (Mertia and Upadhyay, 1993). The beneficial effects of the shelterbelts are more clearly seen in drought affected areas. In such areas windbreaks of 3-7 rows and 15-30 m wide are more effective. It modifies the micro-climate favourable for crop production and shelters for birds, honeybees and pet animals. A shelterbelt plantation consisting of double row of tree species viz. *Azadirachta indica, Acacia tortilis* and *Acacia senegal* flanked by two rows of *Prosopis juliflora* and *Zizyphus mauritiana* was started by planting these species in September 1996. In February 1998, maximum survival was recorded in *Acacia tortilis* (94%) followed by *Z. mauritiana* (71%), *Acacia senegal* (68%), *Prosopis juliflora* (44%) and *Azadirachta indica* (55%). Plants of *A. tortilis* were tallest (68 cm) lowed by *Zizyphus mauritiana* (30 cm), *Acacia senegal* (27 cm) and *Azadirachta indica* (20 cm) (Anon., 2000).

Plantations of casuarinas and other species on dunes are being taken up on a large scale along the entire east and west coasts of India. This has had a major effect on large areas of dune landscape of the sea coast influencing wind velocity and vegetation cover. In a study on the effects of strong desiccating wind on teak (*Tectona grandis*) terminal shoot growth was minimized by planting windbreaks of *Casuarina* on either side of teak tree row in boundary planting (Fig 2.6; Buvaneswaran *et al.*, 2013)). Three channels were formed at a distance of 1m all along the field boundary and within each channel superior clones of Casuarina were planted at 1 m interval within the rows in the two outer rows. Teak was planted in the middle row at 2 m spacing. There were around 800 trees per hectare for *Casuarina* around 200 trees per ha for teak (at Puthinampatty village in Trichy district of Tamil Nadu). Agriculture and horticulture crops were cultivated after planting of tree seedlings, as per standard package of practices. *Casuarina* recorded mean height of 5.2 m and mean girth of 14.1 cm while teak registered mean height of 4.5 m and mean girth of 13.8 cm after two years of planting (Table 2.6). While comparing growth of teak and growth of adjoining *Casuarina* rows in four directions of the farm boundary, it was observed that both girth and height of teak was corresponding to the girth and height of *Casuarina* in adjoining rows (Buvaneswaran *et al.*, 2013). The interaction between tree and agricultural crops was negligible in the first two years. However, the yield from annual moringa (variety PKM2) cultivated inside the windbreaks recorded yield of 56,160 fruits in three seasons on an average @ 240 fruits per tree which was more than the reported average yield (average yield being 220 fruits per tree for the annual Moringa variety PKM2).

Table 2.6. Mean height (feet) and girth (cm) of 2 years old *Casuarina* and Teak in boundary planting in Puthinampatty village in Trichy district of Tamil Nadu. Source: Buvaneswaran *et al.* (2013).

Casuarina tree rows	Height (feet)	Girth (cm)	Teak tree rows	Height (feet)	Girth (cm)
Outer C1	19.2	18.0	Middle T1	16.8	14.2
Inner C2	20.4	19.2	Inner T2	16.5	16.4
Outer C3	19.5	13.7	Middle T3	16.1	13.9
Inner C4	16.9	14.7	Middle T4	14.7	16.2
Inner C5	20.3	16.4	Middle T5	13.6	12.0
Outer C6	15.3	13.4	Middle T6	10.5	9.9
Outer C7	12.4	9.1	-	-	-
Middle C8	13.5	9.4	-	-	-
Inner C9	16.7	13.3	-	-	-
Mean	17.1	14.1	Mean	14.7	13.8

Fig 2.6. Windbreaks of Casuarina with teak in the middle flanked by two rows of Casuarina (left) and growth of teak in inner row with profuse branching (right). Source: Buvaneswaran et al. (2013).

Evaluation study has also been done on the effects of windbreak agroforestry systems developed utilizing superior clones of *Casuarina junghuhniana* viz. IFGTB-WBC 6, IFGTB-WBC 8, IFGTB-WBC 9, IFGTB-WBC 17 and IFGTB-WBC 18 on minimization of deleterious effect of wind on banana crop production as well as to make agro-ecosystems as more climate change resilient by enhanced productivity, reduced evapo-transpiration and in turn increase in water use efficiency of the agro-ecosystem. These clones have more number of branches, greater branch thickness, wider branch angle along with greater growth rate and biomass productivity and are suitable clones for windbreaks. Cultivation of these superior clones in farmer's field proved good compatibility of Casuarina and banana (Buvaneswaran *et al.*, 2014). Three channels were formed at a distance of 1m all along the field boundary and within each channel, superior clones of Casuarina were planted at 2 m interval within the rows in 'Quincunxs' pattern. The number of trees per hectare was 600. After planting of tree seedlings, rhizomes of plantain were planted inside the field in the "Quincunxs pattern at 4 m distance within a row and 2 m distance between rows that lead plantain density of 2500 per ha (Fig 2.7).

Fig 2.7. Cultivation of Banana crop protected by Casuarina wind break at Rayarpalayam in Tamil Nadu (left) and normal growth of banana crop adjoining to the trees of wind break. Source: Buvaneswaran et al. (2014).

For Casuarina plants girth at breast height was 12.0 cm and total height was 6.0 m at the end of first year of the plantation. Predicted volume production was 12.0 cubic metre per hectare at this growth rate. At harvest age of three years, the estimated wood yield on fresh weight basis would be 8.0 metric tonnes per hectare. The average plantain (variety-kadali) yield of 7.0 kg of fruit weight per bunch was recorded under windbreak agroforestry system. The fruit yield from plantain was not affected by co-cultivation of superior clones of Casuarina junghuhniana and Kadali variety even very adjoining to the tree rows. An additional income from pulpwood @ Rs. 2300 per MT amounting to Rs. 18,400/- and income from branch wood @ Rs. 1000 per MT amounting to Rs. 2500/- was expected from the tree component after excluding the cost of cultivation of tree component (Rs. 6000/-). Hence, the net additional income from tree component amounts to Rs. 14,900/ after three years (Table 2.7).

Table 2.7. Expected additional income from the tree component. Source: Buvaneswaran et al. (2014).

Particulars	Value (Rs.)
i) Cost of cultivation of tree component:	6,000/-
ii) Benefits from tree component after three years: a) Income from pulpwood (@Rs.2300 per MT) b) Income from branch wood (@Rs.1000/- per MT)	
iii) Net Additional Income from tree component	14,900/-

Wind break study carried out at IFGTB, Coimbatore, had successfully released tree varieties (clones) in Casuarina suitable for wind breaks. The effect of such windbreaks with superior tree varieties in crop protection and moisture conservation was evaluated in farmer's field at Narasimmanaicken Palayam (Vinothkumar et al., 2017). The results revealed that there was a significant effect of windbreak on air flow reduction and soil moisture retention inside the field with windbreaks as compared to the adjoining open field. Windbreaks with superior clones of Casuarina reduced the wind speed in leeward side by half (Table 2.8). Windbreak conserved 65.67 percent soil moisture inside the field than the open field, which conserved only 3.2 percent soil moisture from day one to day five.

Table 2.8. Wind speed (m/s) in the farm field with windbreaks and in the adjoining open field (Source: Buvaneswaran et al., 2017).

Month	Windbreak field side	Open field side
	Wind speed (Average m/s)	Wind speed (Average m/s)
June	2.54	5.18
June	0.57	1.41

CONCLUSION AND RECOMMENDATIONS

Wind erosion is a serious problem of environmental degradation in north western as well as coastal regions of India with contrasting seasonal climate and increased human activities in the desert fringes. Over-exploitation of vegetation for fodder and fuelwood are damaging the desert ecosystem and enhancing desertification in the form of soil loss and sand dune formation.

A combination of trees, shrubs and grasses are most suited biological means of controlling wind erosion (i.e. combating desertification) of the soils with additional benefits of livelihood supports. The association of *C. angusifolia* as the surface vegetation is best to control sand drift effectively. Further, a farmer can get more than Rs 10,000 ha^{-1} from this highly stressed site in addition to the product obtained from the trees and environmental benefit. Production of fodder from the *C. cilaris* grass is also promised and could be integrated for fodder production along with the sand drift control.

C. polygonoides is the best neighbour with better soil water status underneath and highest facilitating influences on companion vegetations than *P. juliflora* and *A. tortilis, Calligonum polygonoides* was best neighbour increasing the *C. angustifolia* population and therefore effectively stabilized the dunes and helped in increasing biodiversity. Hence, combination of *C. polygonoides* and *C. angustifolia* was best to increase production of this dry land with additional benefits of sand drift control.

The benefits of carbon sequestration at the rate of 3.72 tons ha^{-1} with *A. tortilis,* 5.24 tons ha^{-1} with *P. juliflora* and 5.66 tons ha^{-1} with *Calligonum polygonoides* can also be achieved through adoption of this technology in addition to the other environmental benefits like microclimate amelioration, soil improvement and sheltering the habitations.

Sowing of under shrubs and grass of local importance can also be done in advance to control the sand drift and burial of the planted seedlings. It will help in improvement of soil condition and control the sand drift when the seedlings attain greater height leaving bare the under canopy soil.

Considering a range of benefits like protection to roads, railways, open canals ea beaches; sheltered area for cropping, horticultural and livestock enterprises; and supplementing basic needs of fuel, fodder and timber, shelterbelt plantations provide relatively cheap and long-term option for reducing wind erosion and associated hazards prevailing in western Rajasthan and coastal areas as well.

Plantations of casuarinas and other species on dunes in coastal areas influences wind velocity growth of teak plants and productivity of positively. Thus judicious use of shelterbelt would not only substantiate potential productivity of natural resources but also help in their sustainable management of dry ecosystem and to harness highest benefits of the shelterbelt plantations, careful consideration should be given to the location, species, desired height, length, density and composition of the shelterbelt.

Because of availability of pasturelands and sacred groves, the Western Rajasthan holds a big potential for development into a rangeland. The highly nutritive fodder grasses *Lasiurus sindicus, Cenchrus ciliaris, C. setigerus* and *Cymbopogon jwarancusa* etc are well adapted to the region and should be utilized in restoring these degraded community lands

Effective research should be conducted so as to protect such ecologically sensitive ecosystems that include dune vegetation and associated flora and fauna.

Effects of introduced exotics and invasive species including *Prosopis juliflora* needs to be investigated in view of the apprehensions of scientific and village communities.

Understanding the consequences of ecological and physical changes either inland of in the shoreline and coastal areas as a result of such large scale plantation of introduced species also needs to improved.

3 WATER EROSION AND CONTROL MEASURES

Like weathering, erosion is also a natural geological process. Water erosion is the action of surface processes like water flow that removes soil, rock, or dissolved material from one location on the Earth's crust, and then transports it to another location. It is the slow destruction of soil surface under action of water from rain, runoff, snowmelt, and irrigation. Rainwater in the form of runoff is the main driver of water erosion in many areas including the dry lands. It refers to the movement of soil organic and inorganic particles along the soil surface with flowing water and deposition of the eroded materials at lower landscape positions or in aquatic ecosystems. The eroded material can either form a new soil or simply fill the lakes, reservoirs, and streams and thus reducing their storage capacity. Water erosion occurs in all soils to varying degrees. While slight erosion is actually beneficial to the formation of soil but severe or accelerated erosion adversely affects soil and environment. In India, water erosion is the major problem causing loss of top soil and/or terrain deformation in about 148 million ha area that represents about 45% of the total geographical area of the country.

Ever increasing human and livestock population is resulting in overexploitation of existing common resources as well as the forests in adjacent areas of the villages. Grazing pressure, vegetation removal and illegal mining are mounting pressures on already degraded forests particularly in the Aravalli hill regions of Rajasthan-an ancient mountain system in India. The livelong human activities coupled with climatic abrasions make the hills degraded and barren – limited vegetation. Most of the hillocks in Aravalli ranges are naked and exposed to water erosion resulting in loss of soil and nutrient in addition to invaluable water resource. The water received through rainfall washes the surface soils leaving behind the gravels/pebbles exposed hillslopes, whereas it causes water pollution through nutrient enrichment and reduces reservoir capacity through siltation in down streams/reservoirs.

FORMS OF WATER EROSION

Water erosion is the detachment and removal of soil material by active force of water. Water erosion occurs when raindrops hit the soil surface and displace soil particles, and when water flowing over the land surface moves soil particles. It is a natural process often accelerated under land use practices, especially on cropped land. Water erosion causes loss of topsoil, reduced crop yields, damaged infrastructure, weed dispersal, eutrophication (algal blooms) and silting of dams and natural waterways. Soil erosion because of water is the major factor responsible for degradation of land resources and the loss

Degraded Aravalli hill ranges

of topsoil resulting in reduced land productivity is a serious land degradation hazard in the Indian subcontinent. Mandal and Sharda (2011) reported that soil erosion due to water is one of the major factors contributing to land degradation not only in India, but also in many other countries. Very high rate of soil erosion to the level of 30–40 tons ha^{-1} $year^{-1}$ occurs in Asia, Africa and South America. In Asia, the average rate of soil loss is about 138 tons ha^{-1} $year^{-1}$ (Sfeir-Younis, 1986). In such a process water erosion reduces agricultural production by removing soil nutrients, taking away valuable topsoil where there is a hostile subsoil, reducing effective rooting depth and plant available soil water, silting of dams, waterways and lowland areas with sandy sediments, which can make flooding and water-logging, and reducing trafficability of roads, tracks, fences and other infrastructure (Fig 3.1).

Fig 3.1. Water bodies affected negatively by siltation under water erosion reducing its water storage capacity and the services.

Water erosion occurs when raindrops hit the soil surface and causes soil particles to detached and displaced, and when water flowing over the soil surface transports soil particles. Deforestation or vegetation removal, over-grazing and trampling, intensive cultivation, mismanagement of cultivated soils and intensive urbanization are major factors triggering the soil erosion. Rainfall and the surface runoff produces four main forms of soil erosion such as splash erosion, sheet erosion, rill erosion, and gully erosion.

Splash Erosion

The splash erosion is the first step of soil erosion, in which the impact of a falling raindrop on bare soil creates a small crater in the soil. The explosive impact of raindrop breaks up soil aggregates so that the individual soil particles are 'splashed' onto the soil surface. The distance travels by these soil particles can be as much as 0.6 m vertically and 1.5 m horizontally on plain soil surface.

Sheet Erosion

Sheet erosion is the uniform removal of soil in thin layers by the forces of raindrops and overland flow. It occurs in case of water saturated soils, or a situation when the rainfall rate is greater than the rate at which water can infiltrate into the soil leading to surface runoff - called overland flow. It can be a very effective erosive process because it can cover large areas of sloping land and go unnoticed for quite some time.

Rill Erosion

In Rill erosion there is development of small, ephemeral concentrated flow paths which function as both sediment source and sediment delivery systems for erosion in sloppy areas. Thus rill erosion is a function of the morphological, pedological and land use characteristics of the area (Auzet *et al.*, 1993). The size of runoff contributing area, soil susceptibility to crusting and land use characteristics are the main factor accounting for variations in such water erosion process. Flow depths in rills are typically of the order of a few centimeters or less and along-channel slopes that may be quite steep. This means that rills exhibit hydraulic physics very different from water flowing through the deeper, wider channels of streams and rivers.

Gully Erosion

Gully erosion occurs when runoff water accumulates and rapidly flows in narrow channels during or immediately after heavy rains or melting snow, removing soil to a considerable depth. Thus gully erosion is an advanced stage of rill erosion where surface channels are eroded to the point where they cannot be removed by tillage operations, i.e. lateral and vertical erosion of rills. Gully erosion is responsible for removing vast amounts of soil, irreversibly destroying farmland, roads and bridges and reducing water quality by increasing the sediment load in streams. It is thought to be a response to excessive water in the local environment caused by the removal of perennial vegetation through deforestation and overgrazing. Most gullies extend up slope as a result of headwall migration. However, it is the collapse and slumping of the sidewalls which usually contributes the greatest proportion of soil loss. Sandy soils are more prone to formation of gullies.

Other Types of Erosion

In addition to the above, other types of erosion are: valley or Stream erosion, river bank erosion, coastal erosion and gravity erosion.

- Valley and stream erosion: Valley erosion occurs with continued water flow along a linear feature and is both vertical that deepens the valley and horizontal that extend the valley into the hillside, creating head cuts and steep banks. In the earliest stage of stream erosion, the erosive activity is dominantly vertical, the valleys have a typical V cross-section and the stream gradient is relatively steep. When some base level is reached, the erosive activity switches to lateral erosion, which widens the valley floor and creates a narrow floodplain. Streams are very dynamic ecosystems that move, grow and change naturally or when human activities influence them. The stream gradient becomes nearly flat, and lateral deposition of sediments becomes important as the stream meanders across the valley floor. In all stages of stream erosion, the most erosion occurs during times of flood, when more and faster-moving water is available to carry a larger sediment load. In such processes, it is not the water alone that erodes, but suspended abrasive particles, and pebbles and boulders can also act erosive as they traverse a surface.
- Bank erosion: Stream bank erosion is the most common problem facing many streams in waterway systems now days. It lead the wearing away of the banks of a stream or river. This is distinguished from changes on the bed of the watercourse, which is referred to as scour. Erosion and changes in the form of river banks may be measured by inserting metal rods into the bank and marking the position of the bank surface along the rods at different times.
- Floods: At extremely high flows of water, vortices are formed by large volumes of rapidly flowing water. Vortices cause extreme local erosion, plucking bedrock and creating pothole-type geographical features.

- Coastal erosion: Ocean is a huge force of erosion. The wearing away of rocks, earth, or sand on the sea beaches change the shape of entire coastlines. During the process of coastal erosion, waves pound rocks into pebbles and pebbles into sand. Waves and currents sometimes transport sand away from beaches, moving the coastline farther inland. Thus sea waves, tidal waves and tsunamis dash along the coast and cause heavy damage to the soil-called littoral erosion and it is most intense along the Kerala coast.

WATER EROSION CONTROL MEASURES

Most important principle in controlling water erosion is to develop a new balanced system which is not only productive but is also stable. Water erosion control schemes should therefore be based on the selection and introduction of correct land use. Different methods are being adopted over the years to control the soil erosion caused by water, but these methods have proven to be insufficient to reduce the soil erosion at permissible level (Ul-Zaman et al., 2018). In such a case engineering structures are also designed to control run-off and soil erosion in fields where biological control practices alone are insufficient to reduce soil erosion to an effective level. Relatively wetter parts of an area in general are more prone to water erosion. Vegetation cover on farmland, forest or pastureland either as a consequence of conversion to arable land or plant succession has the greatest effects on rainfall in?ltration capacity and soil erosion. Vegetation dynamics is a key factor in quantifying and interpreting the hydrological and erosion response of the land use and land covers (Nunes et al., 2011). Conservation measures on soil and water are necessary parts of the system for combating erosion during critical times of the year and show certain effect on the environment (Adimassu et al., 2012). There are various measures adopted for soil and water conservation or diversion of water into natural and/or artificial ponds and reservoirs. These conservation measures include: (i) water harvesting and utilization, (ii) on site conservation measures, (iii) micro-catchments and trenches, (iv) drainage line treatments and, (v) recharge of ground water. Depending upon the rainfall in different regions, either alone or combinations of RWH and conservation measures are adopted.

Water Harvesting and Utilization

Rainwater harvesting is the systematic accumulation and storage of rainwater for reuse on-site, rather than allowing it to run off. Its uses include water for gardens, livestock, irrigation, domestic use with proper treatment, indoor heating for houses, etc. The harvested water can also be used as drinking water, longer-term storage, and for other purposes such as groundwater recharge. Harvesting and storage of rainfall and its release for multiple uses are an age old practice. In western Rajasthan, about 40 -70% of the rural drinking water supply is sourced from 'Nadi' and 'Tanka', 15-20% from wells/tube-wells and only 8-12% from other sources (Singh, 2015). Almost 100 percent of village of hyper arid district of Rajasthan have ponds, wells and other water harvesting structure in it vicinity (Goyal et al., 2007; Singh, 2018). These water bodies meet about 37% of the water needs of the villages. Jodhpur town itself has about 25 numbers of 'Nadis' in and around it. Though, the water is not very suitable sometimes for human consumption but is important source of water for livestock and for irrigation. Besides, these Nadi's recharge the groundwater in surrounding areas. The larger ones, 10 to 30 hectares in size, feed several thousand hectares of irrigated land. They are equipped with sluices, which deliver water to an extensive canal system suitable for irrigated cultivation in large parts of the country. These rainwater reservoirs are not only employed for irrigation in extremely dry regions, but in semi-humid areas up to 1300 mm annual rainfall also. A major disadvantage connected with surface storage of water in dry areas is high rate of surface evaporation. In addition to this, reduction in storage capacity caused by siltation, pollution problems and loss of agricultural land are the other drawbacks associated with surface storage of water (Fig 3.2). Underground storage of water is an effective alternative, where storage is done in near surface aquifers, calling for a conjunctive management of water resources.

Fig 3.2. Nadi (left) and Kuan in a Talab bed (right) –rainwater harvesting devices in dry areas of western Rajasthan.

Micro-Catchment Rainwater Harvesting

To improve the early establishment and growth of plantations various techniques of in situ water harvesting and conservation structures- known as micro-catchments have been studied by various workers and organizations (Krupnik, 2004; Ojasvi *et al.*, 1999; Sharma *et al.*, 1986; Sreedevi *et al.*, 2008). These micro catchments reduce velocity of runoff water and allow the water to stay on ground for longer period and enhance the infiltration of the rain water in to the subsurface soil. The in-situ water harvesting structures permit the storage of water around the vicinity of tree roots also (Gupta, 1995). Plant rhizosphere remains moist for longer part of the year offering favourable conditions of water and nutrient availability to trees resulting in better growth and biomass production.

- Planting pits: Planting pits for afforestation purpose are also micro catchment structures made in advance allowing runoff collection and time for infiltration into deep soil profile (Fig 3.3 top). They are usually fertilized with organic matter in the form of plant debris or compost to enhance growth and biomass of plantation.

Planting pits exists in variable size and spacing depending upon species and soil conditions. The planting pits are suitable for semi-arid area to enable crops to survive dry spells. They are used on a wide variety of soil types but most suitable are silt and clay soils, where runoff can be generated due to limited permeability. Pits combined with RWH structures like ring trenches (40 cm wide and around 52.5 cm radius) with a central pit of 45 cm x 45 cm x 45 cm volume for planting purpose, are beneficial for plant growth and biomass production in plantation forests as they prevent runoff losses and maintain higher soil moisture regime, facilitate root system and improve water and nutrients use efficiencies thus give a good start to young plantations (Gupta *et al.*, 1993). Ring pits (trenches) are widely applied along road side plantation in dry areas, where it not only able to harvest sufficient rainwater for its utilization by the planted seedlings but the ring pit around the planted pit is also beneficial in terms of protection from the domestic and wild animals (Fig 3.3). Only needs an improvement is to provide a way to collect water from the adjacent area otherwise it collect only direct rainwater.

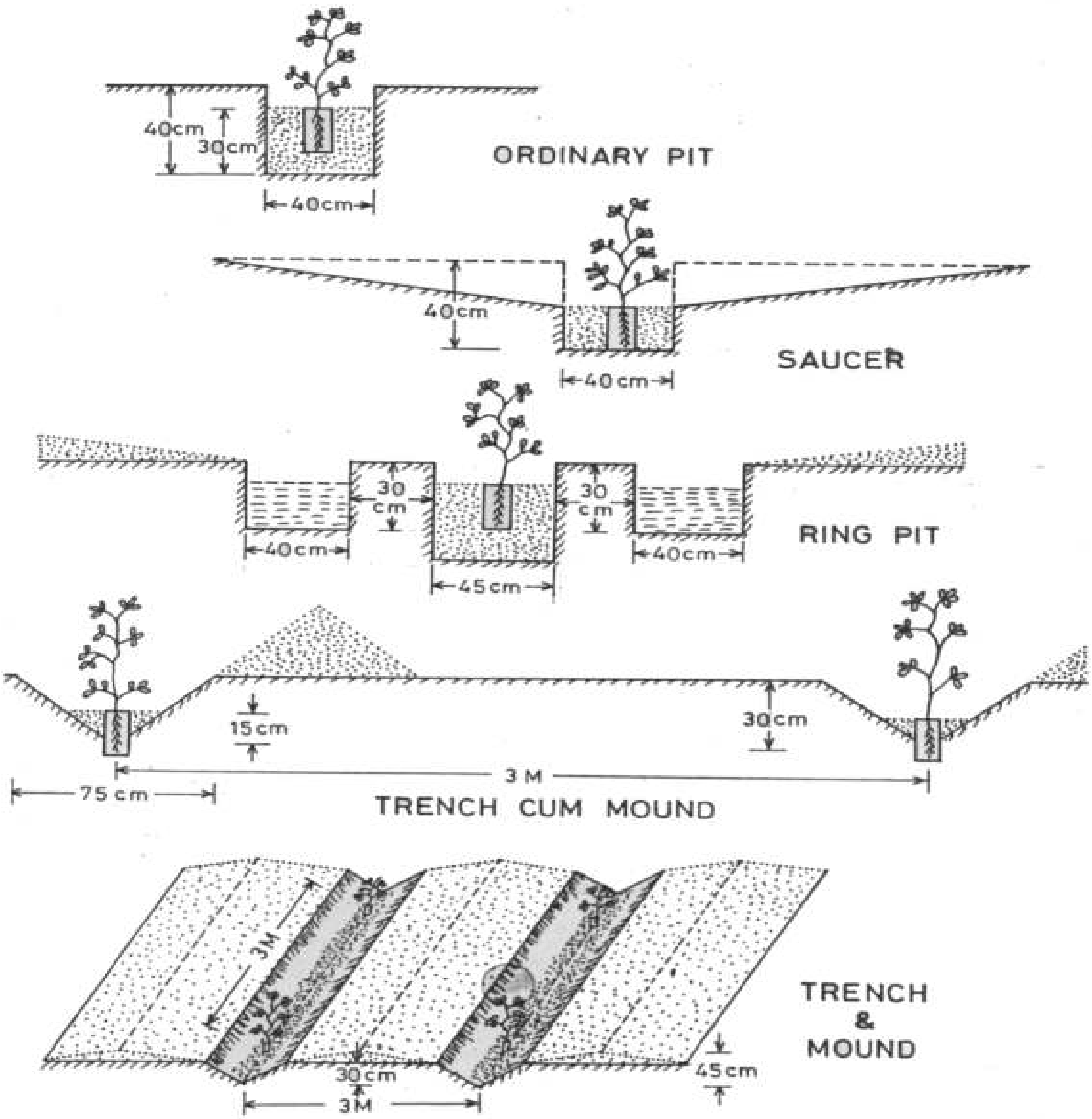


Fig 3.3. Different micro-catchment for rainwater harvesting and utilization in afforestation programmes. Source: Gupta (1995).

- Saucers, semi-circular bunds or half moons: Big saucers of 3.0 m diameter with 10-20 % slope are beneficial for plant establishment, growth and biomass production as they prevent runoff losses by 30-50 % and maintain higher soil moisture regime, facilitate root system and improve water and nutrients use (4-7 times) efficiencies thus give a good start to young plantations (Gupta *et al.*, 1993). Semi-circular bunds are earth embankments in the shape of a semi-circle with the tips of the bunds on a contour line. These are constructed in staggered lines with runoff producing catchments between structures in rainfall region of 200 to 750 mm and land slope of 2 to 5%

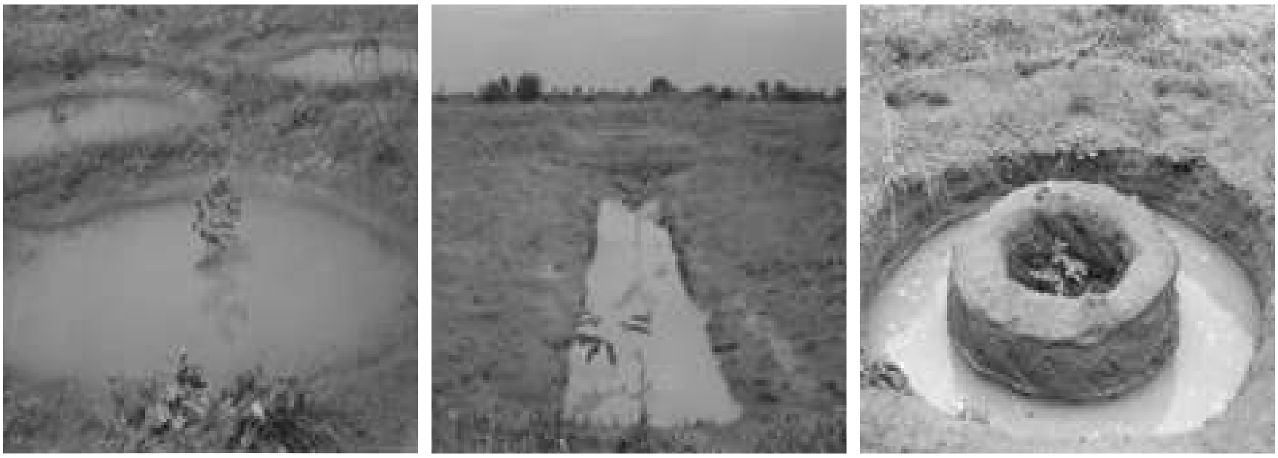


Fig 3.4. Different micro-catchment rain water harvesting structures like saucers pit (left), ridge and furrow structure (centre) and ring pit (right).

or more as applied in Aravallies in Rajasthan. Semicircular bunds are used in Africa are quick and easy method of improving rangelands productivity. These bunds are more efficient in terms of impounded area to bund volume than other equivalent structures like trapezoidal bunds. Semi-circular bunds can be constructed in a variety of sizes, with a range of both radii and bund dimensions. For tree growing and production of crops semi-circular bunds of small radii, i.e. 2 to 3 m and bunds height of about 25 cm are commonly used. Soil for the bund is either drawn from within the hoop by creating a furrow inside or outside the hoop.

Gupta (1994) conducted a field experiment to investigate the influence of various rain water harvesting and conservation techniques on soil moisture storage, growth and biomass production of *Azadirtichta indica* (Neem) in the Indian desert. The treatments were: control: weed removal; weed removal plus soil working; saucers of 1.0 m diameter; saucers of 1.5 m diameter-, saucers of 1.5 m diameter covered with mulch around the trees; bunding around each tree in a checkerboard design; inter-row slopes of 20% (Fig 3.3 and 3.4). The treatment with inter-row slopes of 20% produced the highest amount of soil moisture storage, a four times increase in total biomass of a 26-month-old neem plantation (from 1.69 to 6.39 t ha^{-1}), a 4.5 times increase in root mass (from 0.43 to 1.92 t ha^{-1}) and a 70% increase in tree height, as well as an appreciable enhancement in all the growth parameters. The treatment with larger saucers (1.5 m diameter) combined with a surface mulch was equally effective. Growth increases owing to the other water harvesting treatments were lower, though significantly better when compared with the control. The various treatments significantly improved the water use efficiency of Neem. In case of *Tecomella undulata*, water harvesting technique of inter row slops (20 per cent) caused a more than five-fold increase in the total biomass of a 26 month old plants, four-fold increase in root mass and 35% increase in tree height as compared to that in the control plants (Gupta *et al.*, 1993). Saucer of 1.5 m diameter covered with organic mulching was the second best treatment. Both significantly improved soil moisture storage water use efficiency of trees.

- Contour ridges (furrows or bunds): Contour furrows or ridges are micro catchment technique that follows the contour at a spacing of usually 1 to 2 m for agricultural crop and at wider distance for tree plantation or range land development. Runoff is collected from the uncultivated strip between the ridges and stored in a furrow just above the ridges. It is simple and can be constructed by hand or by machine and is less labour intensive than the conventional tilling of a plot. It is applicable in annual rainfall zones of 350 mm to 750 mm and land up to 5% slope and to all soils but heavy and compact soil should be avoided. This technique is used in a variety of climatic and soil conditions and can be adapted to rainfall by adjusting the distance between contours and also the area of cropping/plantation. Water harvesting potential is reduced or lost if the catchment area is planted. Evaluation work carried out in Bhilwara district of Rajasthan indicated beneficial effects of contour ridging on productivity of Cenchrus setigerus grass sown for developing pastureland in the district (Singh and Singh, 2010). Leveling off the ground between contours assists in water spreading when runoff is collected.

Ridge and furrow structures are designed to increase the available soil water in order to improve the establishment and growth of plantations and stabilization of yield of agro-pastoral system (Feng *et al.*, 2012). Use of crop straw, plastic film, gravel–sand or stone materials to mulch the soil surface reduces soil evaporation, increases water availability and decreases soil erosion (Feng *et al.*, 2012). Different methods of water harvesting and moisture conservation viz. Control (T1), weeding (T2), weeding with oil working (T3), weeding and saucers of 1 m diameter (T4), weeding and saucers of 1.5 m diameter (T5), weeding and saucers of 1 m diameter + mulching (T6), micro-catchment structures by raising bunds around each tree in checker board design (T7), and ridge and furrow structure (T8) with 20% slop (Fig 11.1) were tested with *Azadirachta indica, Tecomella undulata* and *Prosopis cineraria*, where ridge and furrow method found the best by improving the growth of all three species (height by 58%, 35% and 40%, collar circumference by 73%, 56% and 63% and crown diameter by 111%, 51% and 131%, respectively). Biomass accumulation increased by 3.8-fold and 4.6-fold in *A. indica* and *T. undulata*, respectively (Table 3.1). Mulching with locally available weed was also beneficial to *A. indica*, whereas weeding improved growth of most of the species (Gupta, 1994, 1995). Tree roots in water harvesting plots were deeper and had several times larger spread than the control. Nutrient uptake by these tree species increased several-folds as a result of the different water harvesting and moisture conservation treatments. The increase in cost of plantation due to T8 treatment was 50% (Gupta, 1995).

Table 3.1. Influence of rainwater harvesting and conservation practices on growth of 26-month old trees of different species in Indian Desert.

Treatments	*A. indica*				*P. cineraria*			*T. undulata*			
	Height (cm)	Collar girth (cm)	Crown dia. (cm)	Biomass (g)	Height (cm)	Collar girth (cm)	Crown dia. (cm)	Height (cm)	Collar girth (cm)	Crown dia. (cm)	Biomass (g)
T1	216	13.8	127	1016	119	7.3	65	151	150	9.4	230
T2	301	21.3	210	2060	138	9.5	100	186	162	14.1	601
T3	295	20.0	213	2004	145	9.4	85	190	170	14.0	572
T4	308	22.0	197	2296	151	10.6	95	176	180	13.7	630
T5	319	23.6	222	2465	156	10.8	175	193	210	14.7	919
T6	315	23.1	245	3329	148	10.5	90	200	204	15.8	942
T7	299	22.4	255	1953	138	9.5	140	176	146	12.8	699
T8	342	23.9	268	3836	166	11.9	150	211	227	14.7	1061

Source: Gupta (1994a, 1995)

- Terracing: Terracing is applied in nearly level steps along contours normally by half cutting and half filling procedure. Terraces are constructed by putting soil up slope from a ditch to form a bund along a contour to make the surface level to some extent. The terracing of sandy slopes and sand mounds in ravenous sites in western Rajasthan have been found quite effective in soil and water conservation (Singh, 2004c). In general, in this type of soil condition, irradiation and hot winds affects soil water availability on the top of the sand mound in ravenous areas resulting in poor growth of the planted seedlings particularly at the top of the mound. Terracing and preparation of V-ditches on the top facilitate soil and water conservation at the mound and enhances plant growth (Fig 3.4). Soil and rainwater are conserved within the bunds, and the bunds are usually stabilized by planting fodder grasses. A cutoff drains may also be prepared to protect the terraces from surplus runoff. Wherever stones are available, stone terrace walls are relatively better as they allows surplus water to pass through and overtop the walls. Distance between the bunds ranges from 5 m on steeply sloping lands to 20 m on more gently sloping lands. It is used in growing horticultural crops like bananas, papaya, citrus and guava planted in the ditches, whereas fodder grasses or scrubs are planted on the bunds. This technique is suitable for regions with about 700 mm annual rainfall or above with sufficient soil depth ranging from gentle slopes to greater than 5%. Cost of construction of this structure is estimated at 150 to 350 person days/ha for terraces and cutoff drains.

Fig 3.5. Soil working and terracing of sandy slopes for water conservation at ravenous site in Jalore forest division. Source: Singh (2004c).

Bench terracing is applied in nearly level steps along contours normally by half cutting and half filling procedure. It is an earthen embankment or a ridge and channel, constructed across the slope at a suitable location to intercept surface runoff and help slope stabilization. It can be constructed with an acceptable grade to an outlet or with a level channel and ridge. By adopting bench terracing, both degree and length of the slope are reduced which help conserved soil moisture and enhance plant growth and crop production. Bench terracing is recommended for slopes from 10 to 30%. Design of bench terraces depends upon soil depth and uniform spreading of top soil, slope gradient of land,

Fig 3.5. Contour dykes in conserving soil and water and facilitating rehabilitation of rocky areas. Source: Singh (2004).

amount of rainfall, farming practices in the region and proposed crops to be grown in the area, terrace spacing, terrace grade along the width and length and terrace cross section. In general, terrace spacing is the vertical distance between two successive bench terraces. It is equal to the double the depth of cut and depends on the soil depth and land slope. The width of terrace should be such that it enables convenient and economic agriculture operations.

- Contour dykes: Use of stones in making bunds is a traditional practice in rocky areas. Improved construction and alignment of stone bunds along the contour makes the technique considerably more effective (Fig 3.6). Such bunds are used to slow down and filter runoff, thereby increasing infiltration and capturing sediment. In addition to less maintenance the great advantage of this system is non-requirement of spillways, where potentially damaging runoff is concentrated. The filtering effect of the semi-permeable barrier along its full length provides a better spread of runoff than earth bunds. This is effective in rehabilitation of barren and crusted soils by using a combination of stone bunds and planting pits by keeping the water spread throughout the area resulting in deposition of sediments in the cracks and crevices and can be utilized for seed sowing and rehabilitation of such rocky areas (Singh, 2004; 2008). It is often started at the lower points of a field and work upslope rather than the conventional wisdom which would suggest starting at the higher points in the catchment and working down slope. Stone bunds of a single line following the contour are laid across fields. The resulting structures are up to 25-45 cm high with a base width of about 35 to 40 cm. To increases stability these are set in a trench of 5 to 10 cm depth. The spacing between bunds varies depending largely on the amount of stone and labour available. Bund spacing of 20 m for slopes of less than 1% and 15 m for slopes of 1-2% observed effective. A common error is the use of large stones only, which allow runoff to flow freely through the gaps in between. Hence a mix of large and small stones is recommended and the bund should be constructed in such a way that smaller stones placed upstream of the larger ones to facilitate rapid siltation.

- Continuous contour trenches: Contour trenches are ditches generally dug along a hillside in such a way that they follow a contour line and run perpendicular to the flow of run-off water. The soil excavated from the ditch is used to form a berm (a narrow shelf) on the downhill edge of the ditch. Contour trenches are used to slow down and collect runoff water, which then infiltrates into the soil. It reduces soil erosion and salinity in ground water, assists in recharge of shallow wells and prevents pollutants from draining into the water bodies. Continuous trenches of 60 cm x 30 cm or 45 cm x 45 cm cross section spaced at 5 to 6 m (depending upon slope conditions) horizontal interval control the runoff effectively (Fig 3.6) This leads to uniform in-situ rainwater and soil conservation to the extent of 96 to 97% (Dalvi *et al.*, 2009; Singh, 2011). Trenches primarily favour plant growth and increase agricultural productivity rather than just as a means to increase groundwater levels (Singh et al., 2013a). In general contour trenches are applicable in the soils with sufficient infiltration capacity and potential sub-surface storage capacity. It is generally avoided in the area with slopes greater than 10%. In region sensitive to very heavy storms it may be dangerous to prevent the water completely from flowing down a slope. In such areas building of waterways or drains at a slight angle so that the excess water could safely channeled away. The excavated soil of the trench can also be used to fill up the existing gullies and the trenches can also be connected to the wall of a sand dam. Small scale contour trenches can also be used at field level. The water that infiltrates are utilized as soil moisture for plant/crops growth after a rainfall event, directly for pumped irrigation, or extracted from shallow wells in the area for irrigation. The major limitations of contour trenches are errors occurring in contouring over long distances resulting in water flow from the high point to the low point, cutting a path and increase in soil erosion. In such a condition intermittent plugging of the trenches is recommended to avoid

Fig 3.6. Contour (left) and staggered/box (right) trenches for rainwater harvesting and rehabilitation work. Source: Singh (2011).

accumulation of stored water in limited area. The berm can also be planted with permanent vegetation like native grasses or legumes to stabilize the soil and for the roots and foliage in order to trap any sediment that would overflow from the trench in heavy rainfall events. It facilitate soil carbon storage in deeper soil profile and facilitates growth of the species with characteristics of deep root systems like *Holoptelia integrifolia, Emblica officinalis, Ziziphus mauritiana* etc. (Singh, 2011; Singh *et al.*, 2013a). Based on the effects of RWH treatments on the growth performance of tree seedlings, the planted species *Dendrocalamus strictus, Emblica officinalis, Ziziphus mauritiana, Holoptelia integrifolia* and *Syzygium cumini* have been observed best suited to contour trench rainwater harvesting divices (Singh, 2011)

- Staggered contour trenches: Staggered trenches on a contour line are prepared in medium rainfall region with highly dissected topography and slope between 10-25%. The length of the trenches is about 2-3 m and the spacing between the rows vary from 3 to 5 m, though depends upon slope condition. Size of the trench depends on the depth of the soil and other factors. In general, the most popular size used in the watersheds is 50 cm (depth) × 50 cm (width) though trench dimension of 45 cm x 45 cm is also adopted (Fig 3.6, Singh, 2011). The soil excavated is piled up 20 cm away, downstream of the trench. The gap between the trench and soil called berm is essential so that the soil does not fill up the trench again. The chances of breaches of staggered trenches are less as compared to continuous contour trenches. This appears better as compared to contour trenches because of invariably errors occur in contouring over long distances resulting in water flow from the high point to the low point, cutting a path and increase in soil erosion. For this one can dig trenches of 2 m long on a contour line giving a gap of 4 m. The gaps in the contour line should fall below the trenches in the higher contour line. Chains of staggered trenches could be made along successive contour lines so that water left by one line of trenches is captured by the immediately lower line. In areas where there is an abundance of trees and vegetation, gaps in excavation are in any case essential to allow space for the roots of the trees to spread. Wherever there are hard rocks underneath the soil, trenches must be staggered. In some cases contour staggered trenches supported by vegetative barriers like *Cymbopogon flexuousus* are more efficient in soil erosion control and are effective in reducing run-off and soil loss compared to vegetative barrier of different grasses including *Vetivera zizanoides.* If grass has to be planted along the trenches, then the excavated soil can be piled up in a 10 cm high rectangular layer, whereas for plantation purposes, seedlings can be planted either in the space after the trench or on either side of the trench (Fig 3.7). In fact, it will be more appropriate to plant the seedlings downside of the trench to fully utilize the stored water in the trench (Singh et al., 2011). Because of its capacity of increasing soil moisture throughout the area, species showing surface spreading roots like Gmelina arborea performs better in this structure (Singh, 2011).

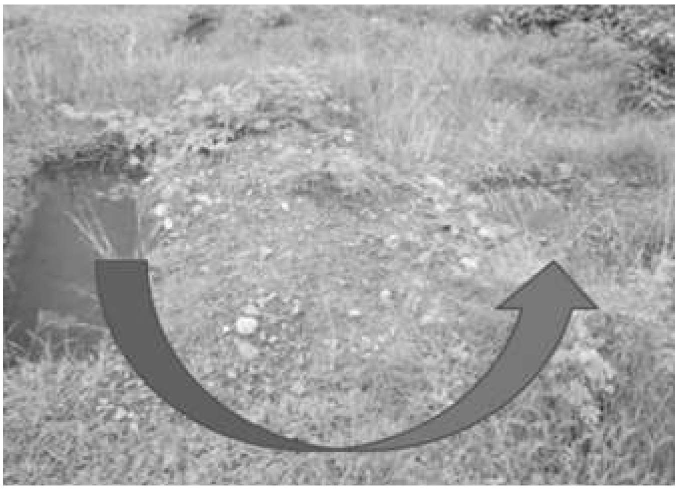


Fig 3.7. Planting position along a box trench for effective utilization of harvested water. Source: Singh (2011)

- Gradonie and V-ditches: Gradonie and V-ditches are across the contour and 1800 cm2 in cross section area [(30 × 120)/2], but differences were only in vertical cut of 30 cm height. Gradonie ditches are constructed and bunds are made out of the excavated soil from the ditch. The vertical (height of 30 cm) cut is upside of the slope but the excavated soil is heaped towards the down slope (Fig 3.8 left). They are excavated at different contour levels to reduce velocity of surface run-off and facilitating infiltration of stored water underground and utilization of stored soil water by the seedling growing in or along the ditches. The V shaped ditches across the contour are constructed and bunds are made out of the excavated earth in the form 'V' ditch. The vertical (height of 30 cm) cut is downside of the slope. Ditches are of 1800 cm2 cross section area to conserve the run off in the prepared ditch facilitating infiltration of stored water underground and there utilization by the seedling growing on the bund and/ or ditches. The excavated soil is heaped towards the down slope to form a bund of about 20-25 cm height (Fig 3.8 right). Study carried out in Banswara areas indicated *Acacia catechu* and *Azadirachta indica* as the tree species best suited to V-ditch rainwater harvesting

Fig 3.8. Gradonie (left) and V-ditch (right) rainwater harvesting structures under rehabilitation of degraded lands. Source: Singh (2011).

devices. Further, all Acacia species either planted or regenerated performed best with V-ditch RWH treatment (Singh, 2011). Further, average increases in herbage dry biomass over the control plots was 27.58% in contour trench area, 45.34% in Gradonie ditch area, 23.85% in box trench area, and 61.63% in V-ditch treatment area indicating that Gradonie and V-ditches are better suited for increasing herbaceous vegetation and hence developing range lands (Singh, 2011; Singh *et al.*, 2013a).

Drainage Line Treatments

Check dams or gully plug are temporary or permanent dam constructed across a drainage ditch, swale, or channel to reduces the velocity of runoff, while minimizing channel erosion and promoting sediment deposition (Ruffino, 2009). Stormwater enters a channel (gully or stream) or vegetated ditch is ponded temporarily behind the check dam in the sediment control basin. This ponding allows sediment and other pollutants to settle out, while allowing some water to infiltrate and evaporate. Small and medium gullies are reclaimed through clearing and leveling of gully bed, followed by construction of check dams and ramps with suitable grasses. Gully plugging, planting of grass species like *Dichanthium annulatum* on gully heads and sides, and plantation of tree species like *Prosopis chilensis, Acacia nilotica, Dendrocalamus strictus,* etc. help control soil erosion and water loss. Methods available for gully control include:

- Diversion of runoff,
- Vegetative methods,
- Construction of temporary structures, and
- Construction of permanent structures.

- Diversion of runoff: Diversion of runoff water is achieved by constructing diversion drains. In general the diversion drain is a shallow channel put across the slope above the gully. In the diversion drains the slope is kept generally less than 0.5 per cent and usually between 0.1 to 0.25 per cent. The diversion drains intercept the runoff coming from the area above the gully. The intercepted runoff is let off at a point in the gully well protected so that no further erosion at that point occurs.

- Vegetative methods: In these methods, the objective is to control gully erosion using different types of vegetation, which may be natural or artificial. If the runoff is diverted and grazing is controlled from the eroded area, natural vegetation begins to get established. The growth of natural vegetation will eventually protect the gully area with grasses, shrubs and trees native to the region. Development of natural vegetation may also be stimulated by application of fertilizers or by spreading some mulch to conserve the moisture and facilitate regeneration. Artificial vegetation of the gully beds and banks accelerates the process of establishing the vegetation and will help in stabilizing the gullied area. Where the gully banks are not deep and contain soil, they are sloped and then vegetation is established on the slopes of the gully. Selection of grasses, shrubs or trees should be carefully done and should suit the local conditions as well and they should be of some economic importance. Grasses are primary vegetative cover used in general to gully control. It is established both on the bed and the sides either by seeding or clump planting. The head of the gully is shaped to a gentle slope not exceeding 6: 1 and grass is established by clump planting.

- Temporary Structures: Temporary structures for gully control are designed to retard the flow of water and reduce the channel erosion. In addition, they retain some quantities of sediment and moisture which helps in establishment of vegetation. These temporary structures for gully control are advantageous in terms of (i) There are cheap as compared to permanent structure, (ii) material used are locally available, and (iii) No technical skill is needed for their construction. There are a wide variety of designs developed for temporary structures, which include earthen check dams, brushwood dams and loose stone dams.

- Earthen check dams: In fact the earliest known earthen dams or embankments were made of earth and are still in use to plug gullies presently. Under large quantity of water storage or pounding of water, embankment dams are prepared by placement and compaction of a complex semi-plastic mound of various compositions of soil, sand, clay or rock. It has a semi previous waterproof natural covering for its surface and a dense, impervious core. The earthen check dam is prepared to stabilize water flow and minimize further erosion by using locally available soils (Fig 3.9). Thus it utilizes natural material with a minimum of processing and can be built with primitive equipments under the conditions where any other construction materials are not available or impracticable. Dimensions of the dams depend upon the width of the gully and load of the run-off. Seed sowing of grasses or Acacias (like *A. senegal*) further strengthen and extend the life span of the earthen check dams (Singh, 2004; Fig 3.9).

Fig 3.9. Germinated of A. senegal seedlings on the earthen chechdam at Malwada plantation site in Jalore forest division.

- Brushwood check dams: These structures are constructed using brushwood/vegetated material available locally to conserves small gullies up to 1.2 m to 2.1 m deep. These are further classified into; (i) single row brushwood checkdams, which are a single row of posts erected across the channel with brushwood laid along the flow of water. The brushwood is kept in position by tying it to the posts; and (ii) multiple row brushwood checkdams are used for 7 or 8 feet deep and about 29 feet wide gullies. The posts about 6 inch diameters are driven in two rows across the flow of water and brushwood are tied with galvanized wire. It can also be constructed by planting bamboo across the drainage line to have dense rows of bamboo.

- Loose stone dams: Loose stone checkdams are made up of dry stones without mortar. In this the slope gradient of the gully banks is first reduced to 45 °; then a foundation of 30-50 cm deep is dug and the dug up soil is piled upstream to be used later for the refill. The largest stones should be placed at the bottom layer. Sometime cemented copping is provided to strengthen the structure from top (3.10 left). In most of the cases it is constructed in the form of an arch with convex side facing the water current. The walls are built leaving a step of 6 inch on the down streamside without deviating from the arch so that the top width could gradually reduce. After reaching 0.60 m above bed level, a notch is use to left in the middle. Notch is half the span long and 0.30 m deep. Apron and wind walls are also built of stones. At the back of checkdams, earth brushwood and stones are piled upon the notch to make it more effective. Size of the structure depends upon the site with 0.30 to 1.5 m in height and a minimum width of 0.6 m. Besides, the slopes should have a maximum ratio of 2:1 as greater slopes may become unstable and will require excessive maintenance. The center of the check dam should be at a minimum and 15 cm lower than the edges to allow water to flow over the top of the structure.

Fig 3.10. Loose stone check dam (left) and masonry check dam (right) for treating drainage line.

    - Rock filled and woven wire dams: The rock fill dams and the woven wire dams are long lasting than the loose rock dams. There are no standard principles of the design of these temporary structures. They are to be designed keeping in view of the needs and availability materials in a given situation.

- Permanent structures: Permanent structures are constructed when the benefits from such structures are justifiable compared to the cost of construction. The permanent structures protect the gullies from further development and at the same time, help in storage of water. General characteristics of the permanent structures for gully erosion control are:

    - They are constructed with permanent materials,
    - They have adequate capacity to handle the runoff, and
    - They help in stabilizing the gully and store water wherever necessary.

  These structures are built in deeper and wider gullies where other measures are unable to stop erosion. There are generally three types:

    - Drop spillway: It is an efficient structure for controlling relatively low head upon 3m and discharge capacity of up to 3 cubic meter per second.

- Chute spillways: This structure is useful in high overflows where a full flow structure is required and where the site condition does not permit to use a detention type of structure.
- Gabions: These are pre- fabricated rectangular basket made up of galvanized wire netting. Stone-filled gabions are very flexible structures able to withstand significant movements from undercutting or land slippage. They can be constructed on a better or level drainage. These structures work well in unimproved channels because they provide surface roughness more in harmony with natural channels. Gabions can also absorb significant deflections when undercut by the stream. In this the basket is placed in position and filled with stones, and then the lid is wired down. Basket has size of 4 m × 1 m × 1 m. A well graded stone of 3 to 8-inch size, clean and hard are specified to fill up the basket and increases density. Stones must distribute evenly by hand to minimize voids and ensure a pleasing appearance along the exposed faces. Baskets should be square and diaphragms should be straight. However, the fill in adjoining cells should not vary in height by more than 1-foot. Leveling of the final stone layer allow the diaphragms tops to be visible.
- Masonry Check dams: These are weir like structures constructed across a swale, drainage ditch, or waterway either with masonry and concrete to counteract erosion by reducing water flow velocity (Fig 3.10 right). At top of the structure, a notch is use to left in the middle. Notch is 3 feet to half the span long and 0.30 m deep. These are mostly designed at hilly region, mountain areas. To discourage concentrated flow, water velocity in the channel can be reduced by using multiple check dams. The distance between check dams will depend upon the slope of the drainage line, but should be spaced so that the base of the upstream check dam is even with the peak of the downstream structure. Thus increase in the slope of the drainage line will require increased number of check dams to prevent concentrated flow in the channel.

SOIL AND WATER CONSERVATION STUDIES

Effects of Mulching

RWH practices improve hydrological indicators such as infiltration and groundwater recharge, enriches soil nutrients, and increases biomass production with subsequent higher yields (Vohland and Barry, 2009). High biomass production supports a higher number of plants and animals. Adoption of moisture conservation techniques such as mulching, tillage, weeding, etc. have enormous potential in success of afforestation by conserving soil available moisture which are utilized by the plants (Ludwig *et al.*, 2005; Yu *et al.*, 2008). Moisture conservation practices such as mulching with local under shrub like *Crotalaria burhia,* soil tillage and intercultural operations in dry zones adequately demonstrate their utility in plantation establishment and early growth of *Azadirachta indica* seedlings by increasing height by 24% and collar circumference by 27% (Gupta, 1994). This impact is attributed to the prevention of evapo-transpiration losses and consequently high soil moisture regimes and moderation of thermal regimes (by 5°C) in the vicinity of roots and consequently maintaining better microbial activities resulting in transformation and availability of nutrients (Gan et al., 2013). Coir pith mulching together with application of 50 g of single superphosphate and 25 g urea per plant of *Peltophorum pterocarpum, E. camaldulensis, A. nilotica* and *A. plantifrons* enhances survival (by 12 to 37 percentage), growth and biomass of these species (Gupta, 1991).

A field experiment was conducted during 1995 in an existing four year old plantation at 3 m x 6 m spacing and performance of different tree species on a moisture stressed arid sandy site of Jodhpur with mulching and no mulching treatments was recorded. *Azadirachta indica* was the best performer attaining an average 43.1 cm girth and 511 cm height at 78 months of age, followed by *Acacia nilotica* (31 cm girth and 524 cm height), *Albizia lebbeck* (34 cm girth and 391 cm height), *A. planifrons* (35 cm girth and 380 cm height), *Prosopis cineraria* (22 cm girth and 279 cm height) and *Tecomella undulata* (23 cm girth and 262 cm height). Performance of all the species was better on mulched than unmulched plots. Leaf water potential (LWP) values varied considerably from species to species, lowest being -7.22 MPa (mega Pascal) in *A. planifrons* followed by *A. lebbeck* (-6.2 Mpa), *P. cineraria* (-6.70 Mpa), *T. undulata* (-6.20MPa), *A. indica* (-5.45 MPa) and *A. nilotica* (-3.94 MPa). These values indicate that even at very high LWP of -5.28 Mpa, neem exhibited best growth indicating its high tolerance to moisture stress. For this site Neem appeared to be the most suitable species and *T. undulata* (rohida) the least suitable species.

The effects of deforestation and loss in forest quality can be balanced by promoting natural regeneration of forest and the establishment of plantations to some extent. A study was conducted in Coimbatore Forest Division, Tamil Nadu as eco-restoration model of degraded tropical dry deciduous forests to meet the social needs of local communities for fuel wood by IFGTB (George and Buvaneswaran, 1997). Tree species like *Acacia planiforns, A. nilotica, A. leucophloea. Eucalyptus tereticornis, Albizia amara, Hardwickia binata* and *Azadirachta indica* were introduced. *A. planiforns* seedlings were planted @ 2500 trees/ha and 50 g each of N, P and K in the form of urea, single super phosphate and muriate of potash were applied as basal dose. Saucer bunds were formed around individual plants as a measure of soil moisture conservation (Table 3.2). A control plot was also maintained for comparison purpose. *A. planiforns* performed better in terms of survival percentage and growth parameters compared to other species. Thinning operation was carried out three years after planting by removing 50% of stocks. Also, one pruning operation was performed at four years of age.

Table 3.2. Growth performance of *A. planifronse* in treatment and control plot during eco-restoration of degraded forest in Tamil Nadu. Source: George and Buvaneswaran (1997).

Height growth (m)				**Basal girth (cm)**			
Year	**3**	**4**	**5**	**Year**	**3**	**4**	**5**
Treated plot	3.1	4.3	5.2	Treated plot	25.5	32.6	42.4
Control plot	1.4	2.2	2.9	Control plot	12.6	17.8	26.3

At the age of 5 years, during second thinning operation, the stand density was again reduced by 50% and a final stand density of 625 tree per ha was retained for future conservation strategies to augment natural regeneration of other native tree species (Fig 3.11). Tree species in the treated plots showed better growth performance compared to control which might be due to the effects of silvicultural operations, organic matter addition, erosion control and changes in soil moisture regime (Table 3.2).

Fig 3.11. Visual appearance of the reforested site before reforestation (left) and after reforestation (right).

In a study conducted on natural regeneration of trees in Silent Valley National Park under protection and conservation showed a positive effect on tree regeneration in the grasslands located in Valiyaparathodu, Chembotti, Poochapara, Poonchola, Kummattamthodu and Aruvanpara areas of the national park formed due to anthropogenic disturbance especially fire. Several trees had regenerated in the grasslands amidst the west coast tropical evergreen forest (Kunhikannan, 2010). Several trees regenerated naturally in these grasslands giving it a mosaic appearance. The various tree species observed in their order of dominance in the grasslands are *Wendlandia thyrsoidea, Symplocos racemosa, Ligustrum perrottetii, Glochidion ellipticum, Olea dioica, Phyllanthus emblica, Measa indica, Psydrax umbellate, Neolitsea scrobiculata, Callicarpa arborea, Elaeocarpus munronii, Elaeocarpus serratus, Syzygium cumini, Ziziphus rugosa, Symplocos cochinchinensis, Apodytes dimidiate* etc. This indicates the positive impact of protection from grazing and fire on revegetation of the disturbed sites. Degraded forests have the potential to regenerate for environmental benefits, if properly managed.

Study on partitioning of water loss in a lysimeter study at AFRI, Jodhpur indicated that water losses from the *E. camaldulensis* plot (irrigated at the rate of 36.2 mm per irrigation) was 4.75 mm day^{-1} (19 lit day^{-1}) during summer as compared to 3.45 mm day^{-1} (13.8 lit day^{-1}) in *A. nilotica* and 2.62 mm day^{-1} (10.56 lit day^{-1}) in *D. sissoo* plot (Singh and Rathod, 2012). The depletion in soil water from bare soil was 7.0 lit day^{-1} indicating substantial that contribute significant amount of water loss. Simple mulching with locally available *Crotalaria burhia* under shrub saved the water loss by 0.15 mm day^{-1}.

Effects of Soil working and Vegetation

In arid and semi arid regions rainfall is concentrated during a small period of July to September. Whatever the amount of rain water stored in soil profile needs to be managed to support tree growth for rest of the period of 9 to 10 months. This stored moisture evaporates faster in arid regions due to high temperature, strong winds and arid climate. Studies on different types of mulching, soil tillage and intercultural operations (Weeding) in plantations of arid and semi arid zones were carried out. The results adequately demonstrate the utility of mulching and weeding practices in arid and semi arid regions in plantation establishment and early growth of trees. This impact is attributed to the prevention of evapotranspiration losses and consequently high soil moisture regimes, moderation of thermal regimes in the vicinity of roots (lowering of the maximum temperature in summers and preventing the drop of minimum temperatures in winter) and consequently maintaining better microbial activities resulting in transformation and availability of nutrients.

Soil working, weed removal and conservation tillage also show profound effects in improving soil water that facilitates plantation growth (Gupta and Meena, 1993; Gupta and Limba, 1995). Effects of deep ploughing and weed removal facilitate infiltration of rainwater that is conserved into deeper soil profile. The conserved soil water in deeper soil profile is utilized by 15 cm deep planted seedlings under capillary action that help in enhancing seedling survival even with one liter of water application that is only to affirm soil contact between seedling soil clog with the bulk soils. With an additional 10% cost of mulching enhances the biomass by 35% (Gupta and Meena, 1993; Gupta and Limba, 1995). The study also highlights the necessity of weeding in arid zone plantations as it prevents unproductive loss of water and nutrients and allows their utilization by plantation thereby improving their growth (Gupta, 1994; Singh and Rathod, 2012). Weed clearing conserve 20% higher moisture, improve tree height by 26% and double the biomass production in A. indica as compared to the plants growing without any amendments (Gupta et al., 1993). Effects of different conservation measures like weed removal, weed removal and soil working, weed removal + soil working + Saucers of 1 m diameter, weed removal + soil working + Saucer of 1.5m diameter, in-situ water conservation structures in checker board design, weed removal + soil working + mulching in saucer round the plants, and water conservation by making inter row slope of 20% showed that inter row slopes of 20 per cent gave highest survival, growth and biomass (Gupta et al., 1993; Gupta, 1994) because of significantly higher soil moisture in the root zone (i.e., 40% higher than the control) enhancing growth. Weed removal alone enhanced tree height by 26% over control. The practices of mulching and making saucers also enhanced soil water content promoting tree growth considerably (Gupta, 1995).

Soil Moisture Gradient and Productivity

Existing vegetation affects growth and productivity of plantation by altering availability of soil resources viz. soil water and nutrients. Therefore, proper management to ensure water availability will be beneficial to enhance the productivity and the population of planted species under afforestation programme. It was confirmed through a study on the influence of soil moisture and nutrient gradient on growth and biomass production of *Calligonum polygonoides* in Indian desert affected by surface vegetation, wherein in different habitats were selected to determine competitive interaction of *Dactyloctenium sindicum* grass for soil water (Singh, 2004b). Bare dune (BD), bare dune plantation (BDP), semistabilized dune plantation with *D. sindicum* (SDP), flat land without vegetation (FW), flat land with *D. sindicum* grass (FG) and flat land plantation with *D. sindicum* (FGP) were the habitats identified on the basis of micro-topography, presence of *D. sindicum* grass and plantation. Growth and biomass production of *C. polygonoides* were observed in relation to changes in biomass from surface vegetation, soil water content and nutrients. *D. sindicum* grass density and biomass were high in FG in 1998 whereas, in 1999 and 2000, FGP produced greater biomass. Soil organic matter, NH_4–N, NO_3–N, PO_4–P and K were comparatively greater in the habitats with *D. sindicum* in 1996. All the nutrients increased in 2000 except NO_3–N and the improvement was more in plantation. High soil water content in FW and BD suggests efficient extraction and utilization of soil water by *D. sindicum* through its extensive root system in the remaining habitats. Soil water content increased in winter and coincided with plant senescence. Plant growth and biomass productions were significantly less and grass production was greater in FGP. Contrasting result was obtained in BDP habitat in absence of *D. sindicum*. Difference in soil water content and nutrients seems to be the main cause for productivity differences of *C. polygonoides*. Lesser plant growth in FGP and SDP habitats was attributed to the competitive effect of *D. sindicum* grass, which seemed to have a stronger competitive effect on resource utilization. The differences in growth and biomass production accounted for the variation in *D. sindicum* grass density and root biomass, which was negatively correlated with growth increments and with soil water.

In another study, growth, biomass production, and soil water dynamics in Acacia tortilis plantation in relation to microhabitat and surface vegetation were studied. In this Bare dune (BD), vegetated dune (VD), bare dune plantation (BDP), vegetated dune plantation (VDP), bare flatland (BF), vegetated flatland (VF), bare flatland plantation (BFP), and vegetated flatland plantation (VFP) were the microhabitats (Singh, 2004c). Soil water content (SWC) was 17% higher in flatland and 35% higher in non planted than those in dune and planted areas, respectively. A 6.9 and 9.4mm lower soil water in VF and VFP, respectively, than in BF indicated that *D. sindicum* extracted and utilized soil water more efficiently. The growth and biomass were similar between BDP and BFP, which were greater than in VDP and VFP microhabitats. Competitive effect of *D. sindicum* reduced biomass of A. tortilis by 6% and 58% and led greater carbon allocation (27% and 38%) in stem in VDP and VFP compared to BDP and FWP microhabitats. Fibrous roots of *A. tortilis* were more in 0–30 cm soil layer of BDP and BFP, whereas they penetrated deeper soil layer in VDP and VFP habitats. *D. sindicum* biomass (shoots + root in 0–90 cm soil layer) was 22–39% higher in flatland compared to dune. It was 438 gm^{-2} in VF in 1998, whereas *A. tortilis* facilitated grass production in 1999 and 2000 in VFP. These results indicate that *D. sindicum* competes with planted species and affects the growth and biomass and requires weeding and soil working to reduce competition and better growth in flatland of dune tracts.

Micro-Catchment and Plantation

Applying micro-catchments over traditional methods of planting improves growth of plant to a varying degree depending upon the amount of water harvested and the response of the species planted. Among water capturing structures like ordinary pits of size 45 cm × 45 cm × 45 cm, saucer pit of 2.0 m diameter, ring pit, trench cum mound, trench and mound, deep ploughing + pitting, trench and mound and bigger saucers of 2.5 m diameter caused dramatic improvement in tree growth and root development. These practices facilitated establishment of plantations and gave them good initiation boost which developed into healthy vigorously growing stands in subsequent years, besides imparting resistance against drought and famines (Gupta et al., 1995). A vigorous root system under micro catchments explores larger soil volume and increases the availability of water and nutrients to the trees. Such techniques also enhanced survival and growth of *D. sissoo, E. officinalis, Z. mauritiana* and *S. cummini* planted at 3 m × 4 m spacing (Annon., 2000). Interestingly, some species like *A. nilotica, Z. mauritiana, S. cumini* and *D. sissoo* performed well in saucers, whereas, *E. officinalis, C. mopane, A. lebbeck* and *E. camaldulensis* performed well in trench cum mound RWH structures at the end of 33 months (Table 3.3). Likewise *Dichrostachys nutans, D. sissoo, Acacia nilotica* and *Prosopis cineraria* observed better performer to 3 m diameter saucer as compared to the other structures.

In a demonstration trial laid out in the month of August in 1995 at Rawal Malinathji Grassfarm in Barmer, Rajasthan district with six treatment of rain water harvesting indicated best performance of Acacia nilotica and Dalbergia sissoo in the treatment where trenches were dug across the slope in between plant rows to harvest the rain water. In comparison to the control 48% and 47% higher height and collar girth respectively was registered in *Acacia nilotica*. In case of *Dalbergia sissoo* the growth was 90% and 63% higher in terms of height and girth respectively (Anon., 2000).

Table 3.3. Effect of rainwater harvesting on the growth parameters of different plant species at Jodhpur (Source: Anon., 2000).

Tree species	Height (cm)			Collar (cm)			Crown dia (cm)		
	Control	T & M	Saucers	Control	T & M	Saucers	Control	T & M	Saucers
A. nilotica	250	292.0	321	4.1	5.4	7.7	54	69	90
Z. mauritiana	338	333	396	4.6	4.7	4.9	152	162	197
E. officnalis	129	145	143	3.1	3.7	3.5	68	44	33
C. mopane	223	253	186	4.4	4.4	4.9	45	154	197
A. lebbeck	386	392	121	6.0	7.0	5.2	169	172	129
E. camaldulensis	266	410	343	4.2	7.0	4.8	115	193	137
S. cumini	67	62	68	3.5	3.1	3.7	23	17	21
D. sissoo	198	253	296	4.3	5.7	5.5	118	123	129

Rainwater harvesting coupled with afforestation has tremendous potential in rehabilitation of degraded hills (Singh et al., 2010a; Singh, 2009; 2014). Restoration practices with water harvesting and plantation of multiple tree species not only reduce water, soil and nutrient losses, but also improve soil water, nutrients and growth and biomass of herbaceous vegetation as well as plantation (Fig 3.12; Table 3.4). About 400 running meter RWH structures per ha could able to control only 2% of the annual rainfall in Banswara area. In such a condition its length can be increased significantly. In addition, it helps sequester carbon in both plants and soils and improves biodiversity in the region as well. Different rainwater harvesting structures show different responses towards water storage, tree seedling establishment and growth and improvement in soil water status. Restoration of a degraded hill involving Contour trench (CT), Gradonie (G), Box trench (BT) and V-ditch (VD) rainwater harvesting devices along with a control in an area with slope gradient of <10%, 10%- 20% and >20% in 2005 showed a decrease in SWC from December to June and it was linearly related to rainfall and vegetation height (Singh et al., 2013a). Interception in photosynthetically active radiations (PARint) by tree, vegetation and tree-vegetation combine were 30.0%, 54.6% and 84.6%, respectively. SWC, plant and vegetation growth and PARint due to tree were lowest, whereas herbaceous biomass and PARint due to vegetation were highest in 10–20% slope (Singh et al., 2013a). Vegetation height and SWC were linearly related to biomass indicating improvement in micro-climate and herbaceous growth. Highest SWC in <10% slope promoted plant growth and mean annual increment (MAI) in height and collar diameter, which enhanced PARint due to tree and PARint due to tree-vegetation combine. These variables were highest in CT/BT treatments and lowest in control plots. Characteristic root distribution of Acacia catechu and A. indica had promoted their growth in V-ditch, whereas *E. officinalis, Z. mauritiana* and *H. integrefolia* performed best in CT treatment. RWH enhanced herbaceous biomass between 22.4% and 60.7% over control. These findings indicated importance of VD/GD structures for growth of herbaceous vegetation as well as *A. catechu* and *A. indica* plants, whereas that of CT/BT structures for growth of other tree species (Singh *et al*., 2013).

Fig 3.12. Restoration of a degraded hills through rainwater harvesting and afforestation.

Table 3.4. Effects of rainwater harvesting and afforestation of soil, water and biological variable during 6 years of observation recording. (Source: Singh, 2011).

Variables	Trend after work initiation
Run-off losses	Decreased (by 2.1% of total rainfall)
Soil losses	Decreased (from 3.43 to 0.19 g l^{-1})
Nutrient losses	Decreased
Soil water	Increased
Soil bulk density	Decreased
Fine earth fraction	Increased (greater in higher slope)
Soil nutrients (NH_4-N, NO_3-N & PO_4-P)	Increased
Soil carbon	Decreased (lower slope)/increased (upper slope)
Plant growth	Increased
Herbaceous diversity	Increased (39 to 92 species)
Regeneration diversity	Increased (22 to 42 species)
Diversity of fauna	Increased
Fodder availability	Increased
Fuelwood availability	Increased
Water availability	Increased

The existing gradient due to soil texture and topographic features affects soil pH, EC, SOC, NH4-N, NO3-N and PO4-P in hilly tracts, where these variables decreased with application of RWH techniques (Singh, 2012). Such improvement in soil status promoted vegetation growth and biomass in higher slope also. Soil water, species diversity and herbage biomass increased from upper to lower position, and RWH techniques had positive role in improving SOC, nutrients, vegetation population, evenness and growth downside of the RWH structures. Despite of lowest soil water, regular rain and greater soil water usage enhances green and dry herbage biomasses in higher slopes as compared to the foothills. Area with contour trenches exhibited higher vegetation diversity and herbaceous biomass, which enhanced concentrations of SOC and PO4-P further. Rainfall influenced SWC, but RWH helped conserve soil and water, promoted plantation and herbaceous growth and facilitated restoration process, and thus promoted restoration of degrading hills. This indicates that applying suitable RWH technique depending upon site conditions and types of species promote regeneration, increase herbage biomass and help rehabilitate degraded hills.

IMPCATS OF WATER HARVESTING AND CONSERVATION

Reduction in water, soil and nutrients loss

Rainwater harvesting, afforestation and protection measures improves soil water and nutrients, reduced the existing gradient in soil water and nutrients between the slopes, facilitated natural regeneration, diversity and productivity and overall sequestered carbon in biomass and soil. Presence of fine shallow truncated soil in 10-20% slope reduced infiltration and facilitated surface run-off to a larger extent in this slope as compared to the other slopes, which have relatively well drained clay loam soil. A study conducted in lower Aravali region of Rajasthan indicated average run-off of 12.58% (varying from 14.63% from 10-20% slope area to 10.22% from <10% slope area) of the total rainfall (Table 3.5).

Table 3.5. Effect of slope gradient and rainwater harvesting devices in reducing water, soil and nutrient losses in a hilly region. Source: Singh (2011).

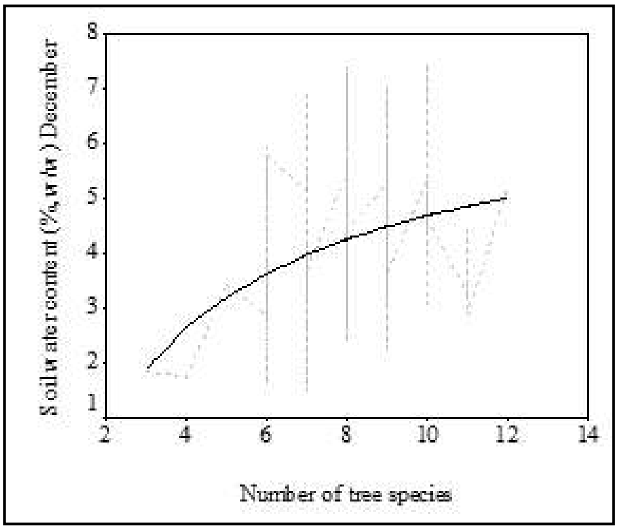
Variables	Slope (%)			Rainwater harvesting devices				
	<10	10-20	>20	Cont *	CT	GD	BT	VD
Water ($m^3 ha^{-1} y^{-1}$)	1193	1735	1454	1712	1336	1486	1496	1274
% reduction				100	22.0	13.2	12.6	25.6
Soil (tone $ha^{-1} y^{-1}$)	1.42	2.60	2.14	2.69	1.64	1.86	2.15	1.94
% reduction				100	39.0	30.8	20.1	27.9
NH_4-N (kg $ha^{-1} y^{-1}$)	1.40	2.23	2.13	2.20	1.73	1.81	2.05	1.81
% reduction				100	21.4	17.7	6.8	17.7
NO_3-N (kg $ha^{-1} y^{-1}$)	1.62	2.70	1.57	2.18	1.85	1.89	1.85	2.02
% reduction				100	11.1	13.3	11.1	2.3
PO_4-P (kg $ha^{-1} y^{-1}$)	0.27	0.49	0.47	0.52	0.35	0.44	0.36	0.39
% reduction				100	32.7	15.4	30.8	25.0

Cont-control; CT-contour trench; GD-Gradonie ditch, BT-box trench; and VD-V-ditch

About 13.55% water loss was from the control plots as compared 11.05% from V-ditch plots. Most effective RWH for controlling run-off losses were V-ditch in <10% slope and Contour trench in 10-20 and >20% slope area (Singh, 2013). Likewise, average soil loss was 3.43, 2.40, 1.21, 0.90, 0.24 and 0.19 g soil $^{-1}$ water loss from the area in September, 2005, July, 2006, October, 2006, July, 2007, August, 2007 and July, 2009, respectively indicating a decreasing trend in soil loss under increased vegetation cover in the area (Table 3.5). Lowest silt load was in the water yielded from the Gradonie plots. Nutrient loss through run-off water reduced throughout the experimental period. It was relatively less in later part of a year as compared to the former part of the year.

Enhancement in biodiversity

Diverse communities of plant on the earth are the result of many abiotic and biotic factors including water. Ecological and hydrological processes interact strongly in landscapes, yet these processes are often studied separately. Most experimental evidences in which production has been increased by enhancement of soil resource availability have shown a corresponding decline in species diversity. Increase in soil resource availability promotes regenerations of many species either from root stocks or seeds available in soil seed bank (Singh *et al.*, 2010a; 2011). However, this is not only the soil water but also nutrients availability, which play important role in promoting and sustaining number of species in a region (Fig 3.13). For example, number of species increases exponentially with soil NO_3-N concentration, though it varies due to variations in species response to different nutrients and soil water availability (Dangwal *et al.*, 2012).



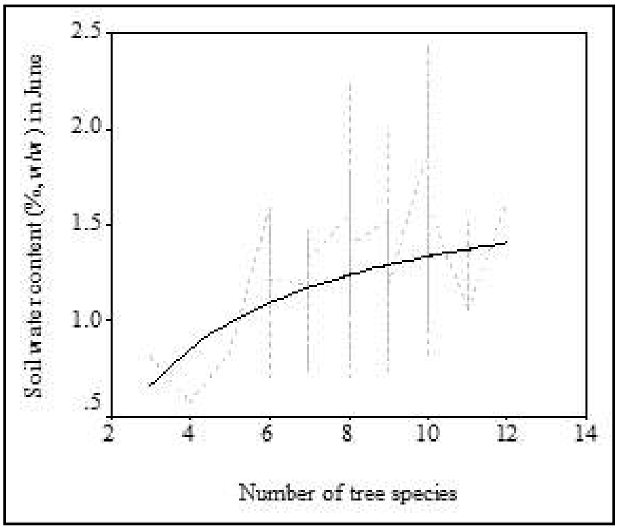


Fig 3.13. Relationship between soil water content (R2=0.139, F1/73= 11.71, P<0.01 in December and R2=0.238, F1/73= 22.82, P<0.001 in June) and number of tree species under rainwater harvesting.

During restoration of a degraded hill, number of species, population and species dominance increased with time, i.e. from 39 in 2005 to 92 in June 2010 (Singh et al., 2011). However, species diversity and richness decreased to the lowest value in 2010 because of increasingly higher dominance of Heteropogon contortus- a C4 grass species with relatively higher adaptability towards environmental stresses. Total numbers of herb/ grass species identified in these years were 151 indicating significantly higher number of species confined to about 17 ha area under restoration. Pooled data for the dry biomass of six years ranged from 275.4 to 535.2 g m^{-2}. The lowest biomass was in <10% slope and the highest was in >20% slope area (26.7% increase over <10% slope), whereas the plots without water harvesting was with lowest values. The increases in herbage biomass over the control plots were 28.2% in CT, 34.9% in Gradonie, 23.95% in BT and 18.84% in VD plots (Singh et al., 2013). A positive relationship between species diversity of herbaceous vegetation and water storage capacity of RWH devices has been observed by greater diversity in CT plots and the lowest diversity value in the VD plots indicating the negative effects of water deficit on diversity of herbaceous species (Anon., 2011). But most interesting is the positive relation of species dominance (which increased with time with negative relation with species evenness) with herbage biomass and vegetation height. In general harvesting of grass increased from 15 tons in 2005 to 36 tons in 2010 in about 17 ha area (Singh, 2012). Among diversity variables, number of species, species population, species diversity and species richness were highest in <10% slope area, whereas species dominance was highest in >20% slope area, and species evenness was highest in 10-20% slope area. There was a significant increase in number of regenerated/ seed sown tree/shrubs plants/seedlings, which increased from 18 in 2005 to 45 species in December 2010 (Anon., 2011).

Effects of rainwater harvesting on herbage diversity and productivity in degraded Aravalli hills was studied by Singh et al. (2011). Contour trench (CT), Gradonie (G), Box trench (BT), V-ditch (VD) and a control were imposed on 75 plots (each of 700 m2) in natural slope gradient defined as <10%, 10%- 20% and >20% slopes in 2005. Each plot had three micro-sites of 1-m2 at up (USP), middle (MSP) and lower (LSP) part of the plot for observation in 2008. The existed gradient (due to soil texture and topographic features) of soil pH, EC, SOC, NH4-N, NO3-N and PO4-P in June 2005 between >20% to <10% slopes were decreased in 2008 after applying RWH techniques. Such improvement in soil status promoted vegetation growth and biomass in higher slope gradients. Soil water, species diversity and herbage biomass increased from USP to LSP, and RWH techniques had positive role in improving SOC, nutrients, vegetation population, evenness and growth at MSP. Despite of lowest SWC, regular rain and greater soil water usage enhanced green and dry herbage biomasses in 10%- 20% and >20% slopes, compared with <10% slope. The highest diversity in CT treatment was related to herbage biomass, which was enhanced further by highest concentrations of SOC and PO4-P. Further, CT treatment was found to be the best treatment in minimizing biomass variance in different slopes. Conclusively, soil texture and topographic features controlled soil water and nutrients availability. Rainwater harvesting techniques increased soil water storage and nutrient retention and also enhanced vegetation status and biomass by minimizing the effects of hillslopes. Thus depending upon the site conditions, suitable RWH technique could be adopted to increase herbage biomass while rehabilitating the degraded hills.

Influences of RWH on habitat heterogeneity, nutrient build up and herbage biomass production was studied in degraded Aravalli hills of Rajasthan (Singh et al., 2013b). Seventy five plots, each 700 m2 in size, with Contour trench (CT), Gradonie (G), Box trench (BT), V-ditch (VD) micro-catchments and a control, were sampled in < 10 %, 10 - 20 % and > 20 % slopes. Soil resources and herbage biomass were studied at up (USP), middle (MSP) and lower (LSP) positions of the plots during June to December 2006. Soil water content (SWC) and herbage biomass increased and soil organic carbon (SOC) decreased downward from USP to LSP. NH4-N, PO4-P and fresh root to herbage biomass (R/S) ratio were highest at MSP. But this trend did not exist at the slope level due to highest sand content, SOC and NH4-N and lowest SWC in 10 - 20 % slope. RWH enhanced SWC and herbage biomass. The effect was highest in > 20 % slope and in VD treatment. Nutrient availability facilitated herbage biomass production. V-ditches enhanced aboveground herbage biomass, whereas CT/BT induced biomass allocation to roots. Thus slope gradient, soil texture and RWH structure influenced soil water-nutrient gradient that affected herbage biomass production and biomass allocation to roots. Efficiency of RWH structures varied in inducing heterogeneity, nutrient status, herbage growth and biomass production.

Tree species responses

Water harvesting enhanced survival of all species used under afforestation. Aonla (*Emblica officinalis*), Sevan (*Gmelina arborea*) and Ber (*Zizyphus mauritiana*) showed greater survival with Box trench structure, kher (*Acacia catechu*) in V-ditch structure, Neem (*Azadirachta indica*) and Churel (*Holoptelea integrifolia*) in CT plots and Jamun (*Syzigium cumini*) in gradonie structure. Among planted species, *D. strictus, E. officinalis, A. catechu, S. cumini* performed better in Contour trench; *G. arborea* and *H. integrifolia* performed better in Box trench, and *A. indica* and *Z. mauritiana* performed better in V-ditch plots. All Acacia spp. either planted or regenerated performed best with V-ditch RWH treatment. Population of many species like Raunj (*Acacia leucophloea*), kegar kher (*Acacia ferugiana*), Desi babool (*Acacia nilotica*) and Emna (*Dichrostachys cineria*) has increased significantly. Populations of the latter three species were relatively greater in > 20% slope area. Seed grown plants of *Acacia catechu, A. senegal* performed better than planted but a reverse trend was observed for *Z. mauritiana* and *Azadirachta indica.*

Improvement in water, fodder and fuelwood

Improved microclimate through rainwater harvesting, afforestation and protection measures enhanced fodder productivity/availability in the area. The grass production increased from 15000 bundles (1 kg each) in 2005 to 33000 bundles in 2006 onwards said by Sh Kanti Bhai, Chairman, VFP&MC of the area and the villagers use to collect the fodder (at minimal member charges) to feed their cattle. The efforts made in this programme resulted in enhanced water availability as well as the duration of water availability up to March as compared to only October –November before the start of the programme. Villagers utilized the water for bathing and washing of the cloths. Domestic animals used to visit the water in well/ surface pond and drink water in evening before returning to the individual house in night. People of the Chhatripada and Gauapada collect fuel wood by cutting *Prosopis juliflora* and *Lantana camara* bushes sprouted every year to the tune of around 24 tons per year (Fig 3.14). This rehabilitation work conserved soil and water and improved soil carbon storage –a carbon sequestration benefits. Soil carbon storage was greater in higher slopes than in the lower slope area.

Fig 3.14. Increased availability of fodder, fuelwood and water after restoration of a degraded hills soil and water conservation and afforestation.

Carbon sequestration

Afforestation and forests development may play a critical role in regulating the climate through the carbon cycle; removing carbon from the atmosphere through the photosynthesis as they grow, and storing carbon in leaves, woody tissue, roots and organic matter in soil. Assessment of carbon stock has been done in vegetation (belowground and aboveground biomasses of trees, shrubs, bamboo and herbaceous layer) as well as in the soils during restoration of degraded hills in southern Rajasthan. In the experiment, rehabilitation of hills was done in varying slope categories viz. <10%, 10-20% and >20% slopes though afforestation under mixed plantation and adopting (excluding a control) four different RWH devices viz. contour trench (CT), gradonie trench (GD), box trench (BT) and V-ditch (VD). As several factors influence the potential carbon content of the plants, for example: the density of plantation, survival and growth rate, change in stock through regeneration etc., the carbon sequestration calculations in vegetation has been done based on the actual measurement of trees, shrubs, bamboo (*Dendrocalamus strictus*) and herbaceous biomass. Above-ground and below ground biomasses were estimated using regression equations from the literature (based on collar diameters/basal area and above-ground biomass, respectively). For carbon content calculation, a factor of 0.48 was applied for tree, shrubs and bamboo oven dry biomasses and 0.43 for herbaceous dry biomass. Soil carbon stock was calculated based on an estimated organic carbon and bulk density of the soils (Singh, 2017). In trees, net carbon sequestered in both above- and below-ground trees (*Acacia catechu, Acacia nilotica, A. leucophloea, A. senegal, Butea monosperma, Emblica officinalis, Holoptelea integrifolia, Tectona grandis, Prosopis juliflora* and *Zizyphus mauritiana* etc.) biomasses were highest in <10% slope (S1) and decreased upslopes (S2 and S3). Among RWH treatments, sequestered carbon was lowest in the control plots and highest in VD plots, i.e. 0.93 tone (t) ha^{-1} in roots (negative bars) and 3.45 t ha^{-1} above-ground (positive bars). Effects of RWH was such that in increased carbon storage in tree biomasses by 20.8%, 33.7%, 39.9% and 46.0%, respectively in GD, BT, CT and VD plots. Average C-sequestered in tree biomass is 3.01 t C ha^{-1}. Carbon sequestered in shrubs (*Calotropis procera, Capparis sepiaria, Helicteres isora, Indigofera argentea, Jatropha curcas, Lantana camara, Zizyphus nummularia* etc.) ranged from 1.08 t ha^{-1} in 10-20% slope to 3.07 t ha^{-1} in <10% slope area. It ranged from 1.09 t ha^{-1} in the control plot to 2.13 t ha^{-1} in BT plots. Average carbon sequestered in above-ground and below-ground biomasses of shrubs were 1.43 t ha^{-1} and 0.39 t ha^{-1}, respectively. Shrubs in VD, CT, GD and BT plots sequestered 73.3%, 76.4%, 94.7% and 96.4% higher carbon as compared to the shrubs in the control plots. Carbon sequestered in bamboo (*Dendrocalamus strictus*) was to the level of 0.54 t ha^{-1} in 10-20% slope to 0.80 t ha^{-1} in <10% slope with mean value of 0.65 t C ha^{-1}. The variations in sequestered carbon were 0.38 t C ha^{-1} in the control plots to 0.79 t C ha^{-1} in the VD plots. Average contribution of root and shoot (above-ground) to the total carbon sequestered were 0.13 t C ha^{-1} and 0.51 t C ha^{-1}, respectively.

Carbon sequestration in soils is mediated through plants photosynthesis, root turn-over, root exudates and litter decompositions. These processes resulted in carbon accumulation up to 29.8 t C ha^{-1} in <10% slope to 36.6 t C ha^{-1} in >20% slope. RWH treatments enhanced carbon sequestration, which ranged from 32.1 t C ha^{-1} in VD plots to 34.6 t C ha^{-1} in BT plots as compared to 29.2 t C ha^{-1} in the control plots. Total carbon sequestered in 65 months (value in 2010 – value in 2005) in both vegetation and soils ranged from 23.86 to 36.94 t C ha^{-1}. Among the slopes it varied from 29.92 t C ha^{-1} in <10% slope to 34.08 t C ha^{-1} in >20% slope (probably due to greater rate of soil formation). Sequestered carbon ranged from 30.29 t C ha^{-1} in GD plots to 32.64 t C ha^{-1} in BT plots as compared to 25.29 t C ha^{-1} in the control plots (Table 3.6).

Table 3.6. Carbon stock (tone ha^{-1}) and sequestration (tone ha^{-1} $year^{-1}$) in vegetation and soil (0-40 cm soil layer) in different slopes and the RWH treatments during rehabilitation of degraded hills.

Slope	**Treatment**	**Vegetation**		**Soil**		**Total sequestered amount (t C ha^{-1})**			**Sequestration (t C ha^{-1} y^{-1})**	
		June 2005	**Dec. 2010**	**June 2005**	**June 2010**	**Veg.**	**Soil**	**Total**	**Veg.**	**Soil**
S_1	Control	0.37	7.41	11.31	28.13	7.04	16.82	23.86	1.30	3.37
<10%	Contour trench	0.25	8.58	6.69	33.74	8.33	27.05	35.38	1.54	5.41
	Gradonie	0.19	8.84	10.64	30.87	8.64	20.23	28.87	1.60	4.05
	Box trench	0.30	9.83	7.34	29.62	9.55	22.28	31.83	1.76	4.45
	V-ditch	0.21	10.68	7.12	26.36	10.46	19.19	29.65	1.93	3.84
S_2	Control	0.17	2.74	6.29	29.42	2.57	23.13	25.70	0.48	4.62
10-20%	Contour trench	0.19	6.79	6.16	24.87	6.61	18.72	25.33	1.22	3.74
	Gradonie	0.28	4.26	7.14	29.57	3.99	22.43	26.42	0.74	4.49
	Box trench	0.22	5.45	9.24	34.81	5.23	25.56	30.79	0.97	5.11
	V-ditch	0.38	5.53	9.63	34.10	5.97	24.47	30.44	1.10	4.89
S_3	Control	0.20	2.64	6.08	29.92	2.45	23.86	26.31	0.45	4.77
>20%	Contour trench	0.22	4.30	8.99	41.86	4.07	32.87	36.94	0.75	6.58
	Gradonie	0.18	5.71	5.83	35.86	5.53	30.04	35.57	1.02	6.01
	Box trench	0.17	4.86	8.78	39.37	4.70	30.59	35.29	0.87	6.12
	V-ditch	0.19	4.33	3.69	35.83	4.15	32.14	36.29	0.77	6.42
	Average	**0.23**	**6.13**	**7.67**	**32.29**	**5.95**	**24.62**	**30.57**	**1.10**	**4.93**

This indicates the impact of these activities in restoration and consequent effects on carbon sequestration in vegetation and soils. Annual rate of carbon sequestration were 1.10 t C ha^{-1} $year^{-1}$ in vegetation and 4.93 t C ha^{-1} $year^{-1}$ in soils. Out of 6.13 t C ha_{-1} sequestered in total biomass, the contribution through plantation was 1.45 t C ha^{-1} ,whereas the rest, i.e., 4.68 t C ha^{-1} was through regeneration promoted though RWH and protection measures. In addition, there was turnover of about 1.60 t C ha^{-1} in herbaceous vegetation harvested per year, though its root added to the soil organic carbon pool. It ranged from 1.53 t C ha^{-1} in >20% slope to 1.62 t C ha-^{1} in <20% slope. Among RWH treatments, it ranged from 1.47 t C ha^{-1} in CT plots to 2.16 t C ha^{-1} in VD plots (as compared to 1.26 t C ha^{-1} in the control plots). Restoration efforts at the Bara Nandra Kho site generated significant carbon benefits in vegetation as well as in soils. Rainwater harvesting, afforestation and protection measures generated carbon benefits (net sequestration) of about 519.69 tones (17 × 30.57 t C ha^{-1}) at 65 months across the slopes and RWH treatments. It means net removal of atmospheric CO_2 in this area equals about 1905.53 tonnes (519.69 × 44/12). However, the amount of carbon sequestered in soil is about four times to that sequestered in vegetation. Net amount of carbon sequestered in soil was highest in contour trench plots, followed by Box trench plots, whereas the amount of carbon sequestered in vegetation was highest in V-ditch plots, followed by Box trench plots.

CONCLUSION AND RECOMMENDATIONS

Rainfall is prime source of water in dry areas, where a significant amount of rainfall is lost in the form of runoff leading to water erosion. Different methods of water harvesting and soil and water conservation measures are in practice traditionally as an adaptation to climate and many of them have been designed based on the local requirements to augment water availability and increase land productivity. Various techniques of in situ water harvesting and conservation structures are being adopted to improve early establishment and growth of plantations.

The engineering methods to control soil erosion are check dams, which are used only in a small, open channel that drain about 4 ha or less area , are usually do not exceed 2 feet high. These check dams are typically constructed out of gravel, rock, sandbags, or straw bales and used to slow the velocity of concentrated water flows and reduce erosion. A check dam can be either temporary or permanent built across a minor channel, swale, bios wale, or drainage ditch. Many check dams tends to form stream pools where water infiltrates into the ground, evaporates, or seeps through or under the dam. Waterways should be covered densely with locally adapted grasses. The deepest cut should be between 0.5 and 1.0 m. Grass waterways are shallow and wide to obtain the maximum spread of water over a wide cross section. These waterways can be used in areas where there is sufficient moisture available to sustain a good grass cover.

These micro catchments reduce velocity of runoff water and allow the water to stay on ground for longer period enhancing infiltration in to the soils. Because of dependency on the quantity and frequency of rainfall, topography, vegetations status, regional hydrology and the socio-economy of the regions, these RWH and conservations measures should be applied based on local requirements. Increased water availability through RWH help enrich soil nutrients and increase biomass production with subsequent higher yields. Higher biomass supports a higher number of plants and animals, i.e., increased biological diversity and food security.

Both *ex-situ* and *in-situ* rainwater harvesting provide reliable soil moisture and in turn increases biomass yield and help adopting diversification. Thus benefits of RWH should extend beyond the rainfed farming to the whole ecological system, as the success in production of agricultural and common resources will minimize interferences in forestry system.

Preparation of rainwater harvesting structure on a contour line should be cautiously done so that water level should be same throughout. Otherwise, intermittent plugging of trench could be done to avoid water accumulation at one place and damage of the structures.

Responses towards rainwater harvesting structures depend upon types of species and their rooting pattern. Hence selection of species and RWH devices should suitably match for a region. For example, most of the *Acacia* spp. shows spreading roots and response better to V-ditch, whereas species with deep rooting performs better under contour trench structures.

Planting position along the rainwater haresting structures should be down side of the RWH structure in slopy area for proper utilization of the water stored in the structure. Though hinge planting appears more approapriate planting position in almost plain land, but it depends also on the edaphic factors. For example in sandy soils where water infiltration is high and chance of water stagnation is less, planting in the structure will facilitate survival and growth. Clay soils with low infiltration rate results in water stagnation for a longer period of time leading to seedling mortality if planted in the structure, hence hinge planting is more suitable.

4 DEVELOPING PROTECTION FORESTS

Conservation of soil and water is quite effective if plantation is done in a planned manner in stabilizing slopes and reclamation of minelands and overburdensas protection forests. The plantation along the banks of streams and rivers regulates their flow and if planted along the road, canals or railway tracts, it ameleiorate microclimate alongwith conserving soil and water (O'Loughlin, 2005; Zagas *et al.*, 2011). A forest with a particular protective function is located on a slope where there is a direct risk for human life or for material goods of high value, due to avalanches, landslides, erosion, debris flows or falling rocks is called as protection forests (Zampa *et al.*, 2004). Following roles are being played by a protection forest:

- Protection against avalanches, landslide, rockfall, snow-drift, earth movement, flood, wind, or similar hazards;
- Provides defense against dangerous emission hazards;
- Protection of holy springs, temples and tourist connections and areas without undermining the requirements of hygiene and relaxation while securing the necessary forestation for these purposes around such places;
- Secure water transfer;
- Ensure the usability of transport routes and energy industry transmission systems,
- Secures the defensive working of the country's defense,
- Protection against hazards arising from the condition of wastedumps, forest or its management.

Soils are degrading in fertility status and excessive run off and droughts are quite common in present scenario of climate change. Plantation of multipurpose tree species (MPTs) on mining overburdens, hill slopes, farmer's land and degrading village common lands not only help stabilize slopes and provides sustainability to production but also reduces run-off losses and soil erosion (Zhang *et al.*, 2015). Water runoff causes soil erosion, a process that sweeps away fine materials, and nutrients, from the sloped areas and strongly affects long-term development of waste dumps (Polyakov and Lal, 2004; Wang *et al.*, 2018).

Revegetation of mine overburdens constitutes the most widely accepted and useful way to reduce erosion and protect soils against degradation during reclamation process (Gose, 2005; Singh and Seema, 2017;). Use of engineering measures are the first line of defense in controlling erosion as it also helps promotes vegetation to come up at a faster pace in mine overburden areas under surface water management measures (Skousen and Zipper, 2014). Multipurpose tree species are preferred by the farmers to their varied uses as fuel, fodder, timber, fruits, etc. The choice of tree species by the farmers varies as per their landholdings. For example, small farmers prefer fodder/ fuel wood species while large and medium farmers prefer small timber or fruit bearing species to integrate into their farmlands. Soil and water conservation save the productivity of land and save the foods for human and animal also. Sound forestry options and smart agriculture are the future needs and should be utilized for maintenance and sometimes restoration of soil productivity coupled with fare harmony between man and the lands (Lal, 2015).

SOIL- PLANT RELATIONS

Plants grow in the soil system by deriving essential portions of their nutrients from the soil (Beeson, 1941). Animals eat plants, and human being, who eats both animals and plants, therefore depends on the soil for his sustenance and well-being. If the soil is deficient in a certain element, the plants will also be deficient in the same element, and consequently animals and man, who depends these will suffer. In technologically advanced areas men make use of food from a multitude of sources and therefore seldom suffer from lack of a specific element.

Soil $\longrightarrow$ Plant $\longrightarrow$ Animal $\longrightarrow$ Man

Calcium and phosphorus occur in inadequate amounts in many parts of the world, particularly in the sandy and the highly leached soils. The monsoon wind and sudden storm not only cause damage to the crops but also is associated with enhanced soil moisture loss and in extreme events soil erosion as well. Further consequence is that loss of organic matter along with the loss of major nutrients like nitrogen, phosphorus and potassium to the tune of about 50 per cent. Loss of top soil contributes to a loss of valuable plant nutrients and moisture that cause yields to decline over time and requires supplemental fertigation. Strong winds also damages crops as observed in Western zone of Tamil Nadu, where plantain crops of worth Rs.5 crore are lost annually. Various anthropogenic activities like introduction of canals irrigation system, deforestation, mining, industrialization and other biotic interferences lead to accelerated land degradation (Chaturvedi and Singh, 2017). Ash ponds are hazardous and devoid of any vegetation. Air pollution from these becomes sources become a perpetual problem at present. Now a big plantation programme are been taken up by state forest departments in reserve forests, catchments areas of irrigation projects and on government waste lands. Millions of trees are planted by the public, agricultural and forest departments and local bodies like Zillah Parishad, Panchayat Samitis and Gram Panchayat on the occasion of Van Mahotsava (https://www.mapsofindia.com/events/india/van-mahotsava.html). However, important is to pay proper attention to the planted sapling until their effective growth.

Nature provides a worth living environment to its creations and accordingly creates its own laws to maintain ecological balance so as to preserve purity of the environment. Natural resources like land, water, climate and vegetation and their interactions with activities of the living beings form the environment for different life forms to carry out physiological processes. However, large pressure of growing population and increased demand for food and fuel-wood combined with industrial activities have led to rapid changes in land use in developing countries including India. Industrial development and environmental pollution though opposite yet intimately associated with each other and one activity can only be accomplished at the cost of other.

RECLAMATION OF MINE LANDS

Continuous expansion of mining activities are creating herculean problems of disposal of large volume of debris coming out after working in the mine areas and creating various ecological hazards with varying magnitude in vertical dumpings. No doubt, mining of these minerals are important not only for the local and national economy but also for the development of industry as well but extraction of these minerals is bringing about superimposition of natural fertile soil by inactive and infertile materials (Taberima *et al.*, 2010). Although, the land under mining operations occupies a very small area in comparison to the total geographical area of the country, but hazardous activities start right from clear felling of vegetation for mining and allied activities which accentuate as the operations increase in intensity. The impact of physical disturbances to the top soil during stripping, stockpilling and reinstatements results in soil degradation byreduced soil structure, accelerated soil erosion, excessive leaching, compaction, reduction in soil pH, accumulation of heavy metals in the soils depending upon mining types, depletion of soil organic matter, reduction in soil available nutrients, decrease in cation exchange capacity, lowering of microbial activities and corresponding decrease in soil fertility and productivity (Hu *et al.*, 2012; Mesah, 2015).

Such areas are thus posing a great challenge for ecologists, biologists, agriculturists, engineers, soil scientist, and foresters as well who are invariably concerned about restoration of this disturbed ecosystem (Singh *et al.*, 2002; Wang et al., 2018). There are 60 mineral mines in India, in which 30 have been grouped under small mines, 17 are small to large mines and 5 are large mines. Surface mining accounts for 100% production of iron ore, limestone, dolomite, bauxite, barites, fire clay, magnesite and lignite. In case of coal, open cast mining accounts for 5% only at present, but it is increasing at the rate of 31% of the coal surface mined area annually. About 683671.50 ha of the area are under mining leases in the country that is spread over 19 states. The highest area under mining is in Rajasthan (141280 ha), followed by Bihar (136759.5 ha) and Orissa (104334.0 ha). The mineral deposits in Himalayan region occur over an area of 24,447 ha. For such disturbed site, a suitable reclamation programme dovetailing scientific knowledge is urgently required. Although, ecological and biological methods of reclamation of mined areas are important, but involvements of engineering measures of soil and water conservation are the first line of defense mechanism in controlling erosion of soil and debris as it also helps promotes vegetation to come up at a faster pace (Skousen and Zipper, 2014; Wang *et al.*, 2018). The proposed structures under surface water management measures involves surface terracing, contouring and formation of gully plugs viz. brushwood check dam, logwood check dams and loose boulder check dam in the gullied areas and treating the drainage lines.

Basic Requirements

Significant increase in rate of accumulation of waste materials generally results in greater height of dumps to minimize ground cover area under mining works. This gives rise to the danger of dump failures, gully erosion and various other associated environmental problems (Campbell, 1992). In addition to soil and water conservation through terracing and drainage line treatments, following steps required to be followed for ecological and biological reclamation of mined areas:

- Selection of the pioneer species coming naturally on the overburdens and broadcasting of seeds and propagules of these species.
- Arrangement of good quality seeds of the species suitable for plantation on mine overburdens.
- Nursery raising of the seedlings of the selected species up to a suitable size.
- Lay out plantation design and pit excavation at least one month in advance before carrying out transplantation.
- Plantation of healthy and vigorously growing seedlings during monsoon/ spring seasons.
- The plants should be planted in the morning and the transported saplings should be planted on the same day.
- Weeding and application of selected doses of fertilizers should be done around the plants to promote their growth. Sufficient moisture availability during and after manuring should be ensured.

- During dry period leaf-litter mulch should be applied. This process will not only conserve moisture but after decomposition will also enrich the mine spoils.
- Weeding should be carried out in the second year only especially in the month of August and October and after this second dose of fertilizers can also be applied for obtaining the better results.
- Protection must be ensured for a successful restoration programme.

Factors and Steps

Some of the important factors on which success of restoration programme depend are: (i) Pre-mining Bench-mark Survey; (ii) Site Preparation, (iii) Restoration of the Site-ecosystem Approach, (iv) Re-vegetation Practices, and (v) Needs of the Local People and Social-forestry.

- Pre-mining bench-mark Survey: This is an effective strategy based on the geological and ecological surveys of the mining area prior to the mining operations. It may even include the contouring of the area, knowledge on the status of ground water aquifers and surface drainage patterns. Overburden if any to be generated, must be analyzed for pH, acid base balance and also for heavy metals concentration like Fe, Mn, Al etc. Complete analysis of the over burden help in suggesting the soil characteristics, which ultimately leads to a better and more suitable selection of species for re-vegetation of the site. Ecological survey must include the major vegetative associations along with assessment of chemical and biological characteristics of streams, drainage line or other water bodies etc. This bench-mark information will prove an asset in re-establishing the productivity of the mining area. Wherever possible, seeds, rhizomes, bulbs etc., of the pioneering species should be collected and preserved so that once the mining operations stop these can be used immediately for ameliorating the site through broadcast of the seeds/ propagules and to provide immediate green look to the area (Schmidt, 2008).
- Site preparation: In the past, reclamation was not getting much importance and only partial or no back filling was undertaken after surface mining. Hence, economic and environmental requirements is necessary in order to achieve the best reclamation results, keeping into account site constraintssuch as slope stability, hauling and dumping issues, and interactions with groundwater (Ogeri *et al.*, 2019). At present most of the country's regulations are segregation and replacement of different soil horizons in the same order as is removed during mining operation. Mining company has to leave the mine lands approximately to original conditions wherever restoration plans requires them to do so. With the enactment of recent environmental laws in our country, it is hoped that in near future miner will take up necessary initiatives towards reclamation of the mined out sites. Reclamation work in opencast mines typically involves replacement of overburden that was removed or repositioned to access buried mine layers. When excavated areas are built up, re-landscaping or recontouring is completed along with drainage control measures. Recontouring will be guided by mine plan objectives, i.e. the intended end use for the land area. Where natural processes are sought, recontouring will typically attempt to return landforms to the mine site's approximate original contour, or to mimic natural contours. Where other human uses are planned for, the land will often be leveled or shaped in a manner that improves access or aids in future infrastructure development (Hayes, 2015).
- Restoration of the Site-ecosystem Approach: Legislations and regulations emphasizes that productivity of the land be returned to the pre-mining conditions (Limpitlaw and Briel, 2014; Sahu and Dash, 2011). These regulations further make it obligatory on the part of miners that the natural vegetative communities that existed on the site prior to mining must be re-established on the site. This will help in restoration of completely natural rather

pre-mining eco-system comprising of vegetation, wildlife, microbial flora and fauna etc.

- Re-vegetation practices: Establishment of vegetation on abandoned, on active mine sites as well as on refuge heaps is rather quite difficult because of altered soil pH, lack of organic matter, coarse rock fragments and many other adverse biological and chemical factors (Ranjan *et al.*, 2015; Sheoran *et al.*, 2010). A package of practices interacting both through biological and mechanical measures -according to the local requirements- only can make a successful headway. A variety of trees, shrubs and grass species are tried on these sites with varying degrees of success, but indigenous species appears better than exotics (Ranjan *et al.*, 2015). Although in most of the reclamation projects stress is given to local species yet in some of the cases depending upon the site, climate and dump characteristics, exotic species are also being tried and have been found successful also (Morgan, 2005). Thus selection of suitable species is extremely important for the development of a self-sustaining eco-system. Selection of the species must be determined by the fact as to what will grow best in that particular soil and climate of the area (Morgan, 2005). Some of the desirable features are:
- Properties of rapid growth;
- Toughness in respect of diseases and pests;
- Ability to compete with less desirable species;
- Adaptability to the local soil; and
- Adaptability to the local climatic conditions.

Besides this, the shrubs and the species those are to be planted on the boundary should be unpalatable for the cattle and goats. The capacities to add leaf litter to the soil, nature of leaf litter as regards to its decomposition etc. are of equal importance. The informations required while selecting species for afforestation includes adaptability to the site conditions, belongs from the group of pioneer species, preferably be of deciduous in nature so that maximum leaf-litter is obtained from the plant and the leaf should have the quality to decompose quickly, have long and deep root system, have ability to fix atmospheric nitrogen and improve soil productivity, have tolerance for altered pH and toxicity of the site, if so, it should be from the indigenous origin, capable to meet the requirement of local people in respect of fuel, fodder, fibre, fruit and small timber, and should have ability to attract a range of fauna.

- Societal needs: Mining operations definitely disturb the local populations. In most of the cases, either local population is shifted by the company or they are deprived of their day to day requirements of fuel, fodder, fibre, cottage industry, medicines and many other products of pre-mining ecological conditions (Arbogast etal., 2000; Kevinen et al., 2018). While taking up any reclamation programme, it must be clearly borne in mind that whatever final use the land is going to be put should be in favour of local population, hence their day to day requirements and use of materials should be given top priority. Hence a comprehensive plan should be prepared in consultation with the local folk.

Experimental evidences

In fact, no single species can fulfill all requirements and as such mixed plantation with preference of indigenous species are advocated alongwith an amalgamation of numerous ecological factors (Datar *et al.*, 2011). The list of species tested in Himalayan region indicates that A*cacia catechu, Bauhinia variegata, B. purpurea, Dalbergia sissoo, Grevillia robusta, Jacaranda mimosifolia, Dodonea viscosa, Vitex negundo, Rumex hestatus*, *Woodfordia* *fruticosa, Eriphorum comosum* and *Chrysopogon fulvus* are better for Doon valley. Likewise *Robinia pseudoacacia, Bauhinia variegata, Grewia optiva, Toona ciliata, Melia azadirach, Dalbergia sissoo, Celtis australis, Acacia catechu, Populus deltoides, Vitex negundo, Ipomea* spp, *Rumex hestatus* etc., are relatively better in Paonta Valley.

In a study conducted by IFGTB, Coimbatore on afforestation of problem soils of Associated Cement Companies (ACC), Madukkarai, Tamil Nadu and Magnesite mine spoils of Burn Standard, Salem involved suitable tree species and silvicultural interventions (Rao and Siddappa, 2001). Various silvicultural interventions for soil and moisture conservation were soil mulching, stone and coir pith mulching once in three months. At ACC, Madukkarai, the tree species were *Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus tereticornis, Gmelina arborea, Muntingia calabora, Azadirachta indica, Leuceana leucocephala, Delonix regia, Samania saman, Cassia seamea* (Fig 4.1) and at Burn Standard, Salem *Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus tereticornis, Muntingia calabora, Azadirachta indica, Grevellia robusta, Swietenia mahogonii, Ailanthus excelsa, Sizygium cummini* and *Pongamia pinnata.* Farm yard manure and compost were applied @ ¼ to ½ kg per plant at every six months in combination with biofertilizers like VAM, Azospirillum, Phosphobacterium and Frankia to *Casuarina equisetifolia*. All species performed well and were found suitable for afforestation of mine spoils with application of minimum silvicultural operations. Litter fall was high under *Acacia auriculiformis, Casuarina equisetifolia, Eucalyptus tereticornis, Gmelina arborea, Muntingia calabora, Azadirachta indica* and *Leuceana leucocephala.*

Fig 4.1. One year after planting at mine overburden (left) and 1 months old A. auriculiformis on Magnesite mines dump (right).

Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore revegetated mined lands by planting tree seedlings of suitable species in bauxite, magnesite and lime stone mine spoils inoculated with Vesicular Arbuscular Mycorrhizal fungi (VAM) and other beneficial microbes like Rhizobium, Phosphobacterium and Azospirillum (Karthikeyan, 2002). Based on the nursery experiments and field trials at mined out areas *Azadirachta indica, Casuarina equisetifolia* and *Eucalyptus camaldulensis* were found suitable for reclamation of magnesite mine spoils along with beneficial microbes (Table 4.1).

Table 4.1. Growth performances of two years old *C. equisetifolia* seedlings inoculated with AM and other beneficial microbes at bauxite mine spoils. Values are mean of ten replicates. Source: Karthikeyan (2002).

Sl No.	**Treatment**	**Height (cm)**	**Collar diameter (mm)**	**Branches/plant (nos.)**
1.	Control	64.8	10.65	12.0
2.	Arbuscular mycorrhizal Fungi (AM)	89.2	14.32	16.2
3.	Frankia	94.6	14.80	15.8
4.	Phosphate Solubilizing Bacteria (PSB)	78.3	14.18	17.1
5.	AM + Frankia	93.8	14.95	15.0
6.	AM+ Frankia + PSB	100.6	16.90	18.1

Acacia auriculiformis with AM fungi + Rhizobium, *E. camaldulensis* with AM fungi + Phosphate solubilizing bacteria + Azospirillum, and *C. equisetifolia* with Frankia + AM fungi were found successful for reclamation of bauxite mined out areas. Likewise, *C. equisetifolia* with Frankia + AM fungi was more suitable for lime stone mine spoils reclamation (Fig 4.2). This technology had reduced the cost of top soil, manures and fertilizers. There was no additional requirement of chemical fertilizers and manures as the seedlings were inoculated with beneficial microbes. The selected plants stabilized soil structure by improving soil aggregation.

Reclamation and rehabilitation plans for individual mines and mines affected districts of Bellary, Chitradurga and Tumkur in Kaernataka have also been suggested (Mohan et al., 2014), wherein grasses and bamboo species were recommended for soil moisture conservation and stabilization of loose material and steep slopes (Table 4.2). For the management of overburden dump, combination of grasses, herbs, shrubs, creepers and tree species were recommended depending on the dump stability and their age. Seed broadcasting, hydro-seeding or planting of seedlings were advocated for stabilization of barren steep slopes and fragile unstable surfaces. The suggested plants for seed broadcasting includes grasses like *Bothriochloa pertusa, Cymbopogon flexuosus, Cymbopogon martini, Cymbopogaon nardus, Dactyloctenium aegyptium, Dichanthium annulatum, Heteropogon contortus* and legumes like *Cassia auriculata, Cassia occidentalis, Crotalaria juncea, Crotalaria pallida, Stylosanthes fruiticosa* and *Tephrosia purpurea*. Afforestation of the mined out and other available areas which are not fragmented but are degraded due to mining activity are major areas of re-vegetation to mitigate the negative impacts of the mining.

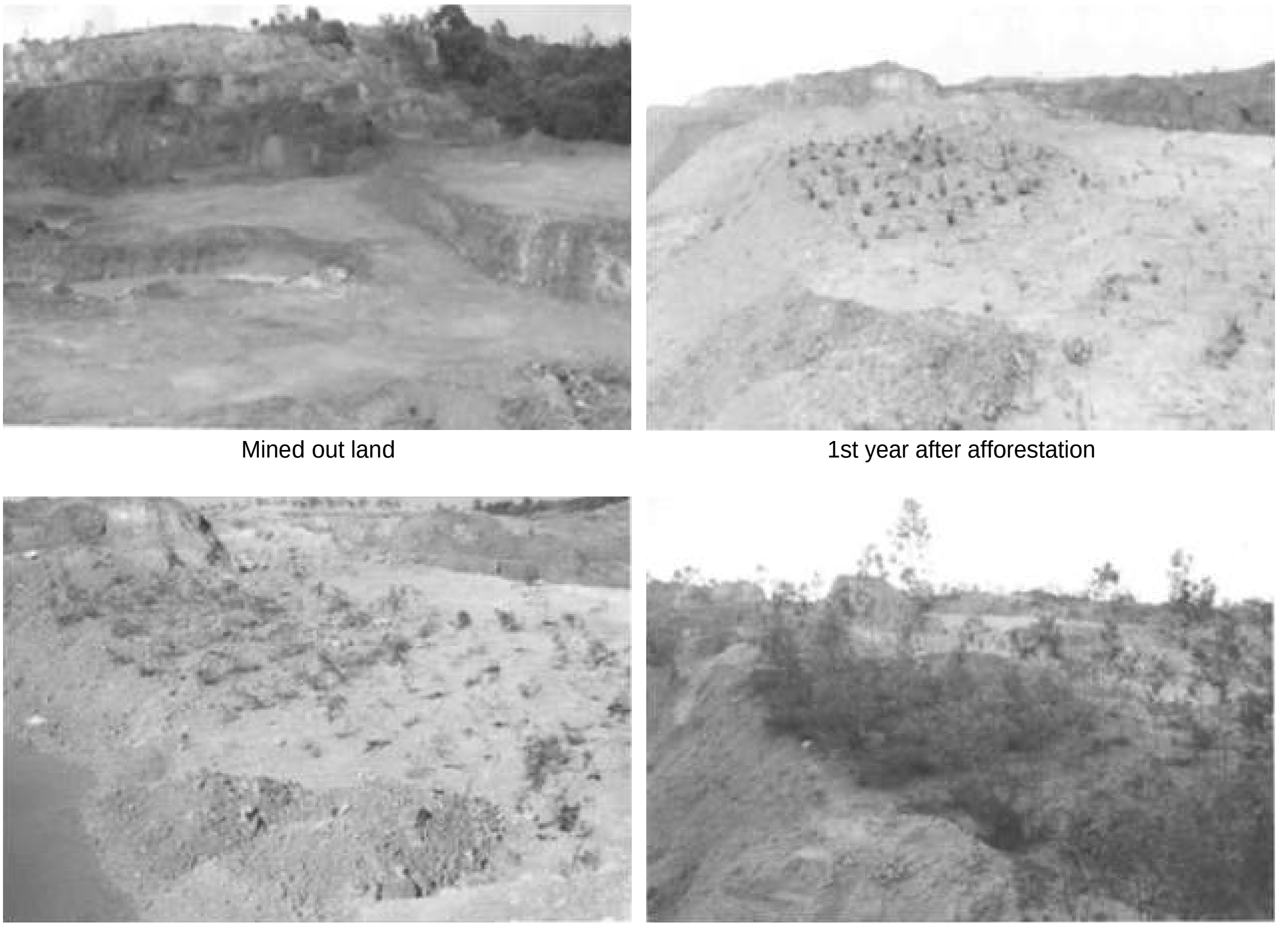


Fig 4.2. Plantation performance in different years after reclamation of mine spoil soils.

Table 4.2. Grasses and bamboo species recommended for soil moisture conservation and stabilization of loose material and steep slopes.

Sl.No.	Species	Propagation method	Kannada name	Hindi name
1	*Bambusa aurndinacea*	Rhizome/seeds	Bidiru	Kanta Bans
2	*Bothriochloa pertusa*	Seeds	Aanekattu hullu	Counch grass
3	*Chrysopogon fulvus*	Slips	Ganjigarike	Dhaulu grass
4	*Cymbopogon flexuosus*	Slips	Anthibale hullu	Lemon grass
5	*Cymbopogon martini*	Slips	Kaashi hullu	Palmrosa grass
6	*Cymbopogon nardus*	Slips	Ganda hanchi hullu	Citronela grass
7	*Cynodon dactylon*	Rhizome/seeds	Garike hullu	Doob
8	*Dendrocalamus strictus*	Rhizome	Gamdubiduru	Lathi bans
9	*Dichanthium annulatum*	Seeds	Ganjala garike hullu	Karad
10	*Heteropogon contortus*	Slips/seeds	Oobina hullu	Kumeria, Lapia

Afforestation plan for restoration of the mined out areas with suitable multipurpose plant species have been recommended to meet the community requirement of timber, fodder, fuel wood and medicinal plant and over all ecosystem development. The species suggested include *Acacia catechu, Acacia nilotica, Aegle marmelos, Ailanthus excelsa, Alangium salvifolium, Albizia amara, Albizia lebbeck, Annona squamosa, Anogeissus latifolia, Aristida setacea, Azadiraachta indica, Bambusa arundinacea, Boswellia serrata, Bothriochloa pertusa, Calotropis, gigantea, Calotropis procera, Cassia auriculata, Cassia fistula, Chloroxylon swietenia, Crotalaria juncea, Cymbopogon martini, Cynodon dactylon, Dactyloctenium aegyptium, Dalbergia latifolia, Dalbergia sissoo, Dicanthium annulatum, Diospyros melanoxylon, Euphorbia tirucalli, Ficus benghalensis, Ficus racemosa, Ficus religiosa, Gmelina arbora, Adina cordifolia, Heteropogon contortus, Jatropha gossypifolia, Limonia acidissima, Melia dubia, Morinda pubescens, Phyllanthus emblica, Pongamia pinnata, Pterocarpus marsupium, Santalum album, Tectona grandis, Tephrosia purpurea, Terminalia arjuna, Terminalia bellirica, Terminalia chebula, Vitex negundo* and *Zizyphus mauritiana.* Engineering measures are important in controlling erosion as it also helps promotes vegetation to come up at a faster pace. The proposed structures under surface water management measures include formation of gully plugs viz. brushwood check dam, logwood check dams and loose boulder check dam. Wire crate (gabion) check dam have also been suggested for construction when the gully bed slope is higher than 10% and these are useful in areas where sediment load is very high. Stone masonry check dam is considered as a key structure at the end of all gully control structures like loose stone check dam, gabion check dam etc. Bio-engineering measures like random rubble cement sand mortar toe walls having a height of up to 3 m have also been proposed for the stability of the dumps. Construction of garland drains has also been suggested for collecting discharging runoff water at the tow of dump and to carry it safely to natural channel.

ASH POND STABILIZATION

Ash ponds are area filled with fly ash and are hazardous and devoid of any vegetation. Air pollution from these becomes a perpetual problem, where natural phyto-sociological succession is utmost important ((Das *et al.*, 2019)). Fly ash is a coal combustion residue of thermal power plants. Chandrapura Thermal Power Station (CTPS), DVC produce huge amount of fly ash and is disposed off from the plant through pipe and deposited in four ash ponds near the plant. The areas in and around the plant are undulating with occasional hills. Institute of Forest Productivity has made an attempt to create greenery on these harsh areas around the Thermal Power Station, Chandrapura in Jharkhand. Under rehabilitation programme following steps were taken:

- Field survey, sample collection and analysis was done to work out the plant growth limiting factors like physical and chemical properties of the ash deposits in ash ponds. pH, EC, texture, water holding capacity, density, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, iron, and microbes like bacteria, actinomycetes and fungi were estimated in soil and fly ash.
- Six sites were selected in different location of the fly ash pond area and nearby degraded land area and afforestation were done by using nursery raised seedlings in pit size of 50 x 50 x 50 cm3 and at row spacing of 3.0 m and plant to plant distance of 2.5 m. These plantations were done at the ridges and slopes of the ash pond areas after clearing the bush present at the site and barbed wire fencing around the plantation sites to protect the plantation from grazing.
- Plantation was done in block and on mounds of the staggered trenches at 2.0 m apart leaving 0.25 m on both side of each trench. Sizes of the trenches were 2.5 m length x 0.50 m width x 0.40 m depth, which was made at 1.5 m intervals and at 3.0 m spacing between the trench rows.

- In order to facilitate plant survival and growth excavated pits were amended with macro and micro-nutrients, bulky organic matter, organic manure and insecticide in the first two years (Table 4.3). Insecticide (10 ml/2lit water) was applied to drench the pits before plantation. In the first year of plantation, N (35 g urea) and P (75 g SSP), Zn (0.10 g Zinc sulphate), B (0.50 g boric acid) and Mo (0.0025 g ammonium molybdate) fertilizers were applied to the pit soil 15 days before. N and P were also applied 60 days after the plantation. FYM and bulky organic matter in the form of burnt/decomposed rice husk @ 500 g /pit and micro-nutrient (Zn, B and Mo) were mix to the pit soil 15 days before plantation. Watering of the plant was done after the application of fertilizer and manures. In the second year, two doses were applied during pre-monsoon and post monsoon periods (Table 4.3).

Table 4.3. Soil amendments (g/pit) for soil pit and fly ash deposited areas

Treatment	**Soil pit**		Fly ash deposit area	
	1st year	**2nd year**	**1st year**	**2nd year**
Earth filling			0.05 m^3/pit	
Insecticide in water	10 ml/2 lit	10 ml/2 lit	10 ml/ 2 lit	10 ml/ 2 lit
N fertilizer (Urea)	35	45	25	75
P fertilizer (SSP)	75	35	50	75
Zn (Zinc sulphate)	0.1		0.1	
B (Boric acid)	0.5		0.5	
Mo (Ammonium molybdate)	0.0025		0.005	
Organic matter (decomposed rice husk)	500	500	1000*	750
FYM	500		1000	
K fertilizer (MP)	-	5		12

*Added with 25 g Mixed Oil Cake (of Neem, Karanj, Mahua etc.)

- Plantation was done in the year 2008-09, 09-10 and 10-11 covering six sites and 38 ha area. Species planted on fly ash pond and degraded area were *Acacia auriculiformis, Acacia mangium, Anacardium occidentale, Albizia odoratissima, Alstonia scholaris, Ailanthus excels, Anthocephalus indicus, Dalbergia sissoo, Delonix regia, Eucalyptus hybrid, Gmelina arborea, Peltophorum ferugineum, Pongamia piñnata, Swietenia mahagoni, Peltophorum pterocarpum* (Radhachura), and *Termalia arjuna*. A total of 40,800 numbers of seedlings were planted in above-mentioned years.

Seedling performance

The survival percentage of the planted seedlings were 87.5% that ranged from 25% in ash pond A and planted in 2008 to 96.67% in degraded forests with plantation year 2009 (Table 4.4).

Table 4.4. Area covered and average survival percent of plantation carried out at different sites.

Sl. No.	Site	Area covered (ha)	No. of plants planted	No. of plant survived	Survival (%)
1.	Ash pond 'A',08	0.5	800	200	25.00
	Ash pond 'A',09	6.5	7000	6100	87.14
2.	Ash pond 'B', 09	6.0	6500	4500	69.23
3.	Degraded Forest, 09	15.0	15000	14500	96.67
4.	Ash Pond 'C', 10	5.0	5500	5000	90.91
5.	Near Chake Naka, 10	3.0	3300	3000	90.91
6.	Behind School, 10	2.0	2700	2400	88.89
Total		**38.0**	**40,800**	**35,700**	**87.50**

Six plant species planted in the ash pond area during 2008 with initial height and collar diameter range of 36.3-125.5 cm and 3.0-7.1 cm respectively showed steady growth in height and collar diameter ranging between 73.3 and 271.5 cm, and between 6.7 and 16.1 cm respectively at 18 months age (Table 4.5). Growth of twelve species planted in 2009 in the ash pond area found excellent where height and collar diameter ranged from 141.5 cm to 517.1 cm and from 12.1 cm to 22.7 cm respectively after 12 months of time (Table 4.5). Likewise, growth of four species planted in 2010 ranged from 141.7 cm to 278.7 cm in height and from 6.9 cm to 14.0 cm in collar diameter respectively after 12 months period (Table 4.5). Fifteen species planted during 2008 to 10 indicated *Albizia odoratissima* (Black siris) as best performing species in fly ash pond area with 517.1cm height and 18.6 cm collar diameter. Other species fell in order: *Eucalyptus* hybrid > *Dalbergia sissoo* > *Gmelina arborea* > *Acacia aruculiformis* > *Acacia mangium* > *Anthocephalus indicus* > *Peltophorum ferugineum* > *Terminalia arjuna* > *Pongamia pinata* > *Delonix regia* > *Peltophorum pterocarpum* > *Ailanthus excelsa* > *Alstonia scholaris* > *Swietenia mahagoni* in growth parameters (Table 4.5).

Table 4.5. Average growth parameters (cm) of different species planted in ash pond area.

Sl. No.	Name of Species	Height (cm)		Collar diameter (cm)	
		Initial	12 month*	Initial	12 month
	Year 2008				
1.	*Alstonia scholaris*	54.8	73.3	5.9	11.1
2.	*Dalbergia sisoo*	125.5	271.5	5.4	13.8
3.	*Delonix regia*	36.3	149.4	3.0	11.6
4.	*Gmelina arborea*	111.0	177.4	7.1	16.1
5.	*Termalia arjuna*	48.2	103.2	2.7	6.7
6.	*Swietenia mahagoni*	38.5	106.8	3.7	8.8
	Year 2009				
1.	*Ailanthus excelsa*	87.5	163.8	5.6	12.1
2.	*Anthocephalus indicus*	86.5	220.3	8.0	16.5
3.	*Acacia mengium*	123.8	243.4	6.7	16.8
4.	*Albizia odoratissima*	122.4	517.1	4.1	18.6
5.	*Alstonia scholaris*	97.3	141.5	5.7	14.2
6.	*Eucalyptus hybrid*	130.1	391.3	4.5	22.7
7.	*Dalbergia sisoo*	106.3	237.9	4.8	16.8
8.	*Delonix regia*	121.1	189.9	6.7	16.2
9.	*Gmelina arborea*	121.0	254.6	5.3	19.9
10.	*Peltophorum ferugineum*	109.9	210.2	5.5	13.7
11.	*Pongamia pinata*	96.7	190.3	5.3	12.09
12.	*Terminalia arjuna*	112.0	193.2	5.8	11.6
	Year 2010				
1.	*Terminalia arjuna*	104.2	141.7	4.5	6.9
2.	*Peltophorum pterocarpum*	104.6	165.6	4.3	7.4
3.	*Eucalyptus hybrid*	124.4	278.7	5.8	13.5
4.	*Acacia aruculiformis*	115.1	244.2	6.7	14.0

• 18 months for the 2008 plantation.

Nine and six plant species were planted in the degraded forest area during the year 2009 and 2010 with initial height and collar diameter of 70.9-146.1 cm and 3.0-5.2 cm respectively attained height of 87.0-339.6 cm and collar diameter of 4.1-16.6 cm after 12 months (Table 4.6). Fourteen species planted during 2009 and 2010 in 20 ha area showed *Albizia odoratissima* (Black siris) as the best performing species (i.e., height of 339.6 cm and collar diameter of 16.1 cm). Performances of other species in descending order were: *A. mangium* > *D. regia* > *A. auriculiformis* > *E. hybrid* > *T. arjuna* > *P. pinata* > *A. excelsa* > *A. indicus* > *A. scholaris* > *S. mahagoni* > *D. sissoo* > *G. arborea* > *A. occidentale*.

Table 4.6. Growth of different species planted in degraded forest area

Sl. No.	Name of Species	Height (cm)		Collar diameter (cm)	
		Initial	12 month	Initial	12 month
Year 2009					
1.	*Ailanthus excelsa*	108.4	170.0	4.2	10.2
2.	*Anthocephalus indicus*	77.9	160.6	4.6	13.2
3.	*Acacia mengium*	114.7	265.9	3.5	13.5
4.	*Alstonia scholaris*	96.8	150.4	4.3	9.5
5.	*Delonix regia*	117.1	262.5	5.2	16.6
6.	*Pongamia pinata*	89.5	179.2	3.7	8.6
7.	*Terminalia arjuna*	112.8	183.9	4.0	9.0
8.	*Acacia auriculiformis*	133.8	230.0	4.1	12.1
9.	*Anacardium occidentale*	70.9	87.0	4.0	10.0
Year 2010					
1.	*Swietenia mahagoni*	112.5	137.9	4.5	9.6
2.	*Eucalyptus hybrid*	146.1	224.6	3.7	8.5
3.	*Acacia mangium*	112.0	177.4	3.0	7.2
4.	*Gmelina arborea*	90.0	110.0	3.0	4.1
5.	*Dalbergia sissoo*	109.5	125.0	4.0	6.5
6.	*Albizia odoratissima*	88.0	339.6	3.5	16.1

This indicates high survival percentage and out of 15 species planted in the ash pond area eight species viz., *Albizia odoratissima, Eucalyptus hybrid, Dalbergia sissoo, Gmelina arborea, Acacia auriculiformis, Acacia mangium, Anthocephalus indicus, Peltophorum ferugineum* showed better performance after one year of plantation as compared to the other species. Out of 14 species planted during 2009 and 2010 in degraded forest areas, five species such as *Albizia odoratissima, Acacia mengium, Delonix regia, A. auriculiformis* and *Eucalyptus hybrid* performed much better. Amelioration of the sites (fly ash pond and degraded forest areas) conditions during three years of plantation indicated the importance of afforestation and soil and water conservation in restoration of ash ponds (Fig 4.3).

Fig 4.3. Location of fly ash pond area of DVC, CTPS, Jharkhand before afforestation (top) and after afforestation (bottom). Source: Das *et al.* (2019).

GREENBELT PLANTATION

Plantation along road sides, canal banks and railway tracts etc., not only helps ameliorate environmental conditions of these habitats but also promotes soil and water conservations. However, performances of such plantations are very much influenced by edaphic factors along such infrastructures.

Alluvial soil

Data reported on the growth of 18 forest tree species under mixed plantations along road sides, canal banks and railway tracts at 17 locations in Midnapore district, West Bengal. All species were planted as 3-4 month old seedlings, whereas seeds of Acacia nilotica were directly sown. Best performing species on alluvial soils were *Eucalyptus* spp., *Acacia auriculiformis, Sesbania grandiflora, Leucaena leucocephala, Gmelina arborea, Anthocephalus cadamba, Salmalia malabarica* and *Acacia nilotica*. Moderate performing species in terms of growth parameters were *Cassia seamea, Dalbergia sissoo, Albizia* spp., *Peltophorum ferrugineum, Casuarina equisetifolia* and *Erythrina indica*. Poor performing species were *Terminalia arjuna, Delonix regia, Alstonia scholaris* and *Pongamia pinnata* (Nath *et al.*, 1989).

Lateritic Soil

Height and girth increment of different forest tree species planted along road-sides, canal and river banks, wastelands and along railway tracks have been studied and correlated with soil attributes of lateritic soil zone of Midnapore district, West Bengal. Some of the sites having better nutritional status accelerated the growth of some selected species. On the basis of the results some species have been identified and recommended for planting in the lateritic belt to meet the demand for fuel wood and fodder (Nath *et al.*, 1990).

Coastal Soil

The growth of different forest species planted along road-sides and canal-banks has been correlated with the soil attributes in coastal zone of Midnapore district of West Bengal. Some of the sites having better nutritional status accelerate the growth of some selected species. On the basis of the results some species have been recommended for Social Forestry Programme under the said soil condition in a given climatic zone (Nath *et al.*, 1991).

REHABILITATION OF SALTLAND

Salt affected soils are wide spread in all climatic zones but dominate mostly in arid and semiarid regions where annual precipitation is insufficient to meet potential evapo-transpiration. Salinization is the accumulation of soluble salts of sodium, magnesium, and calcium in soils. High levels of soil salinity limit plant growth, where increased osmotic pressure of the soil solution reduces the plant's capacity to withdraw water from the soil. In India, about 6.75 million ha area suffers of salinity and alkalinity problems in different states. Approximately 2.60 million ha area is affected with salt problem in Rajasthan (0.38 m ha) and Gujarat (2.22 m ha). Utilization of these salt affected areas has become necessary owing to increasing need for fodder; fuel and other minor produce. Soil of Rajasthan is sandy lithic calcid shallow salty while that of Gujarat is black silty highly saline in nature. The growth of most plants is adversely affected because of impairment of physical conditions, disorder in nutrient availability and suppression of biological activity due to pH going up to 11 and exchangeable sodium up to 90 or so in such soils. The soluble salts contain preponderance of sodium carbonates and bicarbonates capable of alkaline hydrolysis, thereby saturating the absorbing complex with sodium. Swelling of dispersed clay may be considered as the main mechanism responsible for clogging of pore space in alkali soils, thereby restricting their ability to conduct water and air for decreasing their infiltration rate, hydraulic conductivity and moisture transmission characteristics (Itami and Fujitami, 2005).

Rehabilitation strategies

The rehabilitation of salt lands is common through chemical means and engineering approaches, where extension of salt affected soils is controlled by utilizing the resource on sustainable basis. Amongst different technologies utilized in reclaiming saline-alkaline soils, adoption of leaching has been found least costly and could result in an incremental output in the form of agricultural yields of 14 quintals per hectare (Chinnappa, 2005). Green manuring has been observed to be another effective technology and could enhance crop yields on saline as well as waterlogged soils. Adoption of salt-resistant crop varieties is also profitable for small and marginal farmers. Instead of leaving these lands fallow due to their inability to adopt capital-intensive technologies, the lands can be adopted under land reclamation and higher returns. For a comprehensive afforestation programs under rehabilitation of saltlands, there is need of special considerations, which include:

- Identification of the nature of salt problem.
- Assessment of availability and quality of irrigation water.
- Selection of suitable tree species.
- Choice of pitting and planting methods for alkali and saline soils.
- Soil and water management.
- Physical and social fencing during initial years.

Choice of species

Trees help in reducing the wind flow over bare salt areas and their roots help bind the soil, and this reduces further erosion of the site. However, for obtaining maximum production from saline land, it is essential to select the correct species, land-preparation, planting techniques and tree-growing systems. Mesquit (*Prosopis juliflora*), Kikar (*Acacia nilotica*), Sesbania (*Sesbania aegyptica*), Casuarina (*Casuarina equisetifolia*), Eucalypts (*Eucalyptus camaldulensis*), Siris (*Albizia lebbeck*), Parkinsonia (*Parkinsonia aculeata*), Leucaena (*Leucaena leucocephala*) and Karanj (*Derris indica*) are suitable energy plantation species; whereas species like *A. nilotica*, *C. equisetifolia, A. lebbeck, E. camaldulensis*, Arjun (T*erminalia arjuna*), Neem (*Azadirachta indica*), Jamun (*Syzygium cumini*), Khezri (*Prosopis cineraria*), *P. juliflora,* Imli (*Tamarindus indica*), Frash (*Tamarix aphylla*), Jungle jallebi (*Pethecellobium dulce*), etc. are suitable small timber and non-wood forest product species. Various species of halophytes and glycophytes have been tried at AFRI, Jodhpur. Among halophytes *Atriplex lentiformis, A. amnicola* and *Atriplex stocksii* are the shrubs, *Salvadora persica* (Khara Jal) and *Sueada nudiflora* are trees, and Sporobolus diander is grass species. Among glycophytes exotic trees are *Acacia ampliceps, A. colei, A. bivenosa, A. tortilis, Eucalyptus camaldulensis* and *Colophospermum mopane* whereas indigenous trees are *Azadirachta india* and *Zizyhus mauritiana* (Arya *et al.*, 2005; Arya and Lohara, 2006; 2008).

Plantation and management practices

Growing trees on sodic soils requires modification in the root-environment by (i) amending the chemical nature of soil for optimum growth of roots, leaching of salts and maximum retention of soil-moisture; (ii) breaking the hard pan by perforation so that vertical growth of roots should be in place; and (iii) proper maintenance of soil-fertility by applying fertilizers and manure. The technique adopted for afforestation of sodic soils is mainly depend upon site and soil conditions, species to be planted and the purpose of the plantation.

- Soil amendments: For the soil amendment many different methods are used as physical amelioration (deep ploughing, sub-soiling, sanding, profile inversion), chemical amelioration (amending of soil with various amendments like gypsum, calcium chloride, limestone, sulphuric acid, sulphur, iron sulphate), electro-reclamation (treatment with electric current). Gypsum is the most commonly used amendment due to its availability at low cost.

  FYM, Gypsum @100% G.R., nitrogen in the form of urea and CAN (Calcium ammonium nitrate) and phosphorus in the form of SSP (Single super phosphate). Gypsum ($CaSO_4 . 2H_2O$) is most commonly used amendments because it is very effective, cheap, locally available and handling is easy. Wheat straw and Bajara Straw are also used to minimize crakings in the alkaline clay soils (Arya *et al.*, 2005).

- Improved drainage system: A common factor in salt-affected areas is prolonged periods of saturated soils. Double combination of salt and water logging damages plant growth. Plants can withstand a much higher soil salt concentration if the soil around the roots is well drained. Deep ripping the soil of the site greatly improves water infiltration that helps reduce the concentration of salt in surface layers. It may also reduce ponding of surface water. Ridge mounds provide a well drained area of soil for young seedlings to grow during the critical first year (Arya and Tewari, 2009). Tree growth and survival are maximized where the mound is more than half a metre above natural the soil level and where double mounds are formed. This enables trees to be planted in a slight depression that catches rainwater but still keeps initial root growth above the saturated soil profile. Additional deep furrows alongside the mounds will drain the site better and may further boost tree growth. Ridge mounds constructed on a grade can also help to channel water away from the affected areas. However, care must be taken to avoid creating additional erosion problems.

  Double ridge mounds are bunds of 0.50-0.60 m broad at top and 1.2 m at bottom. The height of the bund is about 0.50-0.75 m high with ridges of 20 cm high on both sides (Mullan and White, 2002). Double ridge mound has been observed best for *Atriplex lentiformis, A. stocksii* and *A. amnicola* whereas circular dish mound is best for *A. lentiformis* (Arya, 2009; Arya *et al.*, 2010). Root development observed along the ridges in double ridge mounds and in all direction in case of circular dish mound. Gypsum application enhanced the growth and yield of *A. ampliceps* by 2-fold biomass on deeper and shallow alkali soils at the age of five years (Arya and Lohara, 2008). *Suaeda nudiflora* and *Atriplex stocksii* found on mud flats along sea coast or in saline soils in Gujarat also showed high survival rate and growth. Biomass production was highest on circular dish mound both for *S. nudiflora* (2.25 tons ha^{-1}) and *A. lentiformis* (1.30 tons ha^{-1}) after 36 months (Arya and Lohara, 2006). Circular dish mound supported with gypsum and 9 g N found beneficial for *Colophospermum mopane* with better growth and biomass. Its roots penetrated the $CaCO_3$ kanker pan further enhancing its utility (Arya and Lohara, 2008; Singh and Rathod, 2006 b).

- Reduced evaporation: Organic mulching around young planted seedlings reduces surface evaporation and salt concentration. This also boosts tree survival and growth. Various materials are also used that include straw, spoilt hay, grass clippings, stable sweepings, old animal manure, tree mulch, wood chips, newspapers, old carpet and rags. Available farming byproducts can also be used as mulch for saline soil reclamation. Mulching from locally available grass like *Sporobolous diander* was used in an experiment conducted at AFRI, Jodhpur. Use of mulch provide support in raising the WUE of drip irrigation also.

- Use of fertilizers: Fertilizer like single superphosphate or di-ammonium sulphate which increases acidity in soil and maintains fertility of soil impoverished by leaching and cropping appeared beneficial in saltland reclamation. Work at AFRI, Jodhpur indicates that application of nitrogen along with gypsum (gypsum + 9g N) enhanced the growth and biomass of *Salvadora persica* as compared to application of nitrogen only (Arya *et al.*, 2005).

- Planting practices: In deep soils of 40 cm to 100 cm soil depth, pits of 50 cm x 50 cm x 50 cm were dug and 3 kg farmyard manure (FYM), 15 g single super phosphate (SSP) and gypsum (according to treatment) were mixed with pit soil at the time of planting. Soil drenching with 0.2 % chloropyrophos was also carried out. Crescent shaped drainage trenches of 6'x 1'x1' were made around individual plant along the slope to facilitate the leaching of the salts. In shallow soils of 20 cm to 40 cm depth area, double ridge mound (DRM) was adopted from the studies carried out in Australia (Ritson and Pettit, 1992), while circular dished mound (CDM) was developed on our field experience. For making Double ridge mounds, bunds (0.50 m broad and 0.45 m high) were constructed with the help of tractor and ridges (20 cm high) were made manually. Distance between two ridges (planting space) was 1.2 m. CDM were prepared by raising soil to a height of 20 cm in a circle of 2.0 m diameter manually (Fig 4.4).

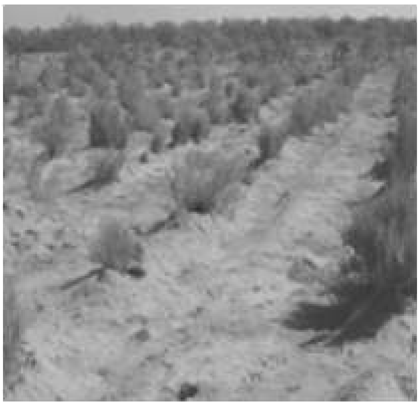
Fig 4.4. Performance of different species in saline area. *Atriplex lentiformis* on double ridge mound (left) and *Acacia colei* on circular disc mound (centre) and CDM

- Species performences: Studies (Arya, 2009) conducted at AFRI, Jodhpur indicates that shrubs of genus *Atriplex* has potential to produce nitrogen rich fodder from highly degraded arid salt affected soils, whereas *Salvadora persica* is the most versatile indigenous tree species maintaining 66.7 -85.2% survival after ten years of plantation and responding well to gypsum and nitrogen applications. Crescent shaped drainage trenches helped in leaching of salts from the soil. *A. ampliceps* (an exotic) adapted well to arid alkali conditions producing sufficient biomass without suppressing the growth of native vegetation and yielded two fold high biomass (12 kg tree^{-1} to 5.43 kg tree^{-1} for gypsum treated soils and 8.1 kg tree^{-1} to 3.9 kg tree^{-1}) for untreated trees on deep and shallow soils at the age of five years (Arya, 2009). *S. nudiflora* from the mud flats and sea shore areas of Little Rann of Kutchch is adapted well on sandy saline soil with 55% to 80% survival after 72 months of plantation. Likewise, *Colophospermum mopane* proved to be ideal species for salty wastelands with 89% survival after five years, when its roots penetrated Kanker hard pan of calcium carbonate.

Among soil working techniques, double ridge mound was observed better in enhancing the survival of shrubs on shallow water logged saline soil though root development was observed in two directions along the ridges (Fig 4.5).Plantation activities on saline soils improved the site conditions as shown by natural regeneration of *S. persica* and *S. oleoides* under each and every *P. juliflora* tree situated along the field boundary.

72 Months old S. persica

White fruits in S. persica



Atriplex amnicola on mounds

Acacia ampliceps

A. ampliceps in flowering

Site during monsoon period

Growth of *C. mopane*

Roots with $CaCO_3$ nodules

Improved site with vegetation

Fig 4.5. Performance of different species under soil amendment and drainage in saline area of Kaparda in Jodhpur district.

In another trial carried out in Kutch area of Gujarat, S. persica proved to be best plant by recording 91.6 % survival after 48 months. For green biomass T5 was the best treatment with 7.13 kg tree^{-1}yield which is significantly higher than all other treatments while minimum yield was for control (2.60 kg plant^{-1}). *A. bivenosa* was at second place with 46.3 % at 36 months. It has shrubby nature and responded to treatments applied and positively influenced the survival, growth and biomass yield. All the treatments recorded higher biomass as compared to control (3.43 kg) at 36 months of age. Maximum 12.68 kg tree^{-1} biomass yield was obtained for T3 (Wheat straw) treatment.

Acacia ampliceps was the most fast growing species and displayed shrubby nature. It maintained appreciably high mean survival 72.6% upto 18 months (Arya *et al.*, 2010). It attained 68.7 & 25.5% more height and crown diameter respectively, as compared to *S. persica* and 64.8 % more height than *A. bivenosa* at 18 months. Plantation suffered with heat shock in May 09. Around 26-28 May 09 and recovery was medium (Fig 4.6).

Both the Acacias flowered and produced viable seed within two years. Natural germination through seed was observed near plant pit in 2010 (an above average monsoon year) for *A. ampliceps*. Plant growth improved the soil conditions, decrease in pH (8.42 to 7.72 and 8.39 to 7.84, EC (2.27 to 1.60 dSm^{-1}, 2.40 to 1.47 dSm^{-1} and increase in organic carbon (0.20 to 0.35% and 0.19 to 0.27 %) in 0-25 cm and 25-50 cm soil layers, respectively, was observed inside plant pit.

S. persica *A. bivenosa* *A. ampliceps*

Fig 4.6. Performance of different species in black silty clay soil of Little Rann of Kachchh under various soil amendments

CONCLUSION AND RECOMMEDATIONS

Water runoff also causes soil erosion in mine overburdens and hilslopes by sweeping away fine materials, and nutrients, from the sloped areas and strongly affects long-term development of waste dumps. Protection forest located on a slope where there is a direct risk for human life or for material goods of high value, due to avalanches, landslides, erosion, debris flows or falling rocks and play significant role not only in stabilizing the slopes (mine debris) and increasing green cover but also help onserved soil and water. Plantation of multipurpose tree species on mining overburdens, hill slopes, farmer's land and degrading village common lands supports livelihoods in addition to stabilize slopes and reduces run-off losses and soil erosion. Reclamation of overburden dumps of different mine areas, ash ponds or saline-alkaline lands can be done effectively once the chemical, physical and biological properties of soil are correctly determined. However, compaction, low water holding capacity, bulk density, deficiency of micro- and macronutrients and soil depth (rooting restrictions) are the major factors limiting the productivity of such areas.

Reclmation of above-mentioned areas can be achieved by careful attention to all aspects of reclamation and revegetation. For example, from initial planning, clearing, soil removal, storage, providing drainage and replacement through species selection and re-establishment of vegetation with its associated organism and to maintenance of areas for future.

Ecological and biological methods of reclamation of mineoverburdens or ash ponds are important, but soil amendments and involvement of engineering measures of soil and water conservation shall be the first line of defense mechanism in controlling erosion of mineoverburdens and debris. Surface terracing, contouring and formation of gully plugs viz. brushwood check dam, logwood check dams and loose boulder check dam in the gullied areas and treating the drainage lines will be important aspects of soil and water conservation.

Revegetation of mine overburdens with mixed species of varying adaptability will constitute the most widely accepted and useful way to reduce erosion and protect soils against degradation during minelands reclamation process. It will also help promote vegetation to come up at a faster rate. Plantations along the ridges on the slopes will result in better growth of the planted seedlings.

Soil and water management play an important role in rehabilitation of saltlands also, where choice of species adapting to saline and alkaline soil conditions, soil amendment by gypsum, organic manure and added nitrogen, phosphorus and micro-nutrients depending upon soil conditions and airation and sufficient soil depth through raised bunds can improve survival, growth and biomass production.

Such reclamation works and creating protection forests must go beyond planting to a new landscape by considering the land as an integrated system that function above and below the ground. The data generated so far through field experimentation appear successful over periods of several years and indicates that there is much more to learn about long-term effects of these plantations.

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