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# 60 Years of Research in Yamuna Ravine Region

ICAR - Indian Institute of Soil and Water Conservation (IISWC)
Research Centre, Chhalesar Agra- 282 006 (Uttar Pradesh)

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# FOREWORD

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डॉ सुरेश कुमार चौधरी
उपमहानिदेशक (प्राकृतिक संसाधन प्रबंधन)
**Dr Suresh Kumar Chaudhari**
Deputy Director General (Natural Resources Management)

Land degradation is an issue as around 24 billion tons of fertile soil and 27,000 bio-species are lost each year. It threatens productivity of land and also water quality, human health and other ecosystems services on which all life depends. In India, land degradation covers 120.4 million ha area out of which 3.7 million hectares land along several river systems in the alluvial zones in India is affected by ravines, posing a considerable challenge to poverty reduction and soil equality. Apart from lowered productivity the ravines contribute to huge sediment load to river systems as these sites are major sediment producing hot spots. The ICAR – IISWC, Research Centre, Chhalesar, Agra has developed scientific and technical know how to deal with the problems of ravine lands on the bank of Yamuna River. The centre has been contributing to research for tackling the problems related to soil and water conservation, agriculture and tree based production systems in the ravine region of Yamuna river system for past six decades. The current publication is the outcome of compilation of the research achievements of the centre.

The document describes the extent of area under ravines in Uttar Pradesh and deals extensively with the extent of land degradation in Yamuna ravine region. It deals with major problems faced by ravine infested areas and suggests remedial measures for tackling them. The technologies developed by the Centre and other research organizations and their adoption in the region has also been discussed in this document alongwith common ITKs followed by farmers. Critical issues confronting ravine regions pertaining to soil and water conservation problems and their prioritization, the research gaps to address the problems and vision statement for future strategy are parts of the document.

I hope this publication will serve as excellent source of information related to problems and their remedial measures related to ravines. I hope that this document will be useful for policy makers, government agencies, non government organizations and other agencies engaged in soil and water conservation, watershed management and land rehabilitation efforts in the country especially in ravine regions. The reclamation/ rehabilitation of ravines may in turn lead to improved social equality and reduced poverty in the ravine region.

18th October, 2021
New Delhi

(S. K. Chaudhari)

# PREFACE

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Dr M. Madhu
Director

Land degradation is a growing global concern and have serious implications on wellbeing of the mankind and various ecosystems. As the land resources are finite, there is urgent need to reclaim degraded and wastelands especially in ravine infested region in parts of Uttar Pradesh and adjacent States of India.

The ICAR – IISWC, RC, Agra was initially established as the Soil Conservation Research Demonstration and Training Centre in 1955, and subsequently upgraded to a full-fledged Research Centre in the year 1957 with the objective of developing scientific and technological know how to deal, understand and negotiate the problems of ravine lands through scientific solutions for sustainable resource conservation and production.

This publication is primarily, the research outcomes and accomplishments of the Research Centre over the period of six decades. Also, the achievements and practices contemplated and adopted by the State Government agencies and other stakeholders are duly documented. India being a traditionally known agrarian society since ages the traditional knowledge available with the farming community in the region has also been given due space.

The document underlines the topics pertaining to soil and water conservation problems and their prioritization in the Yamuna ravine region. The research gaps enlisted and discussed to address the problems envisioning the future strategies make an important part of the manuscript. The ravine reclamation and rehabilitation of technologies evolved and disseminated by the ICAR-IISWC, Research Centre, Agra, are presented which will definitely help the agriculture production, wellbeing of farming communities and overall sustainability of the region.

I congratulate all the contributors for this excellent piece of work and appreciate the efforts in bringing out this publication. I am quite confident that the document will serve as an exceptional source of information for policy makers, Government agencies, NGOs and other agencies especially in ravine regions.

October, 2021
Dehradun

(M. Madhu)

# ACKNOWLEDGMENT

The present publication on "60 Years of Research in Yamuna Ravine Region" is mainly the compilation of results of different research project, experiments and demonstration conducted by the ICAR-IISWC, Research Centre, Agra (Erstwhile, Central Soil and Water Conservation Research and Training Institute, Research Centre, Agra) on soil and water conservation aspects in the Yamuna ravine region through different sponsored schemes of central/state Government.

We, the authors acknowledge the guidance and encouragement given by Dr Suresh Kumar Chaudhari, DDG (NRM), ICAR in bringing out this publication.

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The team also would like to place on record the contribution of former Head of Centres namely Dr L. S. Bhushan, Dr R. C. Yadav and Dr H. C. Nitant along with all the scientists and technical staff who worked at ICAR-IISWC, Research Centre, Agra from time to time.

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The authors acknowledge the help and contribution rendered by Dr Matish Chandra, CTO (OIC Publication) Dehradun in design, layout and appreciate the efforts in bringing out this publication in present form.

The last but not the least, we are grateful to all support staff of the centre, farmers of the region, state line departments, NGOs *etc.* for their cooperation and support during different studies without which these findings would not have seen the light of the day and hence this publication.

**(Authors)**

# EXECUTIVE SUMMARY

Ravines are the worst manifestation of terrain deformation by water and are a major problem in estimated 3.7 million hectares of land along several river systems in the alluvial zones of India. These ravines are most fragile ecosystem, subjected to various kinds of natural resource losses and threat to biodiversity. Out of the estimated 3.7 m ha ravine lands in India, major problem areas are located in Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Bihar. Considering the severity of the problem the Soil Conservation Research Demonstration & Training Centre, Agra was established as one of the centre in the chain of soil and water conservation research demonstration and training centres in India in 1955. It was later on renamed after establishment of CSWCRTI, Dehradun under ICAR and has functioned for about 60 years. The mandate of this Centre is to carry out research and development on rehabilitation and control of Yamuna-Chambal ravines. This document has been prepared for highlighting soil and water conservation problems that exist in Uttar Pradesh and Bihar.

Over a period of sixty years the IISWC (formerly known as CSWCRTI), Research Centre, Agra has developed, evaluated and successfully demonstrated technological packages for rehabilitation and productive utilization of ravine lands. The IISWC, Research Centre, Agra along with two other research centres of IISWC located at Kota and Vasad made an attempt to delineate and characterize the ravine area in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat States and identified a total area of 10.37 lakh ha. The current ravine area mapping shows about 50% reduction in the total ravine area in these states as compared to ravine area statistics reported by National Commission on Agriculture in 1976. About 75% area in UP and Gujarat, and about 50% area in MP and Rajasthan has been reclaimed since 1976. During sixty years of existence this centre has investigated the soil related factors, climatological factors, topographic factors, crops and cropping practices as components required for application of universal soil loss equation. The Centre has carried out physical measurement of gullied extension at Umretha to assess the rate of extension of ravines. In another study the process involved in the development of gully head cut and enlargement of gullies were monitored in a 250 ha watershed at Nandlalpur, Agra.

The rainfall trend analysis is useful in terms of giving precise prediction of rainfall and its distribution enabling better crop planning and management of inputs. The analysis of distribution of weekly rainfall is important for adjusting the variety and sowing time of different crops in such a way that it can avoid the moisture stress period. Analysis of the rainfall data from 1955 to 2002 at the research centre, Agra indicated that high rainfall (more than 20 mm) occurs from 2$^{nd}$ week of July (28$^{th}$ standard week) to 2$^{nd}$ week of August (33$^{rd}$ standard week). During 3$^{rd}$ and 4$^{th}$ week of August to 1$^{st}$ week of September (34$^{th}$ to 36$^{th}$ standard week), the probability of receiving 8.0 mm rainfall per week is 80%.

Frequency analysis is an important aspect considered in designing hydraulic structure, which are based on the occurrence of different hydrological events. The values of probable maximum daily rainfall for 5 years return periods were 115, 114 and 115 mm with Gumbel, Lognormal and Person Type III distribution, respectively for Agra. For 20 years return period, the values of probable maximum daily rainfall were 151, 154 and 156 mm, respectively, for the three distributions.

Probability analysis of 44 years daily rainfall data revealed that at 76% confidence level, occurrence of probable rainfall is 440.0 mm in *kharif*, 26.5 mm in *rabi*, 11.9 mm in summer and 508.0 mm per year compared to annual average rainfall of 685.02 mm. There is 85% probability that there would be no rain after 15th September so there are limited chances of receiving adequate amount of moisture at the root zone level for proper germination of *rabi* crops. Recently a soil erosion map of U.P. was prepared which gives an over view of soil erosion problem in the state of U.P.

The centre had operated 14 watersheds of varying sizes in the research farm under different land uses to assess the hydrological behaviour of land terrain under severe gully erosion. A field version of rainfall simulator was also developed. In addition, surface runoff studies were carried out to understand the ground water hydrology of the watersheds. In addition to natural recharge, artificial means of ground water recharge were also studied. Centre conducted study on the water harvesting practice for enhancement of productivity of the degraded lands. Utilizing hydrological data collected by different watersheds in the research farm, it was established that runoff and soil loss of untreated watershed was 10-14% and 2-4 t $ha^{-1}$, which reduced to 2-5% of rainfall and 0.5 to 1.5 t $ha^{-1}$ soil loss. A finite element simulation model for watershed runoff was developed and interpreted with the data generated from Nandlalpur watershed.

Micro-catchment water harvesting was carried out for six years for cultivation of Ber. V-shape micro-catchment water harvesting produced maximum runoff that in turn produced maximum yield. Utilizing the results of water harvesting specification for terracing of peripheral lands was developed. Studies were carried out on jetty like structures and the velocity along the river bank were measured by current meters. Sediment deposits and carving of the other side of the rivers to have a definite river course away from the bank was studied on the full scale model of the jetties at Tanaura.

The Centre conducted three operational research project at Sheetalpur, Hamirpur; Etmadpur watershed, Agra and Jalalpur watershed in Jagner. There has been remarkable improvement on increase of the crop yield and reduction in the soil erosion because land levelling and terracing is the last resort of land management programmes.

After identification of factors of land degradation the Research Centre conducted studies for finding out ways and means of augmenting sustainable productivity in the deep alluvial soil region susceptible to gully erosion. Likewise cultivation of the inter-terrace measures for cropping, field conditions response to erosion, safe water disposal measures and water retention structures also were required to be studied. In addition to agriculture nutrients management, agri-horti and horticulture are also needed to be developed for deriving economic returns from the lands susceptible to gully erosion. Accordingly, the Centre carried out research on crops and cropping practices, utility of mulches, ways and means of maximization of yield of identified crops and cropping practices. The nutrient management in the form of inoculation, N-doses, long term fertility measurement and green manuring, cultivation practices *viz.* tillage practices have also been investigated. Methods of irrigation and selection of crops for limited water scenario have also been studied. Indigenous methods of moisture conservation and runoff management were studied in Agra district under the NATP project. Assessment of the impact of trenches for rain water management for plantation of multipurpose tree species was taken up.

Terracing and its specifications were devised for reducing erosion. The prefabricated drop spillway was developed to provide outlet structure for safe disposal of excess rainfall without causing gully head cut at the site. A new modified chute spillway was also developed to retain water in the ponds to be located at difference places in the gully. Studies conducted at the centre revealed possibility of double cropping in the area by growing green gram-mustard as a stable cropping pattern under variable rainfall distribution situation, provided greengram matures in about 60 days and is sown at the onset of monsoon *i.e.* first week of July. Among different cropping systems, guar-wheat was found more suitable as guar could reduce requirement of fertilizer to wheat crops by 40 kg N $ha^{-1}$. Intercropping was found to be ideal practice for increasing the cropping intensity in the region. Intercropping of greengram in pigeonpea and castor has been found to be best combination under rainfed conditions. Further optimization of this intercropping system has established that 4 rows of greengram should be sown in between two rows of castor placed at 120 cm apart. Intercropping of potato with limited water supply *i.e.* two rows of potato and one row of mustard gave almost equal yield equivalent to sole potato crop and maximum return while requiring nearly 1/3 of irrigation water of the sole potato crop. Optimization of mustard crop has been studied where in it is found that cultivation of linseed in between two rows of mustard yield highest Indian mustard yield equivalent of 1995 kg $ha^{-1}$. Yield of mustard crop has been found to be maximum with presowing irrigation followed by irrigation at branching and one irrigation at pod formation. Green gram and mustard cultivation applying dust mulch helped in conservation of about 16.5% higher soil moisture which produced 32% higher green gram yield over the un-cultivated plot. In the area of nutrient management, no response of guar to *Rhizobium* culture was found. Maximum yield of guar was found with 25 kg N and 50 kg $P_2O_5$ $ha^{-1}$. A large part of Indo-Gangetic plain zone including the Semi-Arid Agra region is beset with hard sub soil layer (due to kankar/calcium carbonate granules) and high bulk density which impedes the infiltration/downward movement of rain water in soil profile. Deep ploughing up to 20 cm depth with MB plough, once in three years stabilized crop yields in drought prone rain fed conditions of Semi-Arid Agra region, suppressed weed growth and enabled enormous production/ramification of crop roots which improved crop moisture use, soil organic matter/physical properties. Deep ploughing enhanced root production by 34% in pearl millet crop, ameliorated pH from 8.1 to 7.2 and reduced bulk density from 1.60 to 1.46 mg $cc^{-1}$. It has also registered a tremendous increase in initial organic carbon (0.2%), infiltration rate (1.2 cm $hr^{-1}$), water soluble aggregates of <0.25 mm (3.6%) and water soluble aggregates between 1-8 mm (2.6%) that corresponded to 280, 267, 800 and 562% over initial status in a period of six years, respectively.

Inclusion of legumes crops in cropping systems reduced the N requirement of succeeding crop. In the reclaimed Yamuna ravines cluster bean-wheat cropping system produced highest yield of wheat grain (2538 kg $ha^{-1}$) with 120 kg N $ha^{-1}$ among three cropping systems (pearl millet-wheat, cluster bean-wheat and fallow-wheat) under rain fed conditions. The available N in soil also recorded highest value under cluster bean-wheat cropping system at surface (0-15 cm) as well as subsurface (15-30 cm) depths.

Study on the long term fertility management has established that recommended dose of fertilizer or fertilizer applications on soil test basis were statistically at par in producing grain yield of field crop *viz.* pearlmillet-wheat. Application of recommended dose of fertilizer in combination with FYM @ 5 t $ha^{-1}$ produced the highest yield of 1524 kg $ha^{-1}$ of pearl millet and 2825 kg $ha^{-1}$ of wheat. The study has established that if there is optimum rainfall situation it brings optimum yield of both the crops. Study on green manuring has indicated that application of 10 kg N $ha^{-1}$ to sun hemp crop as green manure plus application of 80 kg N $ha^{-1}$ produced highest yield of wheat giving maximum reflection on the increase in 1000 grain weight.

Deep tillage carried out by disc harrow once in three years followed by cultivator has been reported to produce maximum yield of pearl millet and wheat. Under NATP study in Agra district, it is found that conservation furrow at 3 m interval in the line sown green gram produced yield of green gram around 10 q $ha^{-1}$ and thereby net return of Rs. 10000 to 22000 $ha^{-1}$. This practice has reduced fallowing for moisture conservation for cultivation of mustard that in turn increased cropping intensity to 200%. Likewise, conservation diking at 3 m interval in the line sown pearl millet for moisture conservation produced yield of pearl millet in the range of 18 to 32 q $ha^{-1}$ as against 8 to 25 q $ha^{-1}$ in the indigenous method of cultivation both raised with supplementary irrigation. The study enabled derivation of specification for development of seeding machinery to produce uniform speedy crop emergence and desired crop stand. Line sowing of intercrops and placement of fertilizer and maintenance of moisture conservation affect during tillering stage.

Studies for utilizing sub-soil moisture and reducing the tree crop competition for growth resources revealed that ber (*Zizyphus mauritiana*) planted in the bottom less bitumen drum in the rows located 10 m apart with cultivation of different crops in the inter space between the rows produced highest grain yield of wheat and 72 q $ha^{-1}$ of ber fruits. In the pearl millet-wheat rotation with alley crop of subabul the application of green subabool leaves available from the alley saves about 25 kg N $ha^{-1}$. Studies on intercropping of vegetables in the mosambi crop revealed that maximum fruit yield of mosambi were obtained with fenugreek as intercrop.

Evaluation of effect of long term forest in the alluvial soil region revealed that although the soil is deficient in N and P, N content did not improve under forest land use. Various methods of land management practices have been devised for enhancing the productivity of grass lands. Imposition of treatments of contour trenches in 1971 halted runoff water in the watershed. It has helped natural regeneration of 441 trees of mixed species producing 3.5 tons of firewood from the watershed area. Study on unit source, deep gullied watershed led to conclusion that ravine check dams (height 0.5-2.0 m) should be located at 25 m from the toe of gully in the upper catchment and narrow catchment and at an interval of 45 m in wide and riverine catchment so as to induce regeneration of forest trees in the deep gully land. Evaluation of structures established that drop inlet pipe spillways invariably failed, therefore, drop inlet pipe spillways are not recommended in the gullied lands. Drop spillways should be preferred to drop inlet pipe spillways. Regarding compatibility of the tree species it was established that *Acacia nilotica* and *Acacia toritilis* are equally promising species at the close spacing (3 m x 3 m) yielding 27 & 28.7 t $ha^{-1}$ fuel yield in 15 years. For top portion of ravines *A. toritilis* and bottom *A. nilotica* were found better. Among the species from different locations *A. nilotica* of Agra region was found to perform best both on top and side of the ravines. Among all the species of Eucalyptus tried on the marshy land of Yamuna ravines *E. tereticornis* produced highest air dry wood (484 kg $tree^{-1}$) which is also highly adopted species in the climatic conditions of Yamuna ravine at Agra. Likewise in the gully bed study on bamboos established that number of recruits in all the treatments were almost similar indicating that in 25 years the *Rhizobium*/root system is fully developed and given annual production of 2500 bamboos $ha^{-1}$ $yr^{-1}$ at sustainable basis. Successional trend in the enclosures revealed that in general over 2 folds, 4 folds and 10 folds increase in number of species, no. of individuals, canopy area and ground volume, respectively. The maximum canopy area under protected condition was 100% as against 23% under the unprotected condition. In spite of protection for 24 years no woody perennial was observed on the hump tops. However, woody species were recorded from the ravine slopes and bottom at different times. Staggered contour trenches of constant length of 180 cm and width of 60 cm with varying depth revealed that trench of 60 cm depth produced better growth of trees. Among the refilling method, double trench/bundless filling growth proved to be the best. Thus, combination of 60 cm depth and double trenching type of refilling of trench proved to be the best for planting. Study on goat grazing in the established forest indicated that there was no adverse effect of goat grazing on hydrological behaviour of watershed. Goat production was about 1 kg $goat^{-1} month^{-1}$ and grazing of 8 goats $ha^{-1}$ did not induce any kind of land degradation.

Among the various species tried by planting ber at 4 m x 4 m planted in 1975-76 indicated that Banarasi, Ponda and Safeda were most promising varieties for Agra region. The productivity of the non-arable lands have rather remained stunted on account of heavy biotic interference, development of wild life, bird damage, causing of shade effect and weather calamities such as occurrence of drought and prolonged foggy winter etc. During the foggy winter occurrence, frost has severely affected the *Prosopis juliflora* making them dry. The problem of frost can be reduced by providing conservation measures so as to retain more moisture in the soil profile.

Attempt was made to document the indigenous practices of soil and water conservation in the state of U.P. Most of the thumb rules are related to enhancement of the productivity of arable lands for human and animal welfare. Thumb rules are available for nutrient management particularly, nutrients available from animals *viz.* FYM and other such as green manuring. In Chhattisgarh, ITK of nutrient management is practiced under tribal areas. *A. nilotica* trees are grown maintaining 100-125 trees $ha^{-1}$ for increasing soil organic matter and available nitrogen in rice fields. There are indigenous practices of moisture conservation in the central U.P. where people cultivate fields in October and November before sowing the winter season crops to capitalize residual moisture in the soil. There are some indigenous practices for plant protection also *viz*. tying of *heeng* in the wines of bottle guards to save crop from diseases. Farmers use 3.5 lit kerosene $ha^{-1}$ in irrigation for control of termites. There are some practices for post harvesting processing of grain *e.g.,* keeping available seeds such as black grams and okra as whole food after drying by hanging in the kitchen to keep the seeds viable. Dry chillies are mixed for storage of greengram and balckgram. In the area of hydrological behaviour of watersheds, submergence bundhies in the Aravali and Bundelkhand region is a noble practice of water conservation. Mokama group of Tals are another example. *Dabri* is an indigenous practice of water harvesting in Chhattisgarh which is constructed in the individual's fields. The submergence bundhi practice prevailing in U.P. and Bihar can be made more efficient by adopting cropping practice incorporating dhaincha in the likely submerged area and greengram *etc.* in the upland areas. There can be other structural and non-structural measures for enhancement of efficiency of these conservation practices. The most common practice found in the semi-arid tropical region *viz.* guur. The system studied for further quantification of the benefits and improvement. Likewise the nutrient management practices also need improvement in the nutrient use efficiency.

# 1.0 INTRODUCTION

## 1.1 Historic Background

Land degradation is an issue of worldwide concern, as globally around 24 billion tons of fertile soil and 27,000 bio-species are lost each year. Gross soil erosion in our country is 5.11 billion ton per year that occurs at an annual rate of 15.59 t $ha^{-1}$ $yr^{-1}$ (Sharda and Ojasvi, 2016). It not only threatens the productivity of land but also water quality, human health and other ecosystems services on which all life forms depends. As a result the replacement costs (in terms of increasing input costs, mitigation costs and conservation cost) are mounting and reducing the sustainability of production systems. In India, an estimated 120.4 m ha suffers from various forms of land degradation due to water and wind erosion and other complex problems Water erosion is predominant degradation cause in the country with around 93 M ha area *i.e.* 28% of total geographical area affected by it (ICAR, 2010). The space applications centre, Indian Space Research Organisation (2016) reported that during the period 2003-05 and 2011-13 there was a cumulative increase of 1.87 m ha in degraded areas in the country that are undergoing process of desertification/land degradation in the country. Thus, land degradation poses a considerable challenge to poverty reduction and social equality in India. Among the various forms of land degradation, ravines are the worst manifestation of terrain deformation by water. The land degradation due to ravines is a major problem in estimated 3.7 m ha of land along several river systems in the alluvial zone of India. The major ravine areas are located in Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Bihar (Verma *et. al.*, 1986). Sikka *et. al.* (2016) reported that the average annual loss of nutrients from ravine lands due to soil erosion was 5.37-8.4 million tons resulting into loss of production due to non-reclamation of ravines. If left unattended the ravine lands tend to ingress in to the adjacent table lands by head ward extension and vast areas of fertile lands go out of cultivation. Even as varying estimates have been put forward for the rates of extension of ravines in to the cultivable lands, several classifications are also in use for determining the potential for reclamation of these ravine lands. Considering even a very conservative estimate of ravine extension @ 0.175% per annum, Singh *et. al.* (1966) warned that Rajasthan may lose 13750 ha of cultivated land in 25 years. Thus, it is rightly said that extending ravines mark the foot print of death for the cultivator.

## 1.2 Extent of Degradation by Ravines

**Nature and Extent of Ravine Problem**

The word "ravine" is usually associated not with an isolated gully but denotes gullied land containing systems of gullies running more or less parallel to each other in deep alluvium and entering into a nearby river flowing much lower than the surrounding table lands. The word "ravine" means deep gorge. The nature of the alluvial soil in which a major river cuts a channel very deep from its bank lead to the problem of the runoff from the table lands having to negotiate a large vertical fall in short horizontal distance. Such a situation creates water flow conditions conductive to rapid development of gullies running the area along the river banks and formation of ravines. Once a gully is formed, it extends by the phenomenon of saturation and slip of its head and sides. Depending upon the soils, geology, vegetation, topography and the runoff from the watershed, different shapes and sizes of ravine are developed. These ravines are most fragile ecosystem, subjected to various kinds of natural resource losses and threat to biodiversity. Several natural and man made factors have been responsible for ravine formation. Very extensive degradation of land has occurred along some of the major river systems of the country in various states in the form of deep gullies. The largest is the Yamuna-Chambal ravine zone. The ravines flank the Yamuna river for nearly 250 km and attain a depth of more than 80 m in Agra and Etawah. The Chambal ravines flank the river Chambal in a 10 km wide belt which extends southwards from the Yamuna confluence to 480 km to the town of Kota in Rajasthan. Ravines also affect basins of several Chambal tributaries, *e.g.*, Mej, Morel, Kalisindh, *etc.* In Gujarat, ravine belt is spread over the southern bank of the Tapti, banks of the Narmada, Watrak, Sabarmati and Mahi basins. Besides, these river basins, ravines are also found in Chhota Nagpur, Bihar, Mahanadi and upper Sone valley, Indo-Gangetic plains, Siwaliks and Bhabar tract and Western Himalayas (Dhruvanarayana and Babu, 1983). The National Commission on Agriculture (1976) estimated 3.67 M ha of ravine lands in India (Table 1.1), out of these 2.76 M ha (75%) are spread over the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Subsequent periodical assessments using remote sensing techniques by National Remote Sensing Centre (NRSC) in 2000, 2003, 2005 and 2008 have shown sharp reduction in the ravine area of the country. The wasteland maps issued by NRSC show that total ravine area of India has been reduced to 0.74 M ha (2009), which is only 20% of the area reported by National Commission on Agriculture (1976). The NRSC data does not commensurate with the ground realities and therefore there has been lack of agreement on this. Nevertheless, ravine reclamation and ravine extension are continuing processes and there is a need for a realistic and continuous monitoring of the problem area. Out of the estimated 3.972 M ha ravine lands in India constitute 1.21% of the total geographical area of the country (328 M ha). In U.P. alone the ravine area is of the order of 1.23 m ha *i.e.* about 1/3rd of the total ravenous lands in the country. The problem of ravines has assumed urgency because the ravines are dynamic in nature and on conservative estimate it takes annual toll of above 8000 ha of valuable lands in the country. If left unattended the ravine lands tend to ingress in to the adjacent table lands by head ward extension and vast areas of fertile lands can go out of cultivation. The ever increasing demand of food, fuel and fodder has attracted the attention of the Government of India towards the useful utilization of these otherwise waste lands.

The recent estimates by CSWCRTI, (2014) show that the total ravine area in U. P. has gone reduced to 3.40 lakh ha, from initial estimates of 12.30 lakh ha due to implementation of many ravine reclamation projects. Taluka and District wise ravine area is given in Table 1.2.

**Table 1.1: Extent of ravines in India**

| State | Ravine area (Lakh ha.) |
|---|---|
| Uttar Pradesh | 12.30 |
| Madhya Pradesh | 6.83 |
| Rajasthan | 4.52 |
| Gujarat | 4.00 |
| Maharashtra | 0.20 |
| Punjab | 1.20 |
| Bihar | 6.00 |
| TamilNadu | 0.60 |
| West Bengal | 1.04 |
| **Total** | **36.69** |

Source: National Commission on Agriculture (1976)

**Table 1.2: Extent of ravine land in Uttar Pradesh**

| District | Taluka | Taluka area (ha) | District area (ha) |
|---|---|---|---|
| Agra | Agra | 1668.0 | 37075.9 |
| | Bah | 27615.3 | |
| | Fatehabad | 6437.3 | |
| | Khairagarh | 583.7 | |
| | Kiraoli | 771.5 | |
| Aligarh | Hathras | 2.1 | 19.5 |
| | Khair | 17.4 | |

| | | | |
|---|---|---|---|
| Allahabad | Allahabad | 274.6 | 10173.0 |
| | Handia | 37.1 | |
| | Karchana | 2392.7 | |
| | Manjhanpur | 703.6 | |
| | Meja | 6499.1 | |
| | Phulpur | 104.4 | |
| | Soraon | 161.4 | |
| Banda | Baberu | 4309.4 | 39600.5 |
| | Banda | 14911.7 | |
| | Karwi | 6591.8 | |
| | Mau | 3459.0 | |
| | Naraini | 10328.6 | |
| Bara banki | Haidargarh | 330.5 | 2833.8 |
| | Nawabganj | 8.4 | |
| | Ramsanehighat | 2494.9 | |
| Bijnor | Bijnor | 2.3 | 735.2 |
| | Najibabad | 732.9 | |
| Bulandshahr | Anupshahr | 113.0 | 797.1 |
| | Khurja | 6.4 | |
| | Sikandarabad | 677.7 | |
| Etawah | Auraiya | 15588.1 | 48983.3 |
| | Bharthana | 15589.0 | |
| | Bidhuna | 508.3 | |
| | Etawah | 17297.8 | |
| Faizabad | Bikapur | 187.4 | 187.4 |
| Farrukhabad | Chhibramau | 62.8 | 62.8 |
| Fatehpur | Bindki | 9306.3 | 14318.7 |
| | Fatehpur | 3143.4 | |
| | Khaga | 1868.9 | |
| Firozabad | Etmadpur | 3151.6 | 15677.2 |
| | Firozabad | 4910.9 | |
| | Shikohabad | 7614.8 | |
| Ghazipur | Saidpur | 96.5 | 96.5 |
| Hamirpur | Charkhari | 833.4 | 42569.1 |
| | Hamirpur | 7810.0 | |
| | Kulpahar | 3265.8 | |
| | Mahoba | 113.2 | |
| | Maudaha | 8765.2 | |
| | Rath | 21781.5 | |
| Hardoi | Sandila | 88.4 | 88.4 |

| | | | |
|---|---|---|---|
| Jalaun | Jalaun | 11358.0 | 52910.6 |
| | Kalpi | 22053.9 | |
| | Konch | 9167.4 | |
| | Orai | 10331.3 | |
| Jaunpur | Jaunpur | 334.4 | 1694.5 |
| | Kirakat | 1301.7 | |
| | Mariahu | 10.9 | |
| | Shahganj | 47.5 | |
| Jhansi | Garautha | 21905.4 | 29711.8 |
| | Jhansi | 236.6 | |
| | Mau ranipur | 1055.4 | |
| | Moth | 6514.4 | |
| Kanpur Dehat | Akbarpur | 2546.8 | 27887.5 |
| | Derapur | 4759.4 | |
| | Ghatampur | 5334.4 | |
| | Pukhrayan | 15246.9 | |
| Kanpur nagar | Kanpur | 773.2 | 773.2 |
| Lalitpur | Lalitpur | 188.1 | 188.1 |
| Lucknow | Mohanlalganj | 11.1 | 11.1 |
| Mainpuri | Bhongaon | 3.2 | 3.2 |
| Mathura | Chhata | 88.7 | 1696.5 |
| | Mat | 199.9 | |
| | Mathura | 792.6 | |
| | Sadabad | 615.2 | |
| Meerut | Mawana | 30.6 | 30.6 |
| Mirzapur | Chunar | 36.6 | 2181.2 |
| | Mirzapur | 2144.6 | |
| Muzaffarnagar | Jansath | 2308.0 | 2504.2 |
| | Muzaffarnagar | 196.2 | |
| Pratapgarh | Kunda | 864.5 | 3138.0 |
| | Patti | 381.1 | |
| | Pratapgarh | 1892.4 | |
| Rae bareli | Rae bareli | 168.2 | 376.9 |
| | Salon | 208.7 | |
| Sitapur | Misrikh | 196.8 | 273.2 |
| | Sidhauli | 76.4 | |
| Sonbhadra | Robertsganj | 41.7 | 41.7 |
| Sultanpur | Amethi | 461.7 | 3475.5 |
| | Kadipur | 1122.9 | |
| | Musafirkhana | 691.6 | |
| | Sultanpur | 1199.3 | |
| Varanasi | Chandauli | 24.4 | 353.1 |
| | Varanasi | 328.7 | |
| **Total** | | **340469.1** | **340469.1** |

**Fig. 1.1: Typical Yamuna ravines**

The ravines in India are not of recent origin but their formation is estimated to have momentum from the 11th century onwards. Due to the awareness of our Government to conserve and maximize the usefulness of natural gifts on sustained basis, the importance of soil and water conservation programme was conceived during the first five year plan (1951-56).

Immediately after independence, Govt. of India set up a Soil Conservation Board in 1953 with Union Agriculture Minister as its chairman. One of the main functions of the Board was to organize, coordinate and initiate research on soil and water conservation. In pursuance of this objective, in the First Five Year Plan, the Board established nine regional research cum-demonstration-cum-training centres to (i) carryout research on specific regional problems with a view to develop criteria for assessment of erosion hazards and establishing standards of efficiency for various soil and water conservation practices, (ii) carrying fundamental research on hydrological laws govern the watershed behaviour under different management practices and (iii) to serve as demonstration centers for developing proper know how of soil conservation measures.

Consequently, the Government of India established a network of Soil Conservation Research Demonstration and Training Centres in the Country. The Soil Conservation Research Demonstration and Training Centre, Agra, though established in 1955 as a sub-centre, became independent center in 1957 with the main objective of developing scientific and technical know how to deal with the problems of ravine lands on the bank of Yamuna river.

With the reorganization of Agricultural Research, Education and Development in the country, this research station was transferred to the administrative control of Indian Council of Agricultural Research in October, 1966. In order to give coordinated approach to the problem of soil and water conservation research, ICAR upgraded the Dehradun Centre to the status of a research institute in April, 1974 and re-designated it as the Central Soil and Water Conservation Research and Training Institute. Consequently, Agra Centre came under the administrative umbrella of the Institute with the present name "Central Soil and Water Conservation Research and Training Institute, Research Centre Agra.

In 2014 the Central Soil and Water Conservation Research and Training Institute was renamed as Indian Institute of Soil and Water Conservation and thus this centre is now known as Indian Institute of Soil and Water Conservation, Research Centre Agra.

## 1.3 Mandate of the Centre

The objectives of the center are summarized as follows

1. Appraisal of ravines problem and conservation of land and water resources under different land uses along the Yamuna river system.
2. Evaluation of hydrological behaviour and management of watersheds for reducing sediment discharge, improving water regime and productivity.
3. Evaluation and identification of suitable plant materials for different land uses in ravine lands according to land capability.
4. Development of suitable technology for increasing production from ravine lands.
5. Monitoring changes in environment as affected by land uses and management practices.
6. Development of techniques for stabilization of ravine lands.
7. Development of technique for (a) rainfed farming and (b) efficient water management in ravine lands.
8. Demonstration of the soil and water conservation practices for improving production on farmers land.

## 1.4 Research Farm

### Location

The Research Farm of 81.6 ha attached to this Centre is located at village Chhalesar situated on Agra-Kanpur National Highways at a distance of 14 km from Agra city. The Research Farm is representative of the typical features of ravine systems on the bank of Yamuna river and is an ideal site for research dealing with stabilization, reclamation and utilization of ravine lands.

The topography varies from moderate to steep slope. As per the analysis of ravine characteristics, it was observed that in general, the Yamuna ravines at Agra are very much similar to those of Mahi ravines at Vasad (Gujarat). Accordingly the classification of ravines at Agra was done following the classification system of Tejwani and Druvnarayana (1960) and given in Table 1.2. The topography and area under different classes of ravines at research station, Chhalesar are shown in Fig. 1.2.

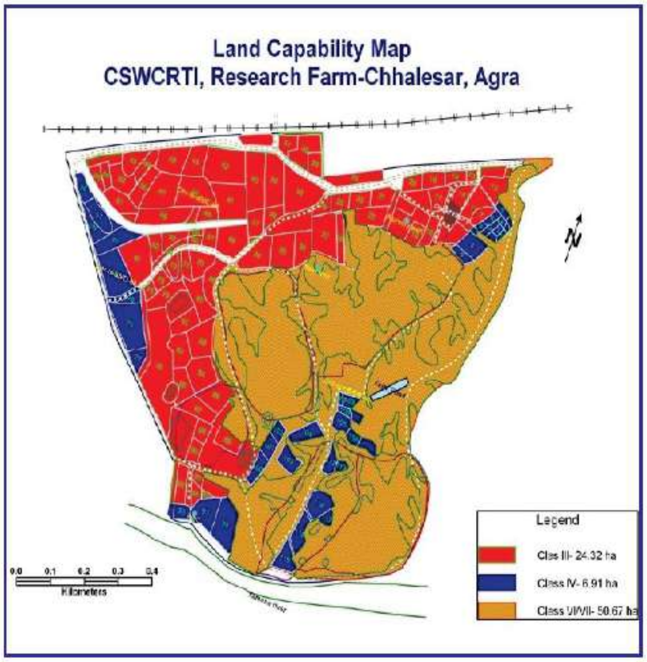



**Fig. 1.2: The research farm Chhalesar, a representative watershed of the Yamuna ravines.**

**Table 1.3: Classification of Yamuna ravines at Agra**

| Particulars of ravine | Description and symbol of the ravine | | | |
|---|---|---|---|---|
| | Very small (G1) | Small (G2) | Medium (G3) | Deep (G4) |
| Depth (m) | Upto 1 | 1 to 3 | 3 to 9 | >9 |
| Bed width (m) | 18 | 18 | 18 | Varies |
| Side slope (%) | Varies | Varies | Uniform slope between 8 to 15 | Slope more than 15. Mostly steep or even vertical with intricate and active breach ravines |

**Soil**

A soil profile (183 cm deep) data revealed that the soil is generally neutral (pH 7.5 to 8.5). The mechanical composition of soil indicates fine sand fraction accounting for 80% and clay + silt less than 20%. The availability of K is medium which has tendency to decrease with depth. The cation exchange capacity of the soil is considerably low owing mainly to low clay content. Ca is the most predominant cation (81 to 91% of CEC).

## 1.5 Extending Activities of the Centre

At the time of establishment of the Centre major emphasis was laid on the research and development towards tackling the problem of gullied and ravine land. Emphasis has been changed from treatment of individual land to management of entire watershed. At the same time state government carried out land reclamation works under various curative schemes. The Centre's activity has been extended in terms of regional centre for land and water resources management. Earlier in undivided Uttar Pradesh, Dehradun Institute was tackling soil and water conservation aspects of Uttarakhand hills and tarai region. Problems related with land and water management both arable and non-arable in Uttar Pradesh and the surrounding states *viz*. Bihar and Chhatisgarh are to be dealt by this Centre.

## 1.6 Brief introduction of Uttar Pradesh

### 1.6.1 Physiographic and demography

Spread over an area of 2, 40,928 $km^2$, Uttar Pradesh is the fourth largest state in the country. Uttar Pradesh is the most populous state of India. The total population of the state is 199581477 with a population density of 828 persons $km^{-2}$ (2011 census). The rural population of state is 1553170000 (77.7% of total population). The literacy rate of state is 69.72% with male literacy of 79.24% and female literacy of 59.26%, respectively. Uttar Pradesh is surrounded by Bihar and Jharkhand in the East, Madhya Pradesh in the South, Rajasthan, Delhi, Himachal Pradesh and Haryana in the West and Uttarakhand in the North and Nepal touches the Northern borders of Uttar Pradesh, it assumes strategic importance for Indian defence. It lies between latitude 24° to 31° North and longitude 77° to 84°East (Map 1.1).

The Great Indo-Gangatic plain covers almost 70% area of the state. Piedmonts and tarai are the most significant and complex part of the plains in the submontane belt running along the foot of Siwaliks from West to East. Alluvial plain is a riverine plain and is featureless. Its monotony is broken by red-stone hillocks of Aravalli hills on the Western part of Mathura district, and on the micro-level by the river bluffs, levees and dead arms of river channels. The Aravalli plain constitutes a discontinuous central hilly sub-surface tract. The southern highlands, plateaux and scarplands comprise Eastern Rajasthan uplands, Bundelkhand uplands, Vindhyan scarplands and Eastern Plateau. Eastern Rajasthan uplands are formed by the riverine action of the Banas and Mahi rivers. These originate from Aravalli ranges. Bundelkhand uplands and Vindhyan scarplands are located in the south of Indo-Gangetic plains; the region forms a part of the foreland of the deccan peninsula. The Western part of this tract is known as Bundelkhand and Eastern part forms natural division known as Vindhyas.

**Geology**

The Indo-Gangetic plains are characterized by an almost imperceptible change in elevation and uniform river-line material. The pre-tertiary river-borne material from the peninsula has later been supplemented rather more vigorously by the upper and post-tertiary Himalayan materials. The South-Western region of the state is largely composed of crystalline igneous and metamorphic rocks. The typical rock of this region is popularly termed as 'Bundelkhand gneiss'. In fact, granite and gneiss both are conspicuous in which former predominates. The Vindhyan scarplands in the South-Eastern part comprise Vindhyan and Kaimur sandstone, shales and mixed conglomerates. However, the plain within the region is formed by the alluvium deposited by the rivers of the central highlands.

## Climate

Climate in general is subtropical with mild winter and dry and hot summers with defined monsoon season. June to September is the rainy season during which 88% of the total annual rainfall is received. The average annual rainfall of Uttar Pradesh is 990 mm. The major portion of rainfall occurs during the month of June to September by South West monsoon. Northern districts adjacent to foothills of Himalayas constitute area of maximum rainfall (>1,400 mm), and the districts adjacent to East Rajasthan receive minimum rainfall (<600 mm). April, May and June are the summer months when hot winds (the 1oo) blow from the West. May is the hottest month with mean maximum temperature of 41°C in the Indo-Gangetic plains. However, Plateau region and elevated places, in general, record 2° to 5°C lower temperature. January is coldest with mean minimum temperature ranging from 6.5° to 10°C. The North-Western districts experience extreme cold during winters. Hailstorms in February and March are not uncommon.

**Table 1.4: Demography of Uttar Pradesh**

| Area | 2,40,928 Km$^2$ |
|---|---|
| Population (As per census 2011 Provisional data) | 19,95,81,477 |
| (a) Males (As per census 2011 ) | 10,45,96, 415 |
| b) Females (As per census 2011 ) | 94, 985,062 |
| Decennial Growth rate (2001-2011) | 20.09 % |
| Sex Ratio (As per census 2011 ) | 908 per thousand |
| Density (persons per sq. km.) (As per census 2011) | 828 per thousand |
| Total Literacy | 69.72 % |
| a) Male Literacy | 79.24 % |
| b) Female Literacy | 59.26 % |
| Districts | 75 |
| Cities & Towns | 915 |
| Development blocks | 821 |
| Members of Lok Sabha from U.P. | 80 |
| Members of Rajya Sabha from U.P. | 30 |
| Members of U.P. Legislative Assembly | 404 |
| Members of U.P. Legislative Council | 100 |
| Principal Crops | Paddy, Wheat, Barley, Millet, Maize, Urad (Black Gram), Green gram (Green Gram) Arhar etc. |
| Principal Fruits | Mango, Guava |
| Principal rivers | Ganga, Yamuna, Gomti, Ram Ganga, Ghagra, Betwa, Ken |

## Soils

The soils are developed from alluvium strata deposited by the two major rivers of the state *i.e.* the Ganga and the Yamuna and their tributaries. The soils are very deep, majority with sandy loam and loamy sand texture having low water holding capacity, responsive to inputs and highly productive. The soils are intensively cultivated for wheat, rice, sugarcane *etc.* However, problems of salinity/sodicity, flooding, water erosion are also confronted in this region. The soils of the state belong to 5 orders, 11 suborders, 21 great groups and 41 subgroups. Nearly 70% of area is under Inceptisols, followed by Entisols (19%), Alfisols (5%), Vertisols (2%) and Mollisols (<1%). The soils are highly susceptible to degradation by water erosion, covering 12,884 thousand ha (54% of total geographical area. Almost all districts are affected barring Gautam Buddhanagar and Bareilly. The highly affected districts are: Lakhimpur Kheri (468 thousand ha), Sondhara (437 thousand ha), Jhansi (426 thousand ha), Lalitpur (416 thousand ha), Baharaich (406 thousand ha) and Allahabad (381 thousand ha). Banda, Agra, Bijnor, Hamirpur, Mirzapur, Sultanpur and Saharanpur each has more than 300 thousand ha area affected by water erosion. Saline soils cover 22 thousand ha, affecting Balia (6 thousand ha), Unnao (5 thousand ha) and Lucknow (5 thousand ha), and about 1,320 thousand ha (about 6% of total geographical area is covered by sodic soils. Jaunpur (125 thousand ha), Mainpuri (120 thousand ha), Azamgarh (100 thousand ha), Pratapgarh (94 thousand ha) and Sultanpur (85 thousand ha) are affected by sodicity. Other districts where sodicity is encountered are Etah, Gazipur, Auraiya and Kannauj. Area affected due to mining accounts for 176 thousand ha. Districts having mining wastes are Lakhimpur Kheri, Sultanpur, Hardoi, Azamgarh and Etah.


**Map 1.1: Political map of Uttar Pradesh.**

### 1.6.2 Land use

Out of 24093000 ha area about 67.92% area (16417000 ha) is net sown in the state. Forests comprise 6.86% of the states area while 13.52% area was not available for cultivation (Table 1.5).

**Table 1.5: Land utilization in Uttar Pradesh (2013-2014)**

| Items | (000 ha) | (%) |
|---|---|---|
| Reported area for land utilization | 24093 | 100 |
| Forest | 1658 | 6.86 |
| Not available for land cultivation | 3268 | 13.52 |
| Permanent pastures and other grazing lands | 65 | 0.27 |
| Land under misc. tree crops and groves | 374 | 1.55 |
| Culturable waste land | 440 | 1.82 |
| Fallow lands other than current fallow | 540 | 2.23 |
| Current fallows | 1408 | 5.83 |
| Net area sown | 16417 | 67.92 |

*https://data.gov.in/resources/land-use-pattern-uttar-pradesh

### 1.6.3 Major crops, cropping pattern and productivity

The principal food crops of the state are wheat, rice, maize, gram and millets whereas sugarcane, groundnut, soybean, potato and mustard are important cash crops. Rice-wheat cropping pattern is more common in the Indo-Gangetic plain of state with rainfall >1000 mm (Table 1.6).

**Table1.6: Area under principal crops in Uttar Pradesh during 2015-16**

| Crop | Area (000 ha) | Production (000 tons) |
|---|---|---|
| Rice | 5867 | 12509 |
| Jowar | 155 | 26874 |
| Pearl millet | 975 | 105 |
| Maize | 679 | 1775 |
| Small millet *Kharif* | 8 | 1255 |
| Wheat | 9645 | 5 |
| Barley | 124 | 269 |
| Coarse cereals | 1941 | 3409 |
| Gram | 268 | 183 |
| Tur | 265 | 216 |
| Black gram | 614 | 253 |
| Green gram | 97 | 44 |
| Other pulses | 621 | 523 |
| Pulses | 1865 | 1219 |
| Groundnut | 97 | 65 |
| Sesamum | 546 | 165 |
| Nigerseed | - | - |
| Soyabean | 36 | 19 |
| Sunflower | 3 | 5 |
| Rape seed & mustered | 593 | 602 |
| Linseed | 17 | 8 |
| Sugarcane | 2169 | 145385 |

*State-*wise Fourth Advance Estimates during 2015-16* http://www.mospi.gov.in/statistical-year-book-india/2018/177

### 1.6.4 Problems of Soil Erosion

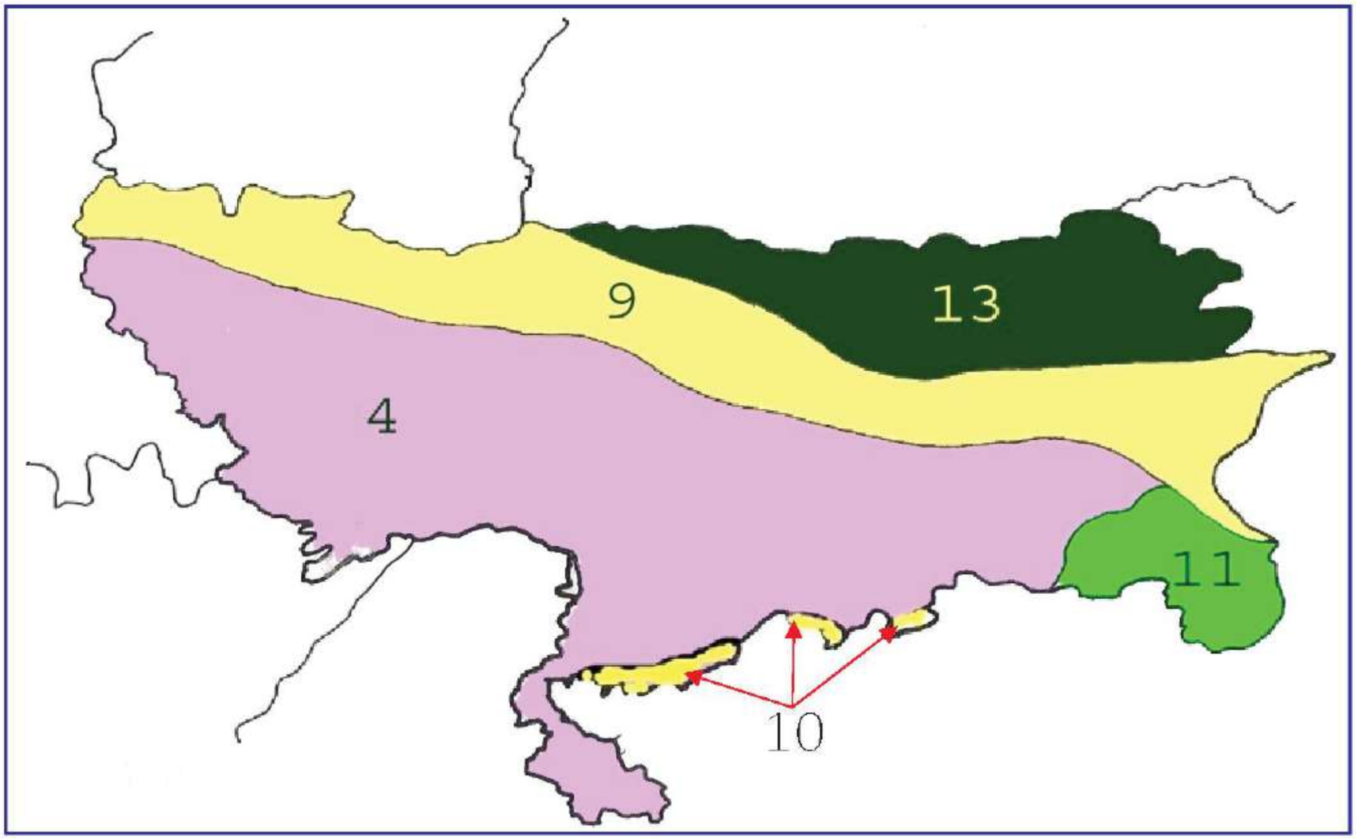
Presently in Uttar Pradesh 68.49 lakh ha arable and 19.94 ha non-arable land is adversely affected by soil erosion. In addition to that 12.30 lakh ha is ravinous, 11.5 lakh ha saline, 15 lakh ha diara, and 8.1 lakh has is waterlogged (Table 1.7). Ground water salinity is a severe problem in Agra and Mathura districts. In Uttar Pradesh, 130 soil conservation units had been operating in plains and 19 units in the hills. These soil conservation units are being managed by 19 divisional soil conservation units. These units are carrying out survey of problem area, planning, and execution. In addition to this, the programme of increasing agricultural productivity and cropping intensity is also an important activity of the soil conservation units. The state has been devided into 05 agro-eco zones (Map 1.2) namely zone 4, zone 9, zone 10, zone 11 and zone 13 out of total agro-ecological region of India. The typical features of land under each zone is described in Table 1.8.

**Table 1.7: Land degradation in Uttar Pradesh**

| Type of problem | Area (Lakh ha) | | Percentage |
|---|---|---|---|
| | India | U.P. | (%) |
| Eroded and degraded land | | | |
| a. Agricultural area | 998.76 | 68.41 | 6.85 |
| b. Non-agricultural area | 321.96 | 19.94 | 6.19 |
| Total | 1320.70 | 88.32 | 6.69 |
| Special problematic land | | | |
| •Ravines | 39.72 | 12.30 | 30.96 |
| •Alkaline and sandy land | 69.94 | 11.51 | 16.45 |
| •Diyara land | 24.80 | 15.00 | 60.48 |
| •Submerged land | 59.86 | 8.10 | 13.53 |

**Table 1.8: Agro-eco-regions of Uttar Pradesh and their characteristics**

| Agro-eco zone | Zone typical feature | Area (Mha) | % |
|---|---|---|---|
| Zone-4 | Northern plain hot semi-arid, alluvium derived soil | 11.75 | 53.3 |
| Zone-9 | Hot sub-humid dry with alluvial derived soil | 5.47 | 24.85 |
| Zone-10 | Central highland Bundelkhand region, hot sub-humid, black and red soil | 0.13 | 0.58 |
| Zone-11 | Eastern plateau, hot sub-humid, ecoregion with red and yellow soils | 1.13 | 5.11 |
| Zone-13 | Eastern plain, hot sub-humid, moist with alluvium derived soil | 3.55 | 16.12 |




**Map 1.2: Agro-ecological regions of Uttar-Pradesh**

# 2.0 APPRAISAL OF WATER EROSION PROBLEMS IN DIFFERENT AGRO-ECOLOGICAL REGIONS

## 2.1 Analysis of Rainfall Characteristics at Agra

Climate is the average weather conditions prevailing in an area over a prolonged period. A climatic zone (region) consists of places having similar climatic conditions. Climate determines the kinds of vegetation and animal population of a place and strongly influences the food habit and life style of people.

### 2.1.1 Probability analysis of annual maximum daily rainfall

Frequency analysis is an important aspect considered in designing hydraulic structure which are based on the occurrence of different hydrological events. Three most widely used probability distributions *i.e.* Gumbel, Lognormal and Log Pearson type III distribution were used to compute frequency distribution of rainfall for different return periods as an annual series. The maximum daily rainfall data for the period 1958-68 recorded at Chhalessar, Agra were used in the study (Table 2.1). The return periods were obtained by using Weibull formula which uses the maximum annual daily rainfall values arranged in descending order of magnitude.

**Table 2.1: Annual maximum daily rainfall in Agra**

| Year | Date | Maximum Rainfall (mm) | Year | Date | Maximum Rainfall (mm) |
|---|---|---|---|---|---|
| 1958 | 11/8 | 74.2 | 1969 | 13/8 | 73.6 |
| 1959 | 16/8 | 88.7 | 1970 | 13/9 | 87.5 |
| 1960 | 28/8 | 126.2 | 1971 | 5/9 | 67.0 |
| 1961 | 5/8 | 162.2 | 1972 | 14/9 | 78.7 |
| 1962 | 7/9 | 66.4 | 1973 | 12/9 | 61.3 |
| 1963 | 14/9 | 106.0 | 1974 | 25/7 | 66.0 |
| 1964 | 26/9 | 145.4 | 1975 | 5/8 | 49.8 |
| 1965 | 3/6 | 158.8 | 1976 | 14/7 | 104.8 |
| 1966 | 2/8 | 90.0 | 1977 | 11/8 | 90.0 |
| 1967 | 23/7 | 75.2 | 1978 | 28/7 | 91.0 |
| 1968 | 19/8 | 65.5 | 1979 | 24/7 | 34.5 |

It was observed that there was no significant difference among the three distributions. However, log-normal distribution was found to give the closest fit to the observed values. In all the three cases, there was increase in deviation of the computed values from the actual data as the probability of occurrence increased. The values of probable maximum daily rainfall for 5 years return periods were 115, 114 and 115 mm with Gumbel, Lognormal and Person Type III distribution, respectively.

For 20 years return period, the values of probable maximum daily rainfall were 151, 154 and 156 mm, respectively, for the three distributions (Sharda and Bhushan, 1985).

### 2.1.2 Frequency distribution of weekly rainfall

Analysis of the rainfall data from 1955 to 2002 at the research centre, Agra indicated that high rainfall (more than 20 mm) occurs from 2nd week of July (28th standard week) to 2nd week of August (33rd standard week). During 3rd and 4th week of August to 1st week of September (34th to 36th standard week), the probability of receiving 8.0 mm rainfall per week is 80%. Hence, crop variety and sowing time should be adjusted in such a way that it can avoid the moisture stress period that occur after 1st week of September.

### 2.1.3 Frequency distribution of monthly rainfall

Based on 44 years data (1959-02), expected monthly rainfall in Agra for various percentage chances was estimated (Table 2.2). The annual average rainfall of Agra was 721 mm. The rainfall during the month of July and August is almost assured at 80% chances. In the month of June, the expected rainfall is 14 mm at 70% chances. Expected rainfall at 50% probability is less than 7.9 mm month$^{-1}$ from October to May. During this period occurrence of drought is a common feature.

**Table 2.2: Monthly expected rainfall of Agra at different percent chances**

| Month | Probability (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 5 |
| | Monthly expected rainfall (mm) | | | | | | | | | |
| June | 5.0 | 9.0 | 14.0 | 21.0 | 30.9 | 42.0 | 60.0 | 100.0 | 180.0 | 310.0 |
| July | 75.0 | 100.0 | 120.0 | 150.0 | 170.0 | 190.0 | 230.0 | 280.0 | 380.0 | 480.0 |
| August | 90.0 | 120.0 | 150.0 | 180.0 | 209.6 | 240.0 | 290.0 | 350.0 | 460.0 | 600.0 |
| September | 15.0 | 26.0 | 40.0 | 55.0 | 75.1 | 100.0 | 150.0 | 220.0 | 370.0 | 600.0 |
| October | 0.7 | 1.70 | 3.0 | 5.0 | 7.9 | 12.0 | 20.0 | 40.0 | 90.0 | 180.0 |
| November | 0.36 | 0.50 | 0.95 | 1.4 | 1.8 | 2.4 | 3.4 | 5.0 | 9.0 | 14.0 |
| December | 0.5 | 0.85 | 1.3 | 1.8 | 2.5 | 3.3 | 4.8 | 7.0 | 13.0 | 20.0 |
| January | 0.8 | 1.6 | 2.5 | 3.4 | 5.1 | 7.0 | 10.0 | 16.0 | 30.0 | 50.0 |
| February | 0.7 | 1.3 | 2.0 | 3.0 | 4.5 | 6.0 | 9.0 | 14.0 | 27.0 | 45.0 |
| March | 0.5 | 0.9 | 1.5 | 2.4 | 3.3 | 4.8 | 7.0 | 11.0 | 21.0 | 38.0 |
| April | 0.45 | 0.8 | 1.3 | 1.9 | 2.7 | 3.7 | 5.4 | 8.5 | 16.0 | 26.0 |
| May | 0.9 | 1.7 | 2.8 | 4.2 | 6.2 | 8.4 | 13.0 | 21.0 | 40.0 | 70.0 |
| **Total** | **190.0** | **264** | **339** | **429** | **520** | **620** | **803** | **1073** | **1627** | **2433** |

### 2.1.4 Frequency distribution of seasonal and annual rainfall

Based on 44 years of data (1959-2002), expected annual and seasonal rainfall was computed. During July-August, the occurrence of rainfall is 220 mm at 80% chance which indicates that a crop having water requirement less than 220 mm has better chance of performing to its optimum level of productivity. The September rain is most important for both *kharif* and *rabi* crops. Probability of getting 55 mm rainfall in the month of September is only 60%.

It can be suggested that the crops must be sown in the first week of July. Any delay in sowing/planting operation after first week of July is most likely to expose the crops to the ill effects of drought.

## 2.2 Rainfall Erosivity Analysis

The ravines are degraded land due to excessive erosion of soil due to high intensity rainfall in the area during the monsoon period. The soils of the ravines are sandy loam and devoid of vegetation hence prone to water erosion caused by rainfall. Hence attempts were made to assess the erodibility of rainfall for estimation of soil loss.

### 2.2.1 Maximum rainfall intensities

The information on intensity-duration-frequency relationship is required for designing soil and water conservation structures (*e.g.* diversion drain, grade stabilization structure and ponds). Based on long-term (1962-02) rainfall data of research centre Agra, maximum rainfall intensities and frequency distribution for different duration have been computed and presented in Table 2.3 (Anonymous, 2002).

**Table 2.3: Rainfall intensities ($cmh^{-1}$) for different frequencies**

| Duration (minutes) | Return period (yrs) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 4 | 10 | 25 | 50 |
| | Frequency (%) | | | | | |
| | 100 | 50 | 25 | 10 | 4 | 2 |
| | Rainfall intensity ($cmh^{-1}$) | | | | | |
| 5 | 2.6 | 12.3 | 15.0 | 20.0 | 25.0 | 28.0 |
| 10 | 2.5 | 12.0 | 13.0 | 16.0 | 20.0 | 22.0 |
| 15 | 2.1 | 9.0 | 11.0 | 14.0 | 17.0 | 19.0 |
| 20 | 1.8 | 7.6 | 9.6 | 12.0 | 16.0 | 17.0 |
| 30 | 1.4 | 6.4 | 8.2 | 10.5 | 13.0 | 14.5 |
| 60 | 0.5 | 4.2 | 6.0 | 8.0 | 10.5 | 12.5 |

The general relation for rainfall intensity-duration return period at Agra is as follows:

$$I = \frac{KT^a}{(t+b)^d} = \frac{6.15T^{0.1751}}{(t+0.02)^{0.3235}}$$

Where,

I = Intensity ($cmhr^{-1}$),

K = Constant, t = Duration (hrs),

T = Return period (yrs),

a = Constant = 0.1751, b = Constant = 0.02,

d = Constant = 0.3235

### 2.2.2 Yearly rainfall forecasting based on antecedent rainfall

Long-term yearly rainfall data revealed a cyclic re-occurrence pattern. The rainfall data from 1963 to 2002 were utilized to predict the rainfall of a particular year based on the antecedent rainfall pattern. The cycle repeats in 3rd to 5th years period which were segregated from the data set. The highest, lowest and intermediate waves were drawn and the patterns were analysed. The cyclic tendency of variation of rainfall was derived by a decay function given by Linsley *et. al.* (1982).

$$I_t = I_0K^t$$

Where, $I_0$ is the initial value of the antecedent precipitation. $I_t$ is the rainfall 't' years after the antecedent rainfall and 'K' is recession factor normally ranging between 0.85 to 0.98. The rainfall for a particular year is equal to the previous years rainfall multiplied by the index 'K'. By using this index it is possible to predict rainfall of the coming year based on the rainfall value of the previous years. The rainfall data from 1963 to 1987 were utilized to derive the parameter values of the function. Using the K, the rainfall were predicted and compared with rainfall received for the validation period not included in determination of optimum value of K. All the predicted rainfall was less than observed ones. This implies that the predicted values are certain (Anonymous, 2002).

### 2.2.3 Rainfall erosivity factor ($EI_{30}$)

Erosion index values are used for several purposes like estimating soil loss and rational classification of rainstorm according to their soil eroding potential. Using the rainfall data (1962-80) recorded by an automatic self recording rain gauge, monthly and annual rain index for Agra were computed by Bhushan and Saxena (1984). The average annual rainfall erosion index ($EI_{30}$) for Agra was 416 metric units and varied from 218 to 751. Ninety five per cent of the $EI_{30}$ values were concentrated in 4 months (June to September). The $EI_{30}$ values estimated for Agra were 386, 540 and 640 for 2, 5 and 10 years frequency, respectively (Fig. 2.1).

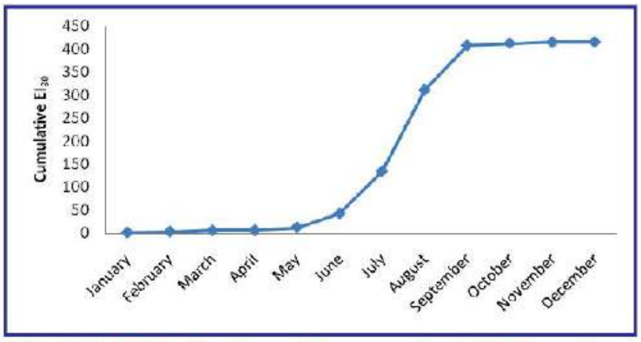



**Fig. 2.1: Distribution of accumulated $EI_{30}$ values**

## 2.3 Probability Analysis of Rainfall for Planning Water Harvesting and Irrigation in Semi Arid Regions

The present study has been carried out for analyzing the rainfall characteristics under changing climatic scenario for better planning of farming practices in this region. Daily rainfall data for the period of 46 years (from 1965-10) were collected from the meteorological observatory at Research Farm of Central Soil & Water Conservation Research & Training Institute, Research Centre, Chhalesar Agra, U. P. for the analysis. Results showed decreasing trend of rainfall and rainy days particularly during last 10 years. Occurrence of long dry spell of 10-15 continuous rainless days even within the monsoon season indicated the need for water harvesting and subsequent irrigation planning even within the rainy season for crop survival. Probability analysis showed that at 76% confidence level, occurrence of probable rainfall is 440.0 mm in *kharif*, 26.5 mm in *rabi*, 11.9 mm in summer and 508.0 mm per year compared to annual average rainfall of 685.02 mm. Similarly at 76% confidence level, occurrence of probable rainy days is 30 days per annum, 21 days in *kharif*, 2 days in *rabi* and 1 days in summer season as against 38 long term average rainy days. The probability of 440 mm rainfall with 21 rainy days in *kharif* season at 76% confidence level demonstrated selection of less water demanding crops such as green gram, pearl millet, and guar which are commonly grown crops of the area.

There is 85% probability that there would be no rain after 15$^{th}$ September so limited chances of receiving adequate amount of moisture at the root zone level for proper germination of *rabi* crops. In such case, pre sowing irrigation through water harvesting in ponds is very good strategy for proper germination of *rabi* crops like mustard, lintel and barley (Sharma and Dubey, 2013).

## 2.4 Soil Erodibility Analysis

Based on soil loss data from cultivated fallow plots (1983-95), the value of 'K' was computed (Anonymous, 1996). During the study period, 'K' value ranged from 0.133 to 0.277 (Table 2.4). Based on the observations of 10 years, the mean value of soil erodibility was found 0.215 for the soils of Agra region. The variability in soil erodibility could be attributed to $EI_{30}$ value, as it was influencing the soil loss during the period of investigation.

## 2.5 Estimation of Evapotranspiration (et) by Using Climatic Data

Using climatic data, evapotranspiration was estimated by five different methods. *i.e.* (i) Radiation method (ii) Blaney Criddle approach (iii) Thornthwaite method (iv) Modified Penman's method and (v) Pan evaporation method. The climatic data from 1962 to 1979 recorded at research farm, Chhalesar were utilized in the study.

The annual evapotranspiration estimated by the above five methods worked out to be 1913, 1559, 1581, 2387 and 2228 mm, respectively.

**Table 2.4: Soil erodibility factor 'K' at Agra**

| Year | $EI_{30}$ | Soil loss ($t\ ha^{-1}$) | Adj. Soil loss | 'K' value |
|---|---|---|---|---|
| 1983 | 84 | 4.85 | 17.32 | 0.206 |
| 1984 | 454 | 17.37 | 62.03 | 0.137 |
| 1985 | 650 | 50.46 | 180.20 | 0.277 |
| 1986 | 203 | 21.60 | 77.13 | 0.379 |
| 1988 | 221 | 15.80 | 56.42 | 0.255 |
| 1990 | 570 | 13.80 | 75.83 | 0.133 |
| 1991 | 76 | 3.76 | 20.66 | 0.272 |
| 1992 | 417 | 15.18 | 83.25 | 0.199 |
| 1994 | 295 | 7.64 | 41.98 | 0.142 |
| 1995 | 330 | 9.30 | 51.10 | 0.154 |
| **Mean 'K'** | | | | **0.215** |

The minimum ET (1559 mm $yr^{-1}$) was obtained by Blaney and Criddly method which was probably due to unavailability of sufficient temperature gradient. ET obtained by Thornthwaite method abruptly increased during April to June. It was because this method mainly uses temperature, which is high during April to June. The values of ET obtained with modified Penman's method during January to March and from July to December were close to that obtained with Blaney Criddle or Radiation method.

From March to June, its values were close to Thornthwaite or Pan Evaporation methods. As the modified Penman's method takes into account both the energy balance and aerodynamic aspects, it appeared that the ET estimated by the modified Penman's method (2387 mm $yr^{-1}$) was more rational and realistic for the semi-arid region of Agra and comparable to open pan evaporation (2228 mm $yr^{-1}$) (Sharda and Bhushan, 1984).

## 2.6 Cover and Crop Management Factor ('C' Factor)

Determination of soil loss by using USLE equation requires crop cover value. Based on soil loss data from cultivated fallow plots, the value of 'C' was estimated for major crops of Agra region and presented in Table 2.5 (Anonymous, 1996). Among the different vegetation cover, 'C' value was found lowest for *Cenchrus ciliaris* grass (0.08) and maximum for castor (0.45).

**Table 2.5: Crop management factor (C)**

| Crops | 'C' value of USLE |
|---|---|
| *Cenchrus ciliaris* | 0.08 |
| Green gram | 0.29 |
| Cowpea | 0.20 |
| Sesamum | 0.33 |
| Clusterbean | 0.37 |
| Pearlmillet | 0.44 |
| Castor | 0.45 |

The lower the value of 'C' factor, lower will be the soil loss. Therefore, growing of pulse crops like green gram and cowpea would reduce soil loss in comparison to wide spaced crops like castor and pearl millet. Among major *kharif* crops, 'C' value ranged from 0.20 (cowpea) to 0.45 (castor).

## 2.7 Drought Analysis

A sustained period without significant rainfall is called drought. Droughts have been defined differently by different workers. Agnihotri and Gupte (1971) considered the rainfall below $\sigma - x$ as a drought year where $x$ is the mean annual rainfall and $\sigma$ is the standard deviation. Using the rainfall data from 1934 to 1968, Agnihotri and Gupte (1971) suggested annual rainfall below 478.8 mm might be considered as a drought year. The probability of getting this amount of rainfall was 16%. They predicted that one out of every six year would be a drought year. Prajapati *et. al.* (1977) considered a year to be drought year, if the rainfall is less than 50% than the mean annual rainfall. The probability of deficient rainfall (33-60%) and coefficient of variability of rainfall (67-122%) are lowest occurrence chances of rainfall (67-100%) are highest during 4th week of June to 2nd week of September, making it the most dependable period for raising rainfed crops. Normally, a period of 11.5 weeks or 54.8% of the wet season is eclipsed by droughts. Three out of four years suffer from early droughts, but only one from serious drought. There are two to five mid season drought involving 4-11 weeks which prove to be highly detrimental to the crops. The late droughts occur in 80% cases, half of them being of 4 to 5 weeks duration resulting into failure of otherwise promising *kharif* crops.

## 2.8 Runoff, Soil Loss and Splash Erosion under Different Crops

A runoff plot based study was initiated in 1989 on 2% slope to find out run off and soil loss under different crops commonly cultivated in Agra region. A commonly found grass species *Cenchrus ciliaris* was also kept for comparison of results (Table 2.6).

**Table 2.6: Average runoff, soil loss and splash erosion on 2% slope (average of 4 yrs)**

| Landuse | Runoff (%) | Soil loss (t ha$^{-1}$) | Splash (g) |
|---|---|---|---|
| *Cenchrus ciliaris* | 9.6 | 0.80 | 12.00 |
| Green gram | 23.8 | 2.92 | 19.75 |
| Cowpea | 25.4 | 2.10 | 18.89 |
| Sesamum | 24.2 | 3.44 | 22.86 |
| Clusterbean | 24.8 | 3.57 | 27.23 |
| Pearl millet | 24.8 | 4.24 | 22.94 |
| Castor | 25.3 | 5.27 | 27.48 |

Inter-relationship between crop canopy and splash erosion and soil loss was also investigated (Narayan and Bhushan, 1992). It was observed that canopy development was much faster in cowpea and green gram, attaining more than 50% of the canopy cover in 30 days. Runoff, soil loss and splash had inverse linear relationship with canopy. A multiple linear regression equation was fitted for predicting soil loss based on canopy, rainfall amount and intensity.

$$Y = -53.0 - 5.58X_1 + 11.21X_2 + 5.372X_3$$

Where, Y = soil loss (t ha$^{-1}$), $X_1$ = crop canopy (%), $X_2$ = Rainfall (mm) and $X_3$ = Rainfall intensity for 30 minute duration (mm h$^{-1}$).

### 2.8.1 Runoff and soil loss under inter cropping on 2% slope

A runoff plot study was initiated in 1981 to evaluate different cropping systems for run off and soil loss on standard size runoff plots having 2% slope. Average of three years results indicated that maximum runoff 258 mm *i.e.* 50% of rainfall and soil loss (15.67 t ha$^{-1}$) occurred from cultivated fallow plot and minimum runoff (70 mm *i.e.* 15%) and soil loss (1.81 t ha$^{-1}$) was recorded from permanent vegetative cover of *Cenchrus ciliaris* grass plot. Among the various cropping system, the soil loss was maximum (6.34 t ha$^{-1}$) from pure crop of pearl millet which was reduced to 4 t ha$^{-1}$ when cowpea/green gram was grown as intercrop (Bhushan and Om Prakash, 1983).

## 2.9 Gully Erosion

Gullies are the extreme form of soil erosion and network of gullies deeper than 0.3 m are known as ravines. Once the process of gully formation is initiated, it rapidly leads to extreme terrain formation.

Apart from land and soil quality degradation in gullied and inter-gully areas and declined productivity of food, fodder, fuel etc these areas becomes major sediment producing sites and increase the sedimentation in rivers. Hence, the extension of these gullies should be checked and gullies may be treated with suitable conservation measures for their reclamation and put them under productive use.

### 2.9.1 Vertical falls and slope distribution in rill formation

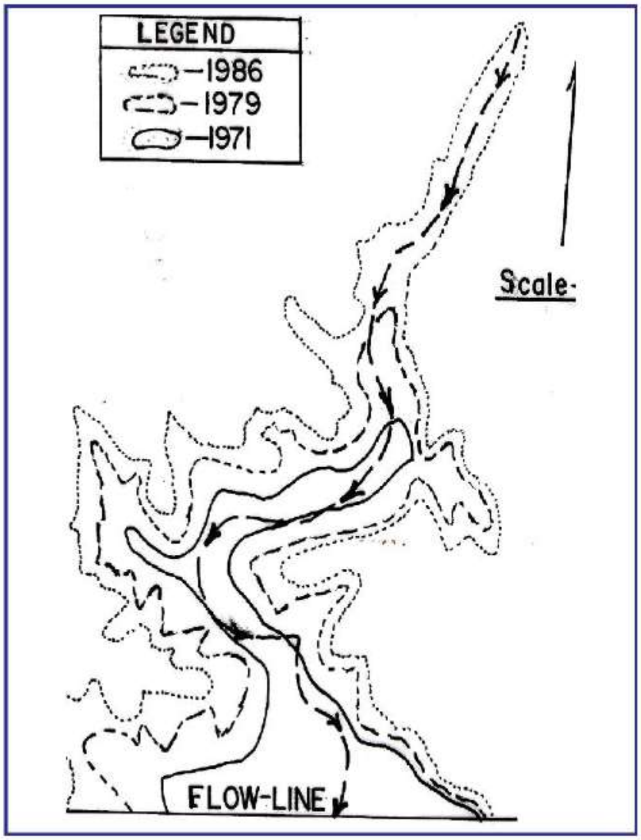
In gullied watershed, land development is a major programme of work to remove limitation of slope and erosion. At such sites, the process of erosion control is important for implementation of land development work.

With a view to evaluate the distribution of vertical fall as per Young's theory of minimum energy expenditure, some representative profiles were studied for elevation, length and slope. The rills were second order channels in all the cases. Leaving aside some cases, vertical fall in $N_1$ and $N_2$ order rills acquired nearly unity *i.e.* equally distributed within one season. It means erosion was rapid and tried to reach the equilibrium condition.

The slope in the $N_1$ rill was about 3-4 fold steeper than that in $N_2$ rills. The slope in $N_2$ rills was 2-5%, whereas general slope of the profile was 3-6%.

### 2.9.2 Rate of ravine extension

A small gully with gullied area of 0.21 ha and catchment of 42 ha open to biotic interference was selected in village Umretha, Agra to monitor the extension of gully (Map 2.1). Survey was conducted every year after the monsoon season.




**Map 2.1: Rate of extension of ravines at village Umretha**

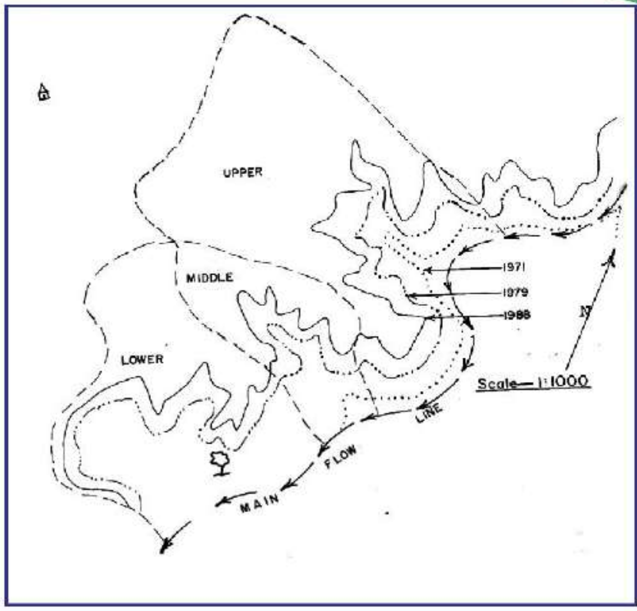
In 16 years, the gullied land increased by 295% (Table 2.7). Similarly, length and width also became double in 15 years. The gully bed slope, which was 10% in 1971 has flattened to 4.4% in the year 1986 (Tiwari *et. al.*, 1986).

**Table 2.7: Characteristics of the ravine area in Agra**

| Year | Gullied area (ha) | Length (m) | Average width (m) | Perimeter (m) | Flow channel bed slope (%) | Increase (%) |
|---|---|---|---|---|---|---|
| 1971 | 0.21 | 137 | 22 | 446 | 10.1 | - |
| 1979 | 0.49 | 163 | 43 | 760 | 9.5 | 133 |
| 1986 | 0.83 | 260 | 53 | 940 | 4.4 | 295 |

### 2.9.3 Dynamics of ravine extension in relation to location of sub-catchment

In order to evaluate the dynamics of ravine extension in relation to the micro-catchment size, three sub-catchments were delineated in the same system under study at Umretha (Yadav *et. al.*, 1987). The progressive extension revealed that ravine extension continues and land is engulfed into it (Map 2.2). In relation to the sub-catchment, the gully erosion is most active in the upper catchment followed by the middle sub-catchment. In the lower catchment, more than half area has gone into gully. In the Chambal ravine, a sandy layer is found in the substrata through which water flows. Movement of sand along with water leads to formation a cavity. Under continuous rain, the overhanging cliffs collapse, turning the gullies into ravines (Table 2.8).




**Map 2.2: Ravine in sub catchment at village Umretha**

**Table 2.8: Dynamics of ravine in relation to catchment and relative location**

| Sub-catchment | Area (ha) | Area under ravine (% of sub-catchment area) | | | |
|---|---|---|---|---|---|
| | | 1971 | 1979 | 1988 | 1997 |
| Upper | 0.655 | 7 | 15 | 28 | 35 |
| Middle | 0.20 | - | 20 | 40 | 43 |
| Lower | 0.475 | - | 38 | 53 | 53 |

### 2.9.4 Gully growth in relation to rainfall factors

Factors of gully growth measured at Umretha were subjected to regression analysis with various rainfall factors (Anonymous, 1996). The length of gully extension was controlled by total rainfall plus total of yearly highest daily rainfall since observation. The width of gully was dependent on annual rainfall plus highest of year plus sum of highest continuous rainfall since observation. Other factors *viz.* area of gully extension, perimeter of extension and decrease in gully slope are dependent on R, Phd, Phc and Phc3. The resulting regression equations are:

Le = 144.3 - 0.033 R + 0.295 Phd ..................(1)

($r^2$=0.99)

We = 25 - 0.033R - 0.018 Phd + 0.117 Phc... .....(2)

($r^2$=0.97)

Ae = 0.222 - 0.0003R + 0.00002 Phd + 1.907 Phc + 0.000284 Phc ..............................................(3)

($r^2$=0.99)

Pe = 493.4 - 0.513R + 0.71 Phd + 1.907 Phc + 0.181 Phc3.................................................(4)

($r^2$=0.99)

Sd = 11.96 - 0.0034R + 0.0236 Phd + 0.02 Phc + 0.01 Phc3 ..................................................(5)

($r^2$=0.97)

Where, Le is length of gully extension (m), We is width of gully extension (m), Ae is area of gully extension (ha), Pe is perimeter of gully extension (m) and Sd is decrease in gully bed (%), R is accumulated rainfall since the beginning (mm), Phd is accumulated highest daily rainfall of the years since observation (mm), Phc is accumulated highest continuous rain spell of the year since beginning (mm) and Phc3 is accumulated three maximum continuous rain spells since observation (mm) (Table 2.9).

**Table 2.9: Successive dependence ($r^2$) of gully growth factors on inclusion of various rainfall factors in the regression**

| Gully growth factors | Due to rainfall alone | Increase due to addition of factors | | |
|---|---|---|---|---|
| | | Phd | Phc | Phc3 |
| Le (m) | 0.786 | 0.21 | 0.00 | 0.00 |
| We (m) | 0.784 | 0.09 | 0.09 | 0.02 |
| Ae (ha) | 0.942 | 0.03 | 0.01 | 0.01 |
| Pe (m) | 0.905 | 0.01 | 0.08 | 0.01 |
| Sd (%) | 0.746 | 0.00 | 0.08 | 0.14 |

## 2.10 Priority Rating of Gully Watershed for Treatment

A method was developed to enable extraction of erosion severity of actual drainage network (on the ground) from the toposheet based information so as to save time, labour and cost. An index designated as Erosion Severity Index (ESI), which is defined as product of stream number and stream length (m) in a watershed, is used to describe erosion severity. Using the toposheet and actual data (on ground), a regression equation was developed.

$$ESIg = 3.34\, ESI_{tp}^{1.545} \quad (r^2 = 0.98)$$

Where, $ESI_g$ is erosion severity index on the ground, and $ESI_{tp}$ is that for topo-sheet.

## 2.11 Process Based Model for Gully Head Retreat

In the erosion susceptible land parcels, both the processes of upland phase covering large area and process of gully phase concentrated in a localized area occur simultaneously. With time, gully erosion under influence of climate, soil, land use and biotic factors becomes major source of sediment production and engulfs agricultural lands in the alluvial soil region.

The process based model using information on quasi-steady flow that resulted in diffusion type equation and its exact solution was found to be a suitable tool for prediction of gully head cut profiles. The model requires flow characteristics, soil factors and physical site details for assessment of degradation coefficient for the site undergoing gully erosion. Such factors can be acquired by laboratory measurements and/or by interpolation. The model provides logical basis to design gully control structures for protection of ravine lands.

Development of gully cut profile with distance and time is given by

$$Y_{(x,t)} = Y_0 erf\left(\frac{x}{2\sqrt{Kt}}\right) + Y_{(x,o)} - Y_0$$

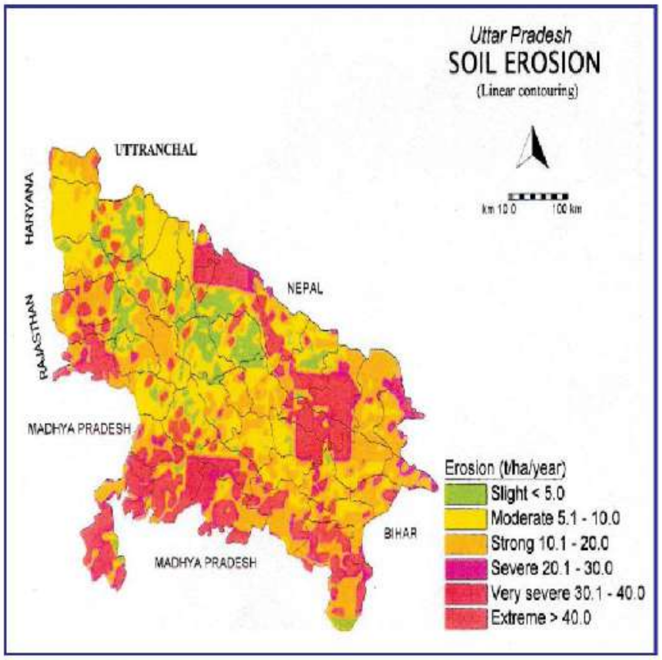
The land loss in due course of degradation can be expressed as:

$$A_n = [X_{ls}]2\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_0 - Z_0}{\tan 45 + \frac{\Phi_i}{2} - \tan i_b}\right) + H_s\{\cot(i_s) - \cot(i_b)\} + H_s\{\cot(i_{ss}) - H\cot(i_b)\} + \ldots\right]$$

where, n is the number of sub sections where Y(x,t)Hc. Thus, gully head cut, degradation of gully bed, gully cross section and associated land loss can be computed by the above mentioned equations. Periphery of such land loss can be drawn to determine area of land loss due to gully erosion (Yadav and Bhushan., 1999).

## 2.12 Soil Erosion Map of Uttar Pradesh

Soil erosion rates were computed by universal soil loss equation. The soil data in 10 X 10 km grid were collected by NBSSLUP regional centre, Delhi and made available to the center for carrying out the soil loss estimation. Utilizing the data, soil erosion map of Uttar Pradesh was prepared in collaboration with NBSSLUP, Nagpur and depicted below (Map 2.3).




**Map 2.3: Soil erosion map of Uttar Pradesh**

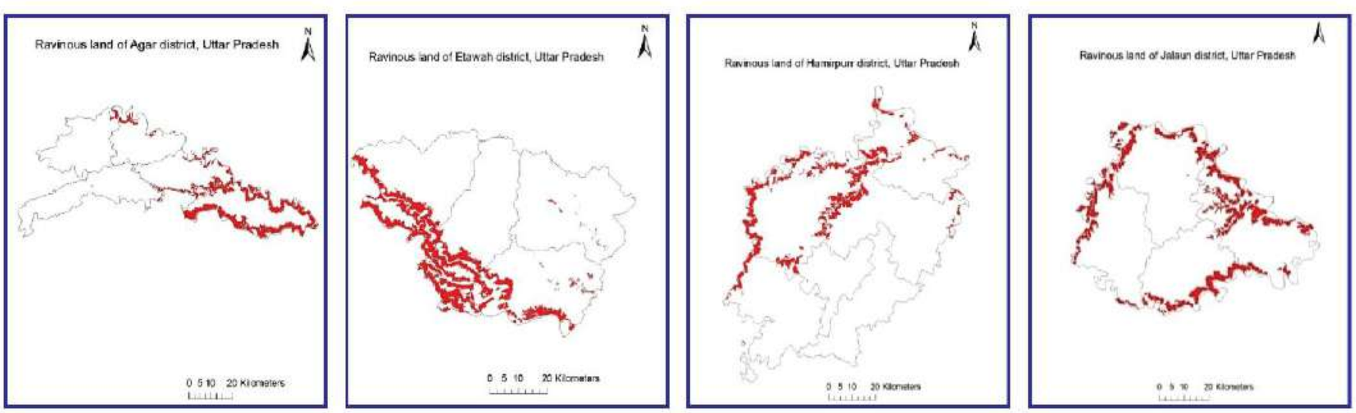
## 2.13 Delineation and Characterization of Yamuna Ravines

Representative bench mark sites in Yamuna regions (Manikpura, Pinahat, Renkala, Pachnada) were identified by using freely available resources. A ground survey of representative identified sites in Yamuna region has been conducted for detailed study regarding geographical information of area of interest for bench mark site selection.

Here site selection means the potential areas of Yamuna ravine in order to collect secondary data and acquiring satellite data. An approximate potential boundary can be made using Google Earth/Google Earth Pro + Ground Truth Verification or available maps. Initial study as like ravines status and some change detection of Yamuna ravines have been conducted by using open series map (OSM) and freely available resources. As per initial study by using freely available resources, ravines are concentrated in southern parts of the state and majority of ravines are along Yamuna river systems.

At tehsil/block-wise ravine area was delineated to the possible extent with the help of freely available resources and presented as a bifurcated total ravine area of the selected districts. Jalaun (52910 ha), Etawah (48983 ha), Hamirpur (42569 ha), Agra (37075 ha), Jhanshi and Kanpur are major ravine districts in UP. Total ravine area in UP is estimated to be 3.404 lakhs ha. The useful data, maps and information have been generated (Map 2.4).

The procured data were processed with different proposed and established methodologies and methodology is finalized for processing of remote sensing data. In present study the final methodology is adopted for comparison of different method on bench mark sites for finalization of appropriate method applicable for large area and change detection study over a period (Meena, *et. al.* 2016).




**Map 2.4: Delineation of ravines in major ravine districts of Uttar Pradesh**

# 3.0 HYDROLOGICAL BEHAVIOUR OF WATERSHEDS FOR CONSERVATION PLANNING

## 3.1 Hydrological Behaviour of Different Land Uses in Ravine Watersheds

The entire research farm (81 ha), a representative site in the gullied region, was subdivided into small watersheds. These watersheds were gauged for runoff and soil loss with suitable gauging devices. The watersheds were under different land uses. Some were unit source watershed, whereas the others were with mixed land uses. Hydrological behaviour of these watersheds was analyzed and some results are summarized below (Table 3.1).

**Table 3.1: Watershed under different land-uses in Research Farm Chhalesar, Agra**

| Watershed name | Gauging device | Area (ha) | Land use | Hydrological behavior of watershed |
|---|---|---|---|---|
| HF1 | 0.45 m H-flume | 0.206 | *Cenchrus cilairis* | Runoff (8.89%), Soil loss (2.69 t $ha^{-1}$) |
| HF2 | 0.45 m H-flume | 0.29 | *Dalbergia sissoo* | Runoff (4.72%), Soil loss (1.33 t $ha^{-1}$) |
| HF3 | 0.45 m H-flume | 0.197 | Grass land | Runoff (4.91%), Soil loss (1.0 t $ha^{-1}$) |
| HF4 | 0.45 m H-flume | 0.155 | *Cenchrus cilairis* | Runoff (6.99%), Soil loss (1.53 t $ha^{-1}$) |
| W1A | 2:1 triangular masonry weir | 6.8 | Grassland 56% with gully plugs in bottom, 44% with *Acacia nilotica* | Runoff (7.65%), Soil loss (0.17 t $ha^{-1}$) |
| W1B | 2:1 triangular masonry weir | 5.16 | 33.4 % agriculture on leveled and bunded terraces + 66.6% forest plantation and gully plugs in bottom. | Runoff (2.47%), Soil loss (1.21 t $ha^{-1}$) |
| W1C | 2:1 triangular masonry weir | 14.74 | 46% agriculture on leveled and bunded terraces + 53% forest plantation and gully plugs in bottom | Runoff (12.71%), Soil loss (4.41 t $ha^{-1}$) |
| W1D | 2:1 triangular masonry weir | 7.3 | 100% grassland and trees and gully plug in gully bed utilized under goat grazing | Runoff (8.5%), Soil loss (2.4 t $ha^{-1}$) |
| W1E | 2:1 triangular masonry weir | 3.1 | Forest plantation 84% agriculture in gully bed 16% | Runoff (23.5%), Soil loss (Traces) |
| W2A | 3:1 triangular masonry weir | 8.4 | 90% agriculture on leveled to terraces, 10% under gassed and checkdam | Runoff (4.08%), Soil loss (1.10 t $ha^{-1}$) |
| W2B | 3:1 triangular masonry weir | 9.6 | 100% agriculture on level and bunded terraces | Runoff (6.28%), Soil loss (1.26 t/ha) |
| W2C | 3:1 triangular masonry weir | 22.3 | 18% denuded and overgrazed land, 82% field bunding of agricultural land by soil cons. Dept. in 1966. | Runoff (2.14%), Soil loss (0.55 t $ha^{-1}$) |
| W2D | 3:1 triangular masonry weir | 61.3 | 30% agriculture land, 63% *Acacia nilotica* and 7% denuded and overgrazed. | Runoff (3.09%), Soil loss (0.66 t $ha^{-1}$) |
| W3A | 3:1 triangular masonry weir | 56.4 | 85.6% agriculture land with field bunds and outlets, 4.4% overgrazed denuded lands. | Runoff (5.4%), Soil loss (Traces) |

The study revealed that runoff and soil loss were high (10-14% of rainfall and 2 to 4 t $ha^{-1}$) prior to imposition of conservation measures like bench terracing and contour bunding. Among $W_2$ watershed series, the highest runoff (6.28%) and soil loss (1.26 t $ha^{-1}$) was observed from the watershed ($W_{2B}$) with 100% agriculture on level terraced land compared with other land uses in $W_{2A}$, $W_{2C}$ and $W_{2D}$ watersheds in agriculture land. Higher runoff trend was also observed in overgrazed wasteland compared to grassland and bunded terraced lands. Though $W_{1E}$, which was having 84% plantation, produced maximum runoff (23.5%) compared to $W_{1A}$, $W_{1B}$ and $W_{1D}$ watersheds of steep slope of ravines and humps. However, soil loss was minimum in $W_{1A}$ where grass land coverage was 56%.

The results established that because of trees the infiltration rate becomes high and it reduces overland flow in terms of runoff. Grassess (*Cenchrus cilairis)* was tried in watershed $H_{F1}$ to $H_{F4}$ to control soil erosion and it was found soil loss was reduced to 1.0 t/ha in ravine lands.

Enforcement of conservation measures in various land use patterns has effectively reduced runoff and soil loss (runoff 2-5% of rainfall and soil loss from 0.9 to 1.5 t $ha^{-1}$). In addition to land use, slope of the ravines also greatly influenced the runoff and soil loss (Anonymous, 1962-88).

### 3.1.1 Rainfall runoff relationship of ravine watersheds

Two regression equations *viz.* straight line and exponential functions were evaluated to ascertain the applicability of mathematical methods for runoff prediction. Higher correlation coefficient with the straight-line equation than that with exponential function proved that straight-line function is better applicable than the power function.

The straight line method also predicted annual rainfall with high correlation coefficient (Anonymous, 1988).

$$R = 0.418X - 131, \qquad r = 0.949$$

Where R = runoff (mm) and X = annual rainfall (mm)

### 3.1.2 Rainfall-runoff relationships of developed and undeveloped gullied catchments under agriculture

Hydrological behavior of gullied catchment developed by terracing, field bunding with outlet and checkdam, constructed in grassed waterways was compared with unterraced, partly forested and overgrazed catchments. Runoff was gauged soon after the land development by 'V' notch weirs equipped with automatic stage level recorders. Terraced catchment produced runoff <5% of rainfall whereas, undeveloped and overgrazed catchments produced runoff that was 10-15% of rainfall. The peak discharge rate per unit area for terraced catchment was almost half the runoff rate from unmanaged and overgrazed catchment when rainfall was only 20 mm. With high intensity rain (80 mm), the peak runoff from all the catchment was similar. Effect of rainfall intensity pattern and antecedent moisture on runoff rate was isolated. Slope showed more consistent influence on runoff than total fall in elevation of catchments. Intensity of rainfall showed increasing influence on unmanaged catchment with the increasing size. The influence was magnified with intermediate type storm more than the advance type. It is recommended that peak design discharge should be taken as one-half the peak discharge calculated for design purposes (Yadav *et. al.*, 1991).

### 3.1.3 Applicability of cover complex method for prediction of runoff from small ravine catchments

The runoff from two ravine watersheds was computed by cover complex method of USDA (Soil conservation Service) which takes account of soil type, land cover and land uses, land treatments, management practices and antecedent moisture condition. The computed runoff was compared with observed runoff from the watersheds. The runoff was generally lower than observed runoff. The difference between computed and observed daily runoff reduced with the increase in the daily rainfall. The major percentage of rain-spells occur either with antecedent moisture condition, AMC I or with AMC III and very little with AMC II condition.

The ratio of observed to predicted runoff was 62:1 for $HF_1$ (nearly square) watershed and 44:1 for $HF_2$ (nearly rectangular) watershed. The ratio of observed to predicted runoff dropped down to considerably low magnitude with the increase in the wetness of watersheds (Anonymous, 1988).

## 3.2 Hydrological Behavior of Untreated Gully Watershed

A study on runoff and soil loss was carried out in a 251 ha untreated watershed having agriculture, grazing and forest land uses at Nandlalpur. The watershed was surveyed for drainage links and length and elevation of stream bed. In the watershed, vertical fall was 14 m and gully was density 23 m $ha^{-1}$. Forty per cent of the area was severely eroded under ravines. The watershed was subdivided into finite elements grid based on hydrologic homogeneity and hydraulic continuity. It was comprised of 7 channel nodes, 6 channel elements and 18 overland flow elements on the left as well as right side of main channel. The stage discharge rating curves were established by slope area method. The gauging sites were provided with staff gauge 3 m upstream of the section. The depth of flow was read manually at half an hour interval at the gauges simultaneously. Rainfall was measured by a self-recording automatic rain gauge installed in the watershed. Results showed that at channel node 4, peak rate of runoff discharge and peak rate of sediment discharge was 1.0 cumec and 2.8 kg $s^{-1}$, respectively whereas it increased to 1.3 cumec and 6 kg $s^{-1}$, respectively at channel node 7 of Nandalalpur watershed. Similarly at channel node 4, runoff discharge and sediment discharge was 0.40 cumec and 0.97 kg $s^{-1}$, respectively where as it increased to 0.43 cumec and 1.82 kg $s^{-1}$, respectively at channel node 7 of Nandalalpur watershed (Yadav and Bhushan, 1998).

### 3.2.1 Impact of different land use practices on hydrological behavior of a watershed in semi arid region

Hydrological behavior of different land uses was studied in a small watershed of 1.2 ha having four land uses such as agro-forestry, agri-horti, horti and agriculture at Garhi Udairaj village, Fatehabad, Agra, Uttar Pradesh. The area comes under semiarid region and average annual rainfall of the area is about 650 mm. The number of rainy days varied from 30 to 35 only. Data on rainfall, runoff and soil loss were collected using rain gauge and multi-slot gauging devices to generate hydrological information on hydrological behaviour and production potential from above four land use systems. Results showed that on an average area received 877.30 mm rainfall during monsoon season in 36 rainfall events. High rainfall event of 133.8 mm occurred in the month of July, 2016 which produced maximum runoff and soil loss. Runoff received from different land use systems such as agri-horti/forestry, horti., agriculture were 84.30 mm (9.60 %), 68.62 mm (7.82%) and 97.01 mm (11.05%), respectively. Similarly, soil loss occurred were 1.14 t $ha^{-1}$, 0.96 t $ha^{-1}$ and 1.66 t $ha^{-1}$, respectively from land use systems such as agri-horti/forestry, Horti. and agri-agri. It has been found that there was no difference in runoff and soil loss between agri-horti and agro-forestry blocks having bael and sagon plantations, respectively. Moreover, runoff and soil loss was observed to be minimum in horti. Block followed by agri-horti./forestry and agri-agri. Sagon (*Tectona grandis*) and bael (*Aegle marmelos*) were planted under agri-forestry and agri-horti blocks respectively. The effect of trees on runoff and soil loss has been clearly found in different treatments. Among all four land uses, the runoff and soil loss was found to be minimum because of presence of vegetation along with anonla trees which increased infiltration and reduced runoff velocity. The increased infiltration due to presences of trees reduced the runoff production *vis-a-vis* soil loss. As survival of seedlings was adversely affected due to extreme drought conditions during 2015 and pre-monsoon period of 2016, casualty replacement was carried out during monsoon of 2016 in both species. Proper intercultural practices were carried out. The survival of sagon and bael plantation was recorded to be 80% and 75% in initial year and reached to 100% in subsequent years. Similarly, in three years time sagon plants attained average height of 189.3 cm and bael plants recorded average height of 70 cm. Pearl-millet and wheat cropping system was followed in all land uses/plots. The average grain and straw yield of pearl millet and wheat was recorded to be 18 and 30 q ha$^{-1}$, respectively (Anonymous, 2017).

## 3.3 Sediment Transport in Gully: Calibration of Process Based Simulation Model

In the first phase, calibration of FEM (Finite Element Model) simulation was carried out for Nandlalpur watershed. In the second phase, the calibration has been carried out for Chhalesar watershed having mixed land use i.e. 18.3 ha top portion of field bunded with outlet under agriculture and remaining portion under reserved forest having mature *Acacia nilotica* stand. The watershed was gauged at the end of agriculture (18.3 ha) at some distance down stream of the agriculture in the forest land $W_{2C}$ (27 ha) and at the outlet (61.3 ha) $W_{2D}$ by masonry *V* notch weir 2:1. The gauging device for agriculture land was GI sheet made 60 cm size Parshall flume. The Parshall flume was distorted with the lateral earth pressure hence the gauging work continued on masonry weir $W_{2C}$ and $W_{2D}$.

The hydrograph shape revealed that with the short rain spell, the effect of forest cover was very visible in retaining runoff. Under rainfall of higher intensity and prolonged duration, the effect of area on increase in runoff was visible. The second peak in $W_{2D}$ was the effect of concentration of flow from the top portion of the watershed. The effect of transmission losses in the main gully was clearly visible as the storm size of 18 mm or so could produce measurable runoff at $W_{2C}$ but failed to produce any runoff at $W_{2D}$. The entire runoff from $W_{2C}$ got absorbed in the main gully. This is a peculiar feature in gullied watershed in alluvial soil region. The impact of these characteristics in the gullied watershed was reflected in various factors of runoff hydrograph. The runoff volume and peak discharge was lowered, time to peak was increased and flow duration was again lowered by the transmission losses. The transmission loss was not simulated and substantiated by experimental evidences. These features were very extensively dealt with in calibration of simulation model for Nandlalpur watershed and again proved with the gauged data of Chhalesar watershed (Yadav and Bhushan, 1999).

## 3.4 Estimation of Depression Storage for Process Based Simulation by FEM

Assessment of depression storage in watershed is difficult but necessary aspect in the runoff simulation. The FEM simulation model is adopted for evaluating the effect of land use on runoff characteristics. A watershed was subdivided into number of sub areas or element of specific characteristics. The FEM simulation was developed by taking St Venants equation for continuity and momentum. Kinematics wave simulation linear element for event based simulation model was derived. The simulation model was calibrated with observed runoff specially generated from Nandlalpur gullied watershed. The depression storages were surveyed for the finite element grid of the watershed. The values were optimized by FEM model for one event for generation of runoff hydrographs. The resulting depression storage runoff volume was than used for simulation of runoff hydrographs for other events. The range of depression storages were 0.00582-0.0068 m, 0.001-0.0012 m, 0.0002-0.0008 m for brick fields, agriculture fields with field boundaries and hump tops, respectively (Yadav *et. al.*, 1997).

## 3.5 Development of Different Hydrological Structures/Instrumentation

For planning different conservation measures for watershed, the hydrological studies of a watershed are to be conducted to understand the hydrology of the watershed and also to determine different parameters for their design. These watershed need to be gauged and monitored for long time. For gauging ravines different hydrological structures and instruments were developed.

### 3.5.1 Development of inexpensive gauge well for hydrological monitoring at remote multiple sites in watershed management projects

Design considerations were evolved in view of the need, circumstances and operational convenience in the remote rugged terrain of gullied watershed. A gauge well consisting of three components *viz.* foundation and connecting channel, the stilling well and standpipe and the recorder house box, was constructed. The standpipe was made of RCC 230 mm ID and 300 mm OD. The recorder house was made of corrugated sheet and facilities provided for removal and quick assembly. One set of gauge well was installed at Nandlalpur gullied watershed in July 1993. The gauge well had been used for 1993 and 1994.

It produced staged graph as expected and fulfilled designs expected requirements. The gauge well cost was Rs. 500 (Base year, 1993) (Yadav and Bhushan, 1994).

### 3.5.2 Development of rainfall simulators for erosion studies

Research on soil and water conservation under natural rainfall condition takes very long time. In order to reduce the time, controlled rain has to be created to continue the research throughout the year. Therefore, simulation device to create rainfall of different amount and intensity is essential for carrying research on soil and water conservation.

A field version rainfall simulator was developed with indigenously available material. It covers an area of 6.3 m x 1.3 m and water flow in length ward direction. The simulator used V jet 80/100 nozzles to produce fan shaped spray. The inflow was provided to each nozzle from a bulk supply pipeline. The gang was accentuated by a 1/3 hp D.C. motor. Water was pumped by a centrifugal pump. The simulator assembly was mounted on a specially prepared stand frame, which was provided with pneumatic wheelbase.

The simulator was operated and transferred from plot to plot by two individuals. The simulator is to be operated with a pressure range established by calibration and trend analysis. The simulator performance with respect to rainfall was with coefficient of uniformity >72%, which is considered very high. The mean rainfall measured at the grids was between 66-93% of that measured with a rain gauge. Its use would facilitate conducting erosion research (Bhushan and Yadav, 1997).

### 3.5.3 Constant discharge water measuring device

Discharge at outlet varies with the change in water head in the supply channel. A device was developed to release constant discharge irrespective of variation in the supply channel. The mechanism consists in laying syphons on floating drum kept in a basin, which is connected to supply channel. The water level in the basin fluctuates and so the drum. The operating head on the syphon at any time is kept constant thereby release constant discharge in multiple of 2.3 $l\ s^{-1}$. More improvement is needed for easy priming of syphons for maintaining constant discharge release from device. The device will serve as a simple gadget for water management (Yadav and Bhushan, 1986).

### 3.5.4 Location of earthen checkdams for improving vegetative cover in deep gullies

The deep gullies remain devoid of vegetation under uncontrolled biotic interference. Study was carried out in a unit source deep gully watershed at the research farm. It was observed that checkdams (height 0.5-2.0 m) should be located at 25 m from the toe of gully in the upper catchment and narrow catchment and at an interval of 45 m in wide and riverine catchments. This pattern of location of earthen checkdams would help uniform regeneration of natural vegetation in the deep gullied lands (Anonymous, 2003).

### 3.5.5 Check dam stability and gradient control

In 1960, small earthen checkdams (0.5 m to 2.0 m height) were constructed in a watershed of 7.2 ha. The watershed was evaluated to study the utility of small earhen checkdams in reducing gradient of ravine bed and functioning and effectiveness of the constructed earthen structures. During 27 years, the structures could withstand the discharge generated from 22 events having more than 80 mm rains. Out of 17 structures constructed, 76% remained intact and 23% breached due to animal tramps, pathways, rodent burrows and some flaws in site selection and construction works. The sub-catchments enclosed by each checkdam were categorized on the basis of contour in the catchment (Table 3.2).

**Table 3.2: Change in mean gully bed slope due to earthen checkdams**

| Type of catchment | No. of sub-catchments | Mean area of sub-catchment (ha) | Channel bed slope (%) | | Reduction in channel gradient (%) |
|---|---|---|---|---|---|
| | | | Original | After 27 yrs | |
| Upstream catchment with broken topography | 4 | 0.41 | 9.1 | 3.9 | 57 |
| Narrow catchment with steep side slope | 9 | 0.31 | 4.1 | 1.4 | 66 |
| Riverine catchment | 1 | 0.24 | 4.0 | 1.23 | 69 |

The original mean valley slope of the catchments varied from 4.0 to 9.1%. The earthen checkdams were most effective in reducing channel gradient or bed slope in the riverine catchment follows by narrow catchment with steep side slopes. (Yadav *et. al.*, 1987)

## 3.6 Ground Water Assessment Monitoring and Development

Surface water resources are inadequate and costly to develop for intensive agriculture. Therefore, it is very important to devise suitable techniques to develop ground water resources, which may have many advantages over surface water resources.

### 3.6.1 Studies on dynamics of ground water table in watershed

Many researchers claim that soil conservation is an effective control measure for augmentation of ground water recharge, but under many situations, this fact becomes controversial. Dynamics of ground water table was investigated in Garapur watershed. A sample survey consisting of 13 pumping sets of Garapur village in the ORP watershed was carried out. The pumping sets were commissioned and operated for irrigation by farmers themselves. The size of the pump sets were 10 cm suction and 7.5 cm delivery. All are being run by electric motors. Pumps are installed inside of well pits and driven by belt and pulley conveyor system. The ground water table at the time of installation of pump sets and in May-June 1994 was ascertained. Linear relationship was developed between the time and depth of water table at the time of installation and in 1994 along with the yearly rainfall of the nearest weather station (about 10 km) at research station, Chhalesar, Agra. The water table depths at the time of installation of the pump sets during late sixties to early seventies were 10-12 m and it has increased to about 20 m in 1993. In 1994, the water table in all the pumping sets had stabilized at a depth of 20 m. There occurs very clear-cut trend of water table depletion with the length of use of the pumping sets. The rainfall has been fluctuating but it did not show any remarkable influence on ground water recharge. The water table had depleted @ 70 cm per year. This depletion of ground water table had direct bearing on command of the well, energy consumption and labour involved in the application. Area under irrigation and frequency of irrigation was almost three times as compared to initial years. Over exploitation of under ground water resulted in the depletion of ground water table. Thus, it is established that although there occurs retention of runoff due to soil conservation and to some extent increase in ground water build up but extensive and intensive agriculture leads to excessive withdrawal that results in depression of ground water table (Anonymous, 1994).

### 3.6.2 Studies on artificial ground water recharge

Artificial ground water recharge is a way to ameliorate the developing difficult situation of water stress during summer. Recharge inflow study was conducted in 96 feet (30 m) deep bore well for hand pump (10 cm) size. Inflow during rising depth of flow decreased and became practically constant at 30 cm head. The recharge of 1.75 l $s^{-1}$ was constant inflow rate. During falling stage, inflow recharge was lower than those under filling stage due to release of air bubbles. The inflow rate during falling depth is 1.5 l $s^{-1}$. In order to operate the artificial ground water recharge in a watershed, Hamirpur watershed was taken as a case study. Based on various parameters studied, total 50 bore wells were installed to augment irrigation potential of 2 ha wheat or 5 ha mustard per bore well. It means, additional 100 ha wheat or 250 ha mustard can be grown on sustainable basis (Bhushan *et. al.*, 1997).

#### 3.6.3 Ground water recharge due to installation of recharge sumps at Bandrauli under NATP

Twenty-seven recharge sumps of size 3 m x 2 m x 2 m were installed in series in the corner of fields before June, 2003. Water table was monitored at five open wells on monthly interval basis. The water table increased from July to October then started declining. Rise in water table was recorded in the range of 2-4 m. This rise in water table was monitored for increasing command area of the open wells. By properly maintaining these recharge sumps, 3.2 ha of area under mustard and 2.4 ha area under wheat could be cultivated. This means crop productivity could be increased with the rise in ground water storage if individual farmers use these simple recharge sumps which cost about Rs. 1500/- (Yadav *et. al.*, 2004).

### 3.7 Water Harvesting and Recycling for Sustainable Crop Production

The average annual rainfall of the region varied from 700-800 mm which is not sufficient to even raise one crop. Erratic nature of rainfall coupled with reducing number of rainy days (28-30 days) in the region is creating problem for crops. Hence, there is need to harvest rainwater and use it when it is needed for crop production.

#### 3.7.1 Water harvesting practices for dry land fruit crop

- The study on concentration of runoff for deep storage in the root zone with a view to cutting down evaporation loss and enhancing water use efficiency was conducted. The interspaces of plantation provided for each tree was shaped so that runoff concentrated in the area close to plant. Plots measuring 20 m x 5 m to accommodate seven plants per plot were laid out in a randomized block having four replications in 1988. The treatments were V-shape catchment; 2 m surface from both side was shaped to 5% to give runoff in the centre all along one metre strip; V+P -as in V shape + one metre up stream covered with polyethene sheet to induce more runoff; L - Contour catchment 4 m catchment from one side only shaped at 5% slope; L+P as in contour catchment + top two metre surface covered with polyethene sheet, L+I as in contour catchment + 5 cm irrigation at the time of fruiting and D - Diagonal catchment - catchment shaped at 5% diagonally to give runoff at the lowest point in the basin. The runoff inducement efficacy of different micro-catchment was assessed in 2 m wide runoff plots of varying length of the treatments (Yadav *et. al.*, 1988). Results are as follows:
- It is possible to concentrate 44-70% of rainfall as runoff in the low rainfall years and 55-78 % in high rainfall years.
- It is possible to predict runoff from daily events with the regression equation developed with data from moderate rainfall year.
- The soil loss an indicator of physical condition of micro-watershed shape was maximum from V shape. The soil loss was proportional to the runoff volume produced.
- Productivity of water can be increased by double density plantation for a period of 10 years.
- Variable moisture distribution can be developed with different micro-catchment shape.
- Roots of ber tree get oriented towards the water pondage side in the microwater harvesting for *in-situ* storage.

#### 3.7.2 Studies on catchment to receiving area ratio for bael (*Aegle marmelos*)

Study was conducted with objective of determining optimum size of micro-catchments for *in-situ* moisture conservation on ravine slopes. Runoff inducement was maximum (59%) with catchment having length of 3 m. Further, runoff inducement with 3m length of catchment was the most sustainable of all micro-catchment sizes under all rainfall situations. The growth of tree was maximum with micro-catchment area of 14 $m^2$ $tree^{-1}$. The overall maximum (79%) runoff inducement was with 3 m length of run. The efficacy of runoff inducement of different length of run was more during rainy season than during winter season. The growth parameters in relation to micro-catchment area were of higher order with catchment area ranging from 8 $m^2$ to 14 $m^2$ $tree^{-1}$. The growth parameters *viz.* height of tree and crown length showed consistent increase in relation to micro-catchment area (Bhushan *et. al.*, 1993).

### 3.7.3 Land formation practices for voluntary adoption

Field experiments were carried out in ustifluvent soil on a specially created erosion susceptible runoff plots of variable sizes (constant width and increasing length) and constant area with variable shapes (L/B ratio of 1, 4 and 16). Infiltration and soil loss data for individual rainstorm and accumulated yearly values established that a land formation of 18 m length for broad landform and a 0.9 m wide strip and secondary operation induced maximum infiltration and minimum soil loss (Fig 3.1). The land formation is related to agriculture practice to avoid runoff accumulation and maintain overland flow in bare as well as planted fields. This practice has been demonstrated to be voluntarily adoptable and can be performed with ordinary tractor and some minor equipment. Such land formation supports water conservation and minimizes rill and gully formation. The danger of water logging or excessive erosion due to breaching that may occur as a result of excessively intense rainfall is also reduced (Yadav *et. al.*, 2003).

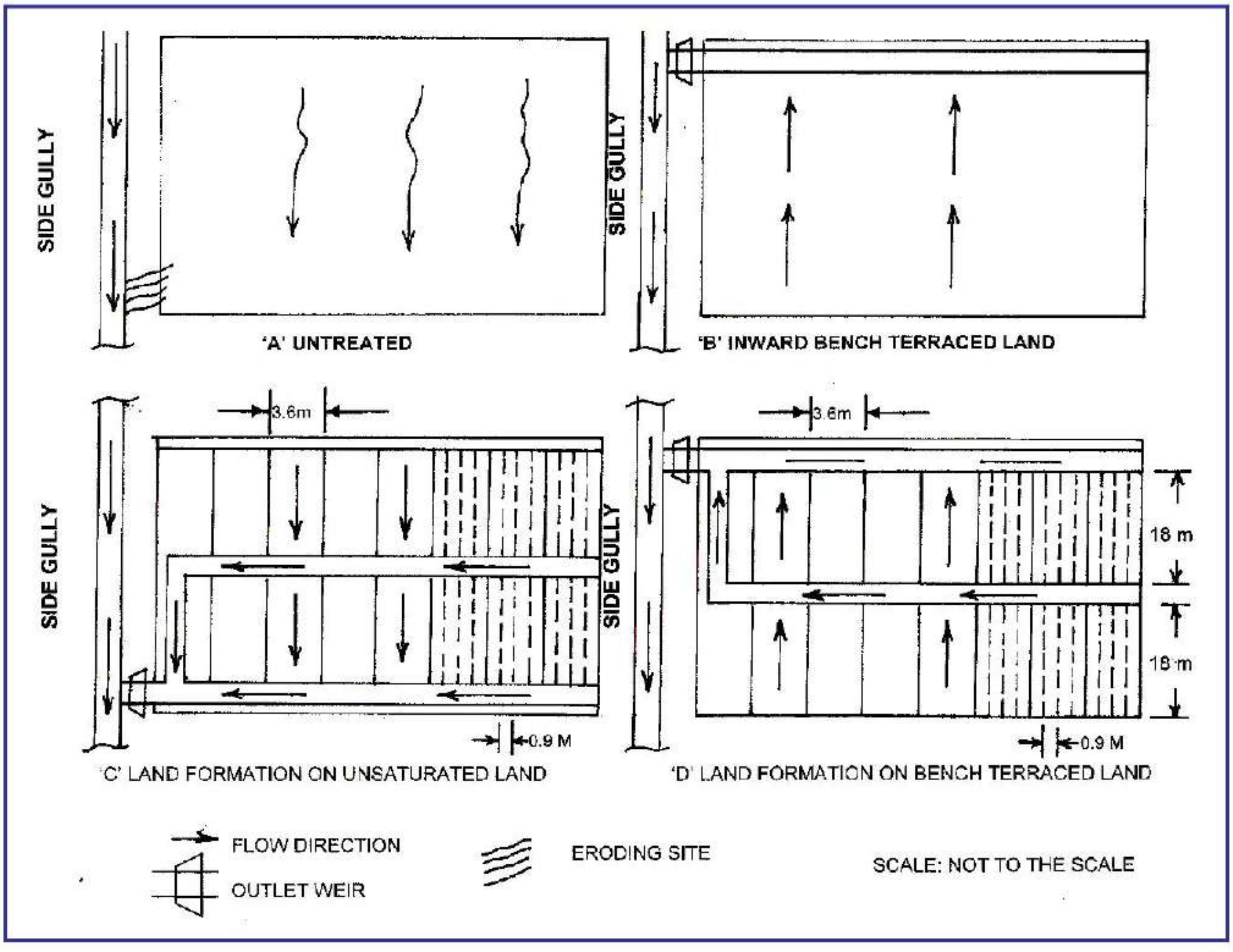



**Fig. 3.1: Layout plan for land formation for optimal hydrologic condition in gully erosion susceptible land in ustifluvent soil**

### 3.7.4 Land modification system for water conservation in reclaimed ravine land

Uneven distribution of rainfall is a common feature which greatly influences the success of cereal production in semi-arid region. Under such situations, development of land management technology evoked consideration for stability in yield of pearl millet crop. For the first three years, land modification systems were tried and then they were combined with surface mulching. From the five years average data, it is brought out that land modification system helped in achieving 10-20% higher yield of pearl millet crop. Sowing of pearl millet on ridges resulted in highest yield. Use of surface mulching at the fag end of monsoon produced about 20% higher yields and this proved beneficial.

### 3.7.5 Irrigation borders for reclaimed ravine lands

A field experiment was conducted for three years in Agra to determine the most suitable border length and width for efficient irrigation on terraced ravine alluvial soils. Border size of 15, 30 and 60 m length and 2, 4 and 6 m width were tested under point discharge of 7 litre $s^{-1}$ with test crop being wheat. Hydraulic study revealed that opportunity time was uniform for 60 m length and 4 m width. Water use efficiency increased with increasing length of border and was highest (151.3 kg $ha^{-1}$ $cm^{-1}$) with border layout of 60 m X 4 m. The maximum grain yield of wheat was also recorded under the border layout of 60 m X 4 m size (Tiwari *et. al.*, 2000).

### 3.7.6 Land form for micro-catchment water harvesting for horticultural plantation

Micro-watershed shape is one of the factors that can be maneuvered for redistribution of precipitation. Four micro-watershed shapes and surface cover combinations *viz.* contour watershed, *V* shaped watershed, and diagonal watershed with and without partial cover (polyethylene sheet spread from upstream side to cover 50% of micro-watershed) were studied under field conditions for determining their runoff inducement capacity and soil loss behavior in deep alluvial soil. The runoff inducement ranging from 40-70% was different for different shapes and surface cover with daily rainfall. The *V* shaped micro-watershed produced (30-85% of rainfall) nearly 8-10% of more runoff than that off contour watershed (20-80%). Partial cover produced 5% more runoff than without cover. Diagonal watershed produced 43% runoff. The treatment induced various spatially differential moisture regimes. The crop performance under these moisture regimes will determine suitability of micro-watersheds in a given agro-climatic zone (Yadav *et. al.*, 1988).

### 3.7.7 Rain water harvesting and recycling through silpaulin lined pond in reclaimed Yamuna ravines for sustainable crop production

The major reason for low productivity in ravine areas is insufficient availability of water to crops due to low, erratic and uneven distribution of rainfall. Hence, the major task in the region is to improve production per unit area and reduce risks of uncertainty. The average annual rainfall varied from 700-800 mm which is not sufficient to even raise one crop. Erratic nature of rainfall coupled with reducing number of rainy days (28-30 days) in the region is major production problem for crops. Hence there is need to store rainwater and use it when it is needed for crop production. The rate of evaporation is high in the region and also soil is sandy loam in nature which has high infiltration and percolation losses. A significant quantity of rain water is thus available for harvesting, which through plastic lined farm ponds could be efficiently used for combating drought-related crop failures.

The runoff during monsoon period could be harvested and recycled for irrigation of crops through plastic lined farm pond. In reclaimed Yamuna ravine land, for a catchment of 3.0 ha, with pond technology, 0.8 ha command area can be provided one irrigation either, pre sowing or life saving irrigation/supplemental irrigation safely or 0.4 ha command area with two irrigation. The pay back period for farm pond (lined with silpaulin) technology has been estimated as 2-3 years, whereas the life of pond is estimated to be 8-10 years.

Earlier, the production from this marginal land was very low and some years there was no yield also because of unlevelled field and total dependency of crop on rainfall. From harvested water, two irrigations of 5 cm each could be provided to 0.4 ha command area of mustard crop, one as a pre sowing irrigation and other as supplemental irrigation. The increase in yield was recorded up to 28 q $ha^{-1}$. Under present climatic conditions, no crop is possible without support of some kind of irrigation facility. Hence, the net return can be calculated as Rs. 39200 with this pond water recycling. In addition to that there was good scope for providing life saving irrigation to *kharif* crops like green gram and sesame during August and September months. The yield was recorded 6.5 q $ha^{-1}$ and 3.5 q $ha^{-1}$ for sesame and green gram, respectively. The area (0.8 ha) could be irrigated and net return could be calculated as Rs. 32000 as per year 2016 data (Sharma, *et. al.*, 2016).

**Photo 3.1: Silpaulin lined rain water harvesting pond in reclaimed Yamuna ravines**

## 3.8 Evaluation of Different Soil and Water Conservation Structures

Soil conservation structures those existed in the research farm, ORP and in other areas were surveyed for their performance characteristics *viz.* erosion damage, breaches and failure of structures. The structures were constructed about 25 years ago. The drop structure installed in gassed waterways where grasses were grew permanently, suffered by rat holes infront of structures. The holes give way for piping especially when head wall extension is short. The structure, which failed had one lacunae or the other. The study revealed that over sizing of one part of structure could not compensate the inadequacy of other component hence, it fails.

Earthen checkdams constructed in gully beds under agriculture were highly over designed. Study established that even the choice to construct earthen dams in the gullied land was wrong. Further, construction lacked adequate compaction. As a solution to this situation, a key trench should be made to induce bond between earthfill and soil at the site (Anonymous, 1996).

## 3.9 Prefabricated Drop Spillway for Rehabilitation of Gullied Lands

Well designed and constructed most effective bench terraces are eroded if outlet structures are not simultaneously constructed. The *in-situ* construction of outlets is limited by requirement of large volume of material, skilled mason, water and time beside its high cost.

**Photo 3.2: Prefabricated drop spillway at site after 13 yrs of installation**

A concept of prefabricated drop spillway for gully control was developed. Reinforced concrete drop spillways can be fabricated anywhere with the help of universal casting frame, designed and developed at the Agra Centre (Photo 3.2). Besides reduction in cost, the prefabricated drop spillway enables construction of outlet for terraces simultaneously with land development. For example a prefabricated drop spillway of 200 lit $sec^{-1}$ of discharge capacity and vertical drop of 80 cm was 23% cheaper (costing Rs. 1900 $unit^{-1}$, base year 1993) than *in situ* constructed structures of equivalent size (costing Rs. 2450/- $unit^{-1}$, base year 1993). Thus, it saves time and ensures required execution simultaneously at reduced cost (Table 3.3).

**Table 3.3: Cost of prefabricated drop spillways versus cost of *in-situ* construction**

| Discharge ($m^3 s^{-1}$) | Slab area ($m^2$) | Cost of prefabricated spillways (Rs. $unit^{-1}$) | | | | Cost of in situ* construction (Rs. $unit^{-1}$) |
|---|---|---|---|---|---|---|
| | | Slab | Transport | Installation | Total | |
| 0.03 | 6.5 | 550 | 50 | 100 | 700 | 915 |
| 0.20 | 15.2 | 1635 | 65 | 200 | 1900 | 2450 |
| 0.50 | 19.7 | 1795 | 65 | 250 | 2010 | 2530 |

*As estimated by field execution unit of Uttar Pradesh State Government

The size of prefabricated drop spillways are site specific as it changes from place to place. Hence, they are to be fabricated as per design requirement. A versatile frame has also been developed to fabricate spillway components of any size. The spillway components are, headwall, head wall extension, basin floor, wing walls, toe wall and toe wall extension. For fabrication of one spillway, there will be need to have component wise details of versatile frame for prefabrication of drop spillway. The frame is made of wood 7 cm x 5 cm section of different length. The frame can be easily adjusted to fabricate any practical size of drop spillway. Out of total 27 brace for one set one member each of crestwall, wing wall and toe wall need replacement for different sizes. The frame will help running a workshop for prefabrication of spillway in soil conservation works of ravine reclamation (Yadav and Bhushan, 1994).

## 3.10 Specification for Terracing of Peripheral Land

The peripheral land i.e. land occurring between shallow or medium and deep gullies are not fit for leveling for arable land. The land can be used for raising horticultural plantations. Since these are vulnerable to erosion terracing specifications are essential. The two experiments resulted in the specification for terracing of proposed land. The plantation may be made at 5 m x 5 m spacing and the interspacing be delineated to micro-catchment for each plant. The 2 m strip should be left adjacent to plant as receiving area. The donor area of 3 m run should be shaped at 5% slope (Anonymous, 2003).

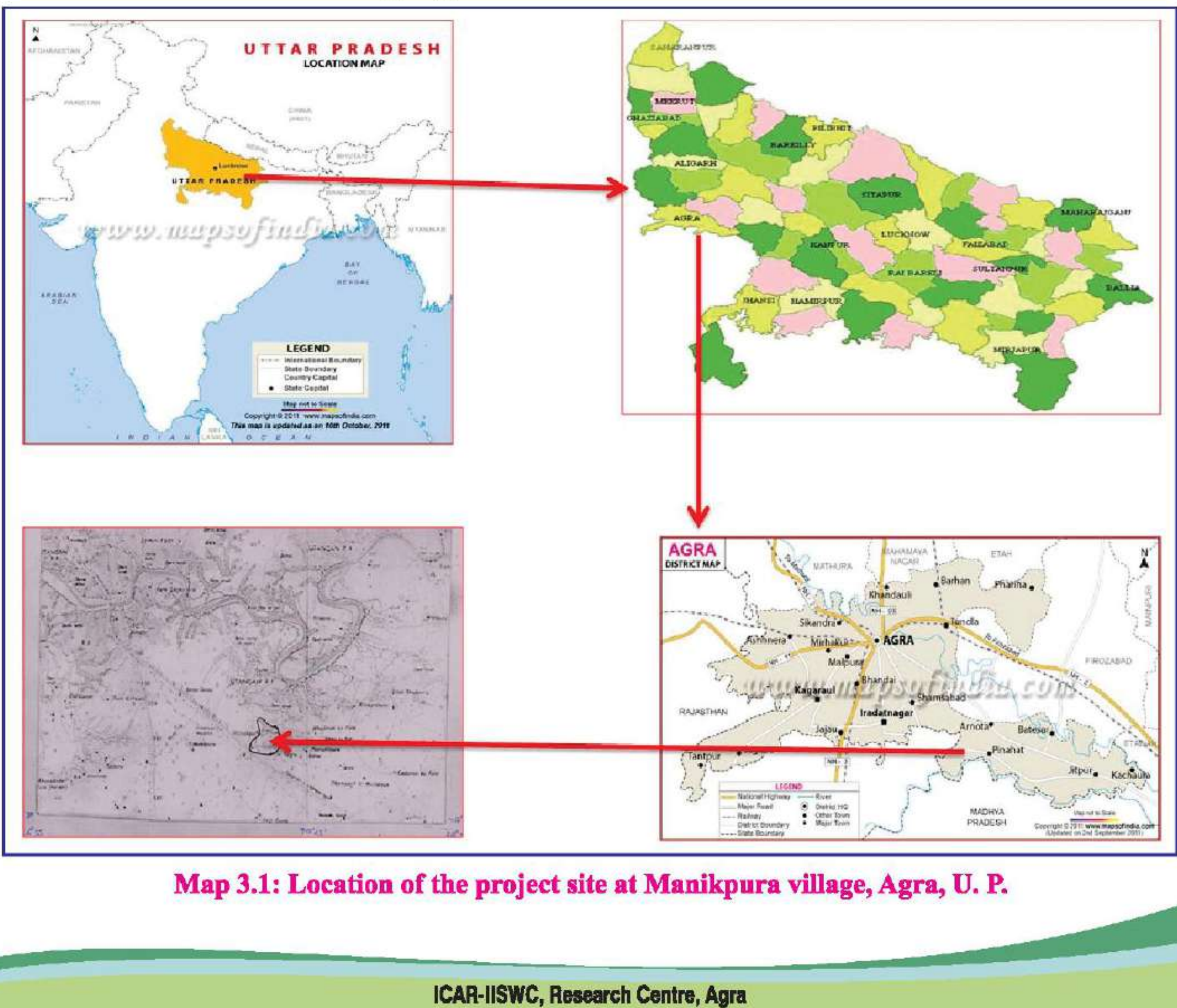
### 3.10.1 Evaluation of bench terraces in the ravines

Terracing work as carried out in early sixties and put under agriculture crops were evaluated and specifications for erosion resistant conditions were derived. Use of theoretical equations did not give terrace widths that were observed in terracing work done earlier. Type of terraces and critical vertical interval above which erosion becomes severe were determined. The inward terracing is ideal keeping vertical interval less than 1 m. The dike top width of 50 cm, height of 35 cm with riser slope of 1:1 giving cross sectional area 0.5 sq m is recommended (Yadav *et. al.*, 1989).

## 3.11 Resource Conservation and Economic Utilization of Yamuna Ravine Land through Bamboo (*Dendrocalmus Strictus*) Plantation

The study was initiated in 2009 at Manikpura village (26°49' - 26°51'N, 77°32'30" - 77°35'30"E and 168 m msl), block Pinahat, Tehsil Bah, district Agra U.P.

This watershed is a part of Uttangan river which is tributaries of Yamuna river system (Fig. 3.3). One micro ravine watershed of 9.8 ha size was selected for this study. A gauging structure with triangular weir was constructed at the outlet of the watershed to collect data on runoff and soil loss of every runoff producing rainfall event. Ravine watershed was planted with two rows of bamboo in staggered manner as vegetative barrier. Before planting the bamboo, the gully bed of watershed was cleared from the trees, bushes etc. to remove all the unplanted vegetation. One year old nursery raised bamboo seedlings were planted during early part of the rainy season in pit of 45 $cm^3$ at 2 m x 2 m spacing in the ravine bed (bed slope 0.75 to 1.5 %). The bamboo plantation was supported with soil and water conservation measures such as trenches, bunding, etc. The pit filling mixture comprised of excavated soil was mixed with 1 or 3 kg of FYM and endosulfan to check the termite attack. Life saving irrigation was given as and when required after planting (Fig. 3.1 a & b). A total of 12 life saving irrigations of 10-15 $plant^{-1}$ were provided for survival of bamboo plants. During first year frequent weeding (7 times) was done for improving survival and growth of plants. Urea was applied at the rate of 20 g $plant^{-1}$ after establishment of the plants. Soil working was done before emergence of new culms that helped in improving the emergence of culms. Organic fertilizers were applied during winter or dry period. The survival percentage of bamboo seedling was observed to be around 78%. Out of 1050 bamboo plants, 100 plants (10%) were selected for monitoring purpose. The data collection was started after about 4 years *i.e.* from 2013 and continued till July 2015. The mean value of bamboo growth parameters *viz.*, average culm height (m), average culm collar diameter (mm), average crown size (m) and no. of culms/clump were recorded and averaged.




**Map 3.1: Location of the project site at Manikpura village, Agra, U. P.**

## I. Growth performance of bamboo plantation

The growth of bamboo plantation and reclamation of degraded ravines has been shown in Fig. 3.1. Culm height increased two folds from 5.12 m to 11.76 m in 4 years (Table 3.4). Similarly, average culm collar diameter and average crown size were increased from 18.25 mm to 42.11 mm and 3.01 m to 7.27 m, respectively which showed more than 200% growth in 4 years. The average number of culms/clump increased from 16.17 (2013) to 29.60 (2015). The excellent growth parameters of bamboo plants *viz*., average culm height, average culm collar diameter, average crown size and maximum no. of culms per clump were observed in the study area (Fig. 3.2 a). Better growth of bamboos may be attributed to decreased soil loss which might have brought changes in moisture and silt retention owing to the growth of a dense vegetative cover in the gully beds. Further, bamboo acts as a good soil binder owing to their dry and hardy nature, peculiar dense clump formation and extensive interlocking fibrous root systems, natural capacity to regenerate through its rhizomes which play important role in preventing erosion, increasing water holding capacity and nutrient cycling under gully beds.

**Table 3.4 Growth of bamboo plants at Manikpura watershed, Pinhat-Agra**

| Manikpura watershed | Av. culm height (m) | Av. culm col. dia (mm) | Av. crown size (m) | No. of culms clump$^{-1}$ |
|---|---|---|---|---|
| April, 2013 | 5.12 | 18.25 | 3.01 | 16.17 |
| August, 2013 | 6.42 | 23.75 | 4.56 | 21.05 |
| December, 2013 | 9.56 | 37.30 | 5.52 | 24.33 |
| December, 2014 | 10.45 | 40.23 | 6.03 | 26.50 |
| July, 2015 | 11.76 | 42.11 | 7.27 | 29.60 |

## II. Hydrological performance of bamboo plantation

The soil physical and chemical properties were considerably influenced by bamboo plants under treatment imposed on ravines lands. The soil studies revealed that low soil pH (8.63) and high soil organic carbon content of (0.86%) was recorded in comparison to initial values (0.62%) apart from reducing reducing soil loss pattern in Manikpura ravine watershed. Four year (2010-13) runoff and soil loss data from the Manikpura ravine watershed revealed that average seasonal rainfall in the study site was 427 mm (Table 3.5). Runoff reduced from 9.65 % in first year to 1.81 % in fourth year due to bamboo plantation in ravine bed. Soil losses over the four year also come down from 4.27 t ha$^{-1}$ yr$^{-1}$ to 0.60 t ha$^{-1}$ yr$^{-1}$. The results are in conformity with findings of Rao *et. al*., (2012) who reported that runoff and sediment behaviour under the bamboo plantation based interventions absorbs more than 80% of rainfall. Due to influence of vegetation on soil, permeability of the soil was increased resulting in reduced surface runoff, soil loss, evaporation and better water penetration into soil as well as increased drainage capacity of soil.

**Table 3.5: Runoff and soil loss under bamboo plantation**

| Year | Seasonal rainfall (mm) | Runoff from bamboo planted area (mm) | % runoff | Soil loss (t ha$^{-1}$ yr$^{-1}$) |
|---|---|---|---|---|
| 2010 | 456 | 44.0 | 9.65 | 4.27 |
| 2011 | 226 | 6.04 | 2.67 | 0.66 |
| 2012 | 531 | 14.50 | 2.73 | 0.78 |
| 2013 | 494 | 8.96 | 1.81 | 0.60 |

### III. Yield and benefits

The analysis carried out using data from the Yamuna ravine system suggests a cash outflow ranging from Rs. 33550 $ha^{-1}$ to 48000 $ha^{-1}$ from 7$^{th}$ year onwards to individual stakeholders in the region in addition to the benefits accrued to society at large in terms of enhanced soil health (Table 3.6). Harvesting commences from 7$^{th}$ year onwards. The sale price per piece of bamboo is considered at Rs. 35-40. Considering 10% harvestable bamboo culms per clump (2 m x 2 m) spacing from 7$^{th}$ year onwards two bamboo culms per clump were available (Fig. 3.2 b)

The financial indicators such as net present worth benefit cost ratio, internal rate of return and payback period were determined for measuring financial viability of the bamboo plantation in ravines. The net present worth (Rs. $ha^{-1}$ $year^{-1}$) was Rs. 7031 in Yamuna ravines. Similarly, the benefit cost ratio workout to be around 1.89 in the Yamuna ravines. The internal rate of return revealed that bamboo performance in Yamuna ravines gave the best rate of return (19.3 %) (Singh *et. al.,* 2015).

**Table 3.6: Yield and income of bamboo plantations in Yamuna ravine systems**

| Year | Yield (Poles $ha^{-1}$) | Net Income (Rs $ha^{-1}$) |
|---|---|---|
| VII | 1200 | 33550 |
| VIII to X | 1200 | 34000 |
| XI year on wards | 1600 | 48000 |

(a) (b)

**Fig. 3.1: Watering to bamboo samplings (a), bamboo plant after 1 years of plantation (b)**


(a) (b)

**Fig. 3.2: Growth of bamboos after 3-4 years in ravine (a), Measurement of growth parameters after 7 years (b).**

# 4.0 RECLAMATION OF AREA AFFECTED BY MASS EROSION

## 4.1 Stream Bank Protection by Vegetative Measures

Floods in meandering Yamuna river cut the banks of river. Vegetative barrier of *Ipomoea carnea* was used to stabilize stream bank (Photo 4.1). To reinforce resisting power of *Ipomea carnea, Taramarix dioica* and *Prosopis juliflora* were also planted which encouraged deposition of silt. Thus, the process of bank erosion was reversed to land reclamation and channelization of river into a straight course. In twenty years, not only the stream bank erosion could be prevented but also by siltation all along the bank, about 30 m width of land had been reclaimed. On the reclaimed and stabilized stream bank, 20 m wide strip was planted with *Eucalyptus tereticornis* at 2 m x 2 m in 1979. In 1984, after 5 years, the *Eucalyptus* was harvested for pole. *Eucalyptus* could attain an average height of 12 m weighing 30 kg $tree^{-1}$. Each plant produced one pole of 5-6 m length. At the rate of Rs. 20/- each pole it could fetch Rs. 50,000/-. Remaining wood also were 25 t $ha^{-1}$ giving a return of Rs. 10000/- at the rate of Rs. 400 $t^{-1}$. Thus, total return worked out to be Rs. 12000 $ha^{-1}$ $yr^{-1}$ (Prajapati and Malhotra, 1985).

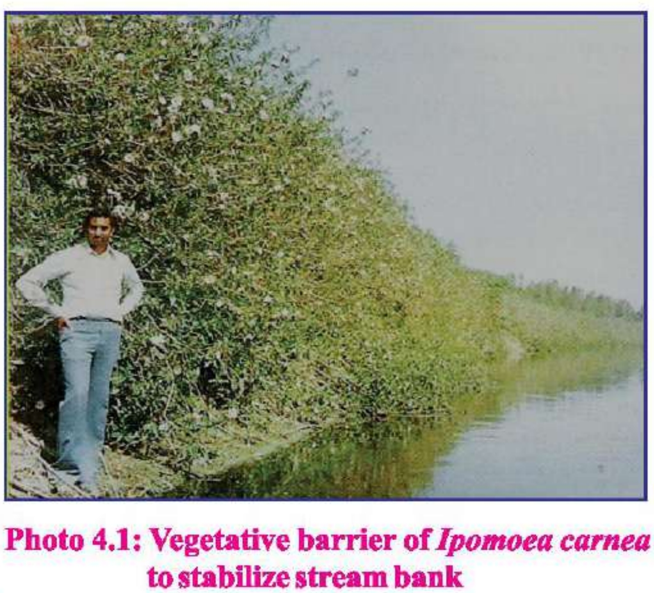


**Photo 4.1: Vegetative barrier of *Ipomoea carnea* to stabilize stream bank**

## 4.2 Stream Bank Protection by Mechanical Measures (Stone Jetties)

The earlier study on riverbank stabilization got set back when the river changed course and engulfed the entire reclaimed land. Therefore, strong structural stabilizing measures were installed at Tanaura and their utilities were established by the centre. The study on riverbank cutting *vis-à-vis* stabilization by full-scale jetty revealed very interesting results. The jetty facing down stream observed to stabilize upstream bank as well as down stream bank. The upstream facing jetty produced reverse current that caused bank caving therefore it had no positive influence on river bank stabilization. The upstream facing jetties were located in the excessively eroded concave bank before Tanaura as well as near Noorpur. The upstream facing jetty constructed by State Govt. (3 nos at Tanaura and 2 nos at Noorpur) shown large erosion at upstream and no protection at the down stream. The sandy bank near Noorpur was more damaged by river cutting than near Tanaura. In between the closely spaced upstream facing jetty some accumulation of sand in the river was found to exist. However, influence on riverbank protection was absent. The upstream facing jetty had no influence on directing streams river current, as shown by the river section near Noorpur. The river cutting beyond Noorpur *i.e.* near Mehara Nahar was very severe that revealed need of immediate control measures. As length of jetty increased from 15 to 27 m, upstream velocity at the tip of jetty increased from 0.4 to 0.975 m $s^{-1}$. The velocity at the down stream increased from 160 m $s^{-1}$ with 15 m length to 280 m $s^{-1}$ with 27 m length of jetty. The magnitude of velocity close to bank increased with the increase in water depth. Moderation in the velocity was noticeable due to jetty. During high flood measured on 3.8.2001 when flow in the river was 5.0 $m^3 s^{-1}$, the velocity at up stream away from jetty was 0.3 m $s^{-1}$ and it increased up to 0.72 m $s^{-1}$. In this situation, zero velocity was up to 100 m with some reverse current at the back of jetty. Velocity beyond 100 m was found to vary in pulsating form *i.e.* 0.5 to 1.0 m $s^{-1}$.

With construction of the other jetties by the UP Irrigation Department, sloping upward, the observations in the year 2002 revealed different pattern of reduction in velocity of flow close to the bank. The velocity at upsteam of earlier constructed jetty (sloping down stream) was 0.45 m at 170 m up stream and 2.5 m $s^{-1}$ at the tip of jetty. At the downstream of this jetty velocity was zero up to a distance of 110 m. It increased to 0.62 m $s^{-1}$ at 180 m and 1.0 m $s^{-1}$ at 360 m. The down stream velocity again increased from 0.75 m $s^{-1}$ at 400 m and 1.5 m $s^{-1}$ at 500 m. The velocity due to jetty sloping upstream was 0.8 m $s^{-1}$ and not reduced. It was 1.5 m at the tip of jetty. Two jetties were at interval of 110 m. The velocity at downstream was zero up to 40 m and 0.60 m $s^{-1}$ in the reverse direction (Photo 4.2). Thus, it is established that velocity of flow increases close to bank as depth of flow in the river increased. With increase in length of jetty velocity at the tip increased as volume of water flow increased under constriction of flow section. The downstream inclined jetty reduced velocity for longer length than the jetty sloping upstream (Yadav, 2005).

**Photo 4.2: Stream bank protection by mechanical measures (Jetties) at Tanaura**

# 5.0 RESOURCE CONSERVATION MEASURES FOR ARABLE LANDS

Mono-cropping of rain fed pearl millet on bed and side slopes of shallow natural ravines and pearl millet (rain fed)-wheat/mustard (irrigated) on reclaimed Yamuna ravines are the most dominant crop/cropping system in Semi-Arid Agra region. However, rainfall pattern of Semi-Arid Agra region is highly erratic both in distribution and commencement/withdrawal of monsoon rains. This situation hatches the droughts of mostly short to medium spells and occasionally of longer durations which make the rain fed *kharif* agriculture a gamble in the hands of monsoon that is full of risk and give rise to subsistent agriculture/poor crop yields/crop failures. More than 90% of annual rainfall (600-700 mm), received during July to mid-September in 70-75 days monsoon period (normally 30-35 rainy days and 3-8 runoff causing events) mainly decides the selection of crops for rain fed rainy season in the region. Droughts at different physiological stages affect crop productivity in different magnitudes. The prolonged droughts of 15 days or more at tillering stage of pearl millet can result in 28-30% yield reduction followed by drought at grain filling and establishment stages (12% yield reduction) even if rainfall is as high as 435 mm during the crop period. A sharp decline in soil moisture on droughts can be ascribed mainly to poor soil moisture/nutrient holding potential of light textured soils. Therefore, to reduce the risk several crops/cropping systems were evaluated on the arable lands for efficient resource conservation/utilization, sustainable agriculture and stability in the agricultural production.

## 5.1 Resource Conservation and Crop Production under Different Tillage Practices

### 5.1.1 Deep ploughing once in three years

A large part of Indo-gangetic plain zone including the semi-arid Agra region is beset with hard sub soil layer (due to kankar/calcium carbonate granules) and high bulk density which impedes the infiltration/downward movement of rain water in soil profile. This poses the problem of moisture deficit even on short spell droughts and decreases the crop yield or lead to crop failure especially in Agra region due to low and aberrant rainfall. This study envisages that deep ploughing suppresses weed growth and enables enormous production/ramification of crop roots which can improve crop moisture use, soil organic matter/physical properties.

As such, considering the tillage depth important from point of view of enhanced rain water conservation and stable/higher crop production, this study involving five treatments ($T_1$: Zero tillage *i.e.* only opening a furrow for sowing, $T_2$: Farmers practice *i.e.* wedge plow 5 cm depth twice every year for shallow tillage, $T_3$: Cultivator 10 cm twice every year for shallow tillage/farmer's practice, $T_4$: Mould board plow 15 cm depth once in three years followed by cultivator once in a year before sowing of pearl millet and $T_5$: MB plow 20 cm depth once in three years followed by cultivator once in a year before sowing of pearl millet) was carried out on 2% runoff plots (3.4m x 15m) constructed on class III reclaimed Yamuna ravines during 1998-2006.

The deep ploughing (20 cm) once in three years ($T_5$) was found practically viable and economically feasible tillage technology for sustained higher /stabilized productivity for rain fed pearl millet-irrigated wheat/ mustard system in semi-arid Agra region. The results showed that $T_5$ stabilized crop yields in drought prone rain fed conditions of semi-arid Agra region where rainfall during the crop period varied from 125 mm in 2002 to 683 mm in 1998.

**Moisture conservation and soil properties:** Deep ploughing ($T_5$) almost doubles the soil moisture conservation in lower soil profiles (25-75 cm).

Deep ploughing ($T_5$) recorded lower soilmoisture in crop root zone (0-25 cm) than shallow/zero tillage but it also involved higher soil moisture use for survival of more green crop biomass.

The higher soil moisture storage in 25-75 cm profile under $T_5$ reflects on more rain water conservation in soil profile which can be ascribed to higher infiltration rate due to loosening of soil. $T_5$ also registered minimum green and dry biomass of weeds among different tillage practice which corresponded to just 26.75 and 20.36% of zero tillage in terms of green and dry weed biomass (Table 5.1).

The higher weed growth in zero tillage treatment ($T_1$) also resulted in maximum removal of N and P on weeding while it reduced to an extent 8.83 kg N and 1.97 kg P $ha^{-1}$ under deep tillage once in three years or $T_5$ (Table 5.2 & 5.3).

Deep ploughing enhanced root production by 34% in pearl millet crop, ameliorated pH from 8.1 to 7.2 and reduces bulk density from 1.60 to 1.46 mg $cc^{-1}$. Deep ploughing also registered a tremendous increase in initial organic carbon (0.2%), infiltration rate (1.2 cm $hr^{-1}$), water soluble aggregates of <0.25 mm (3.6%) and water soluble aggregates between 1-8 mm (2.6%) which corresponded to 280, 267, 800 and 562% over initial status in a period of six years, respectively.

**Crop productivity:** Deep ploughing ($T_5$) enhanced grain yield from pearl millet and wheat crops over all other tillage treatment which corresponded to 1687, 1421, 1081, 486 and 1589, 1380, 950, 562 kg $ha^{-1}$ over $T_1$, $T_2$, $T_3$ and $T_4$, respectively (Table 5.6).

In fact, deep tillage effectively loosens the soil that lead to more rain water conservation and higher root penetration that resulted in higher growth/ productivity under pearl millet-wheat/mustard system than shallow or zero tillage. The highest grain yield (2480 kg $ha^{-1}$ pearl millet; 3691 kg $ha^{-1}$ wheat) was recorded under deep tillage ($T_5$) which was nearly 50% higher than zero tillage that can be ascribed to higher residual soil moisture conservation under deep tillage as compared to shallow or zero tillage treatments. Similarly, significantly higher green fodder yield of pearl millet (6.1 t $ha^{-1}$) was also recorded under deep tillage ($T_5$) which was 74 and 48% more than green fodder yields under zero tillage and farmer's practice, respectively (Table 5.4).

**Runoff and soil loss:** Maximum runoff (36% of rainfall) was registered under zero tillage ($T_1$) while minimum runoff (22%) was recorded under deep tillage; however, deep tillage ($T_5$) registered higher soil/nitrogen loss than zero tillage. Nevertheless, the trend of $P_2O_5$ and $K_2O$ loss was reverse (Table 5.5) (Nitant and Om Prakash 2006, Nitant *et. al.*, 2007).

**Table 5.1: Profile soil moisture storage (cm) under different tillage treatment**

| Treatment | Tillage depth (cm) | Soil moisture (w/w %) 30 DAS | | | Soil water (w/w %) at crop harvest (0-25 cm) | | |
|---|---|---|---|---|---|---|---|
| | | 0-25 (cm) | 25-50 (cm) | 50-75 (cm) | 2004 | 2005 | 2006 |
| $T_1$ | - | 11.6 | 9.6 | 7.8 | 5.94 | 5.24 | 5.82 |
| $T_2$ | 7.5 | 11.0 | 11.2 | 8.0 | 4.00 | 5.06 | 5.08 |
| $T_3$ | 12 | 9.8 | 9.6 | 8.6 | 3.82 | 4.62 | 3.62 |
| $T_4$ | 15 | 9.2 | 12.6 | 12.2 | 3.62 | 3.64 | 3.62 |
| $T_5$ | 20 | 8.2 | 15.8 | 16.6 | 2.20 | 1.84 | 2.62 |

**Table 5.2: Average removal of nutrient and biomass of weeds in pearl millet crop under different tillage treatment (1998-06)**

| Treatment | Weed biomass (kg ha$^{-1}$) | | Average N and P removal on weeding (kg ha$^{-1}$) (1998-2006) | |
|---|---|---|---|---|
| | | | N | P |
| | Green | Dry | Dry | Dry |
| $T_1$ | 1215 | 609 | 10.89 | 3.11 |
| $T_2$ | 778 | 482 | 8.17 | 2.41 |
| $T_3$ | 774 | 408 | 6.98 | 1.90 |
| $T_4$ | 474 | 245 | 3.99 | 1.14 |
| $T_5$ | 325 | 124 | 2.06 | 0.56 |

**Table 5.3: Nitrogen uptake by pearl millet fodder under different tillage treatment**

| Treatment | Average (2004-06) | | Nitrogen uptake in fodder (kg ha$^{-1}$) | Protein content in fodder (%) |
|---|---|---|---|---|
| | Dry fodder (kg ha$^{-1}$) | % Nitrogen concentration in fodder | | |
| $T_1$ | 725 | 1.88 | 16.63 | 11.75 |
| $T_2$ | 1079 | 1.84 | 19.85 | 11.50 |
| $T_3$ | 1470 | 1.79 | 26.31 | 11.19 |
| $T_4$ | 2063 | 1.77 | 36.52 | 11.06 |
| $T_5$ | 2806 | 1.75 | 49.11 | 10.94 |

**Table 5.4: Yield of pearl millet fodder under different tillage treatment (2004-06)**

| Treatment | Green | | | Dry fodder | | | Average | |
|---|---|---|---|---|---|---|---|---|
| | 2004 | 2005 | 2006 | 2004 | 2005 | 2006 | Green | Dry |
| $T_1$ | 2185 | 1254 | 1344 | 993 | 570 | 611 | 1594 | 725 |
| $T_2$ | 3403 | 1782 | 1936 | 1574 | 810 | 880 | 2374 | 1079 |
| $T_3$ | 4291 | 2244 | 3168 | 1951 | 1020 | 1440 | 3234 | 1470 |
| $T_4$ | 4771 | 4136 | 4708 | 2169 | 1880 | 2140 | 4538 | 2063 |
| $T_5$ | 6468 | 5852 | 6197 | 2940 | 2660 | 2817 | 6172 | 2806 |

**Table 5.5: Runoff, soil and nutrient losses in pearl millet crop under different tillage treatments**

| Treatment | Runoff (%) (Average 1998-06) | Soil loss (t ha$^{-1}$) (Average 1998-06) | Nutrients (kg ha$^{-1}$) (Average 2000-06) | | |
|---|---|---|---|---|---|
| | | | N | P | K |
| $T_1$ | 34.15 | 2.63 | 13.08 | 3.48 | 21.48 |
| $T_2$ | 30.46 | 3.91 | 15.80 | 3.56 | 22.04 |
| $T_3$ | 28.35 | 3.48 | 15.86 | 3.82 | 20.72 |
| $T_4$ | 23.89 | 3.73 | 14.94 | 2.70 | 20.86 |
| $T_5$ | 18.69 | 3.36 | 14.64 | 1.84 | 20.20 |

**Table 5.6: Grain yield of crops, root biomass and net returns under different tillage treatment**

| Treatment | Pearl millet (kg $ha^{-1}$) (Average 1998-06) | | Root biomass (kg $ha^{-1}$) (Average 2004-06) | Wheat (kg $ha^{-1}$) (Average 1998-07) | | Net returns (Rs. $ha^{-1}$) |
|---|---|---|---|---|---|---|
| | Grain | Stover | | Grain | Stover | |
| $T_1$ | 793 | 1341 | 1604 | 2075 | 2030 | 6096 |
| $T_2$ | 1059 | 1551 | 2040 | 2284 | 2510 | 9490 |
| $T_3$ | 1399 | 2099 | 3025 | 2714 | 2989 | 14708 |
| $T_4$ | 1994 | 2703 | 3665 | 3102 | 3434 | 18647 |
| $T_5$ | 2480 | 3370 | 4798 | 3664 | 3984 | 23051 |

## 5.2 Nutrient Management for Higher Sustained Production

### Effect of levels and methods of nitrogen application on pearl millet productivity

In order to enhance the productivity of most dominant rainfed pearl millet crop on newly constructed bench terraces, a field experiment was conducted involving three levels of nitrogen (0, 25 and 50 kg $ha^{-1}$) and three methods of application ($M_1$: all nitrogen drilled at sowing 3 cm away and 4 cm deeper to seed, $M_2$: half nitrogen drilled as $M_1$ + half nitrogen top dressed at knee high stage and $M_3$: half nitrogen drilled as $M_1$ and half nitrogen applied as fliarr application at flower initiation) in randomized block design replicated thrice on loamy sand soil during 1970-73. Results revealed that different nitrogen doses significantly differed in grain and straw yield of pearl millet. The highest grain and straw yield and net return from pearl millet crop were recorded at 50 kg N $ha^{-1}$. Among different methods of nitrogen application, $M_3$(half nitrogen drilled as $M_1$ and half nitrogen applied as foliar application at flower initiation) registered the highest grain and straw yield and net return but the variations were statistically not significant (Table 5.7).

**Table 5.7: Grain and straw yield of pearl millet as affected by levels and methods of Nitrogen fertilization**

| Treatment | Grain yield (q $ha^{-1}$) | | | | Straw yield (q $ha^{-1}$) | | | | Net return (Rs. $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | 1970 | 1971 | 1973 | Pooled | 1970 | 1971 | 1973 | Pooled | |
| **Nitrogen levels** | | | | | | | | | |
| $N_0$ | 8.93 | 9.38 | 8.59 | 8.96 | 24.06 | 28.53 | 50.60 | 34.40 | 765 |
| $N_{25}$ | 15.31 | 16.30 | 14.63 | 15.41 | 38.95 | 35.76 | 62.70 | 45.80 | 1189 |
| $N_{50}$ | 26.32 | 26.27 | 19.70 | 24.09 | 63.43 | 62.68 | 68.45 | 64.85 | 1799 |
| CD at 5% | 4.16 | 2.45 | 3.99 | 3.66 | 8.90 | 2.16 | 10.12 | 9.70 | -- |
| **Methods of application** | | | | | | | | | |
| $M_1$ | 18.30 | 17.92 | 17.65 | 17.95 | 44.94 | 44.04 | 62.80 | 50.59 | 1371 |
| $M_2$ | 21.27 | 21.76 | 16.65 | 19.90 | 51.96 | 48.80 | 67.85 | 56.20 | 1517 |
| $M_3$ | 22.77 | 24.15 | 17.19 | 21.40 | 56.67 | 54.82 | 66.07 | 59.16 | 1593 |
| CD at 5% | 3.61 | 2.12 | NS | NS | 7.71 | 1.87 | NS | NS | -- |
| CD at 5% (NM) | NS | NS | 4.88 | NS | NS | 2.64 | NS | NS | -- |

### 5.2.1 Response of mustard varieties to different N levels

In view of fact that mustard is the most important/remunerative crop on reclaimed terraced ravine land, a study to find out most suitable variety and its N requirement under semi-arid Agra conditions was conducted during 1992-93 involving 12 treatments (three popular varieties of mustard: Varuna RH-30 and Pusa bold and four levels of N: 0, 30, 60 and 90 kg ha$^{-1}$) in randomized block design replicated thrice. Results show that Cv. Pusa bold registered the significantly higher seed yield which corresponded to an increase of 9.8 and 24.5% over Varuna and RH 30, respectively (Table 5.8). Pusa bold also recorded significantly higher performance of growth, yield attributes and quality parameters among different mustard varieties by registering highest plant height (153.6 cm), primary branches plant$^{-1}$ (346.5), length of siliqua (12.19 cm), test weight (3.26 g) and protein content (20.38%). Among N levels, 90 kg N ha$^{-1}$ outperformed other N levels in mustard seed yield (1625 kg ha$^{-1}$), plant height (152.0 cm), primary branches plant$^{-1}$ (8.76), length of silique (5.53 cm) and protein content (22.19%).

### 5.2.2 Nitrogen management in different cropping systems

Soils of reclaimed Yamuna ravines are poor both in water holding capacity and fertility; therefore inclusion of legume crops in cropping systems can reduce the N requirement of proceeding crop. In this backdrop, three cropping systems (pearl millet-wheat, cluster bean-wheat and fallow-wheat) in rain fed conditions and four doses of N in wheat crop (0, 40, 80, 120 and 160 kg ha$^{-1}$) grown under irrigated conditions were evaluated in split plot design replicated four times during 1982-87.

**Crop productivity:** Result on interaction (Table 5.9) showed that interaction of cluster bean-wheat and 120 kg N ha$^{-1}$ registered the highest wheat grain yield (2538 kg ha$^{-1}$). Among cropping systems cluster bean-wheat registered the highest wheat grain yield (2198 kg ha$^{-1}$) followed by fallow-wheat (1953 kg ha$^{-1}$) and pearl millet-wheat (1757 kg ha$^{-1}$). Among N doses, 160 kg N ha$^{-1}$ registered the highest wheat grain yield (2436 kg ha$^{-1}$). Another set of data (Table 5.10) elucidated that among preceding crops cluster bean exerted the maximum favourable effect on wheat grain yield (2169 kg ha$^{-1}$) followed by fallow (1955 kg ha$^{-1}$) and pearl millet (1758 kg ha$^{-1}$).

**Soil fertility:** Data (Table 5.11) revealed that organic carbon content and available Nitrogen, Phosphorus and potash registered higher values at 0-15 cm soil over their respective counterparts at 15-30 cm soil depth at all the N doses and under both pearl millet and cluster bean crops excepting the case of available phosphorus in pearl millet crop at 40 kg N ha$^{-1}$. The pH values did not register any definite pattern at different soil depths, nitrogen level and in pearl millet or cluster bean crops.

**Table 5.8: Seed yield, growth and yield attributes and protein content in seed of Indian mustard varieties as influenced by Nitrogen levels (Average of two years)**

| Treatment | Seed yield (kg ha$^{-1}$) | Plant height (cm) | Primary branches plant$^{-1}$ | Siliqua plant$^{-1}$ | Length of siliqua (cm) | No. of seeds/ siliqua | 1000 seeds weight (g) | N content (%) | Protein content |
|---|---|---|---|---|---|---|---|---|---|
| **Varieties** | | | | | | | | | |
| Varuna | 1187 | 144.3 | 7.94 | 327.1 | 4.81 | 11.58 | 3.14 | 3.14 | 19.63 |
| RH-30 | 1047 | 139.5 | 7.44 | 307.5 | 4.44 | 10.97 | 2.91 | 2.91 | 18.19 |
| Pusa bold | 1303 | 153.6 | 8.42 | 346.5 | 5.10 | 12.19 | 3.26 | 3.26 | 20.38 |
| CD(P=0.05) | 130 | 7.8 | 0.31 | 20.6 | 0.20 | 0.56 | 0.12 | 0.12 | 0.48 |
| **Nitrogen levels (kg ha$^{-1}$)** | | | | | | | | | |
| 0 | 581 | 102.2 | 5.45 | 260.6 | 3.88 | 10.05 | 3.44 | 2.80 | 17.50 |
| 30 | 1003 | 125.4 | 7.20 | 314.0 | 4.65 | 11.38 | 4.07 | 3.25 | 20.31 |
| 60 | 1441 | 118.5 | 8.15 | 352.2 | 5.08 | 12.37 | 4.71 | 3.46 | 21.63 |
| 90 | 1625 | 152.0 | 8.76 | 374.7 | 5.53 | 12.91 | 4.96 | 3.55 | 22.19 |
| CD(P=0.05) | 145 | 8.9 | 0.42 | 24.4 | 0.30 | 0.68 | 0.32 | 0.14 | 0.56 |

**Table 5.9: Interactive effects of proceeding crops and added Nitrogen on average yield of wheat (1982-86)**

| Cropping system | Wheat grain yield (kg ha$^{-1}$) | | | | | Average |
|---|---|---|---|---|---|---|
| | 0 | 40 | 80 | 120 | 160 | |
| Pearl millet-wheat | 534 | 1638 | 2065 | 2129 | 2422 | 1757 |
| Fallow - wheat | 1111 | 1725 | 2205 | 2368 | 2357 | 1953 |
| Cluster bean - wheat | 1250 | 2195 | 2451 | 2538 | 2530 | 2198 |
| **Average** | **974** | **1553** | **2250** | **2345** | **2436** | - |

**Table 5.10: Effect of proceedings crops and Nitrogen doses on grain yield of wheat crop**

| Treatment | 1982-83 | 1983-84 | 1984-85 | 1985-86 | 1986-87 | Average |
|---|---|---|---|---|---|---|
| | | | **Proceeding crop** | | | |
| Pearl millet | 1760 | 2512 | 1362 | 1762 | 1396 | 1758 |
| Cluster bean | 2053 | 2830 | 2015 | 2372 | 1576 | 2169 |
| Fallow | - | 2590 | 2012 | 2023 | 1185 | 1955 |
| CD (P=0.05) | 293 | 256 | 277 | 369 | 346 | - |
| | | | **Nitrogen doses (kg ha$^{-1}$)** | | | |
| 0 | 834 | 1475 | 950 | 976 | 498 | 947 |
| 40 | - | - | - | - | - | - |
| 60 | - | - | - | - | - | - |
| 120 | 2411 | 3077 | 2142 | 2257 | 1906 | 2359 |
| 160 | 2394 | 3073 | 2272 | 2626 | 1775 | 2428 |
| CD (P=0.05) | 463 | 605 | 358 | 440 | 328 | - |

**Table 5.11: Soil fertility at experimental site as influenced by doses of Nitrogen and proceeding crops after completion of experiment in 1986**

| Treatment N (kg ha$^{-1}$) | Soil depth (cm) | OC (%) | | Available nutrients (kg ha$^{-1}$) | | | | | | pH | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | N | | $P_2O_5$ | | $K_2O$ | | | |
| | | Cluster bean | Pearl millet | Cluster bean | Pearl millet | Cluster bean | Pearl millet | Cluster bean | Pearl millet | Cluster bean | Pearl millet |
| 0 | 0-15 | 0.19 | 0.17 | 188 | 172 | 31 | 30 | 327 | 328 | 8.80 | 8.60 |
| | 15-30 | 0.14 | 0.15 | 180 | 159 | 16 | 17 | 265 | 267 | 8.88 | 8.76 |
| 40 | 0-15 | 0.24 | 0.22 | 194 | 165 | 38 | 13 | 361 | 383 | 8.78 | 8.70 |
| | 15-30 | 0.18 | 0.18 | 180 | 145 | 17 | 18 | 270 | 247 | 8.78 | 8.71 |
| 80 | 0-15 | 0.24 | 0.22 | 204 | 182 | 35 | 41 | 339 | 369 | 8.80 | 8.53 |
| | 15-30 | 0.16 | 0.16 | 192 | 161 | 14 | 17 | 226 | 239 | 8.79 | 8.68 |
| 120 | 0-15 | 0.26 | 0.24 | 200 | 182 | 36 | 38 | 341 | 347 | 8.69 | 8.63 |
| | 15-30 | 0.16 | 0.18 | 174 | 167 | 17 | 18 | 250 | 244 | 8.81 | 8.69 |
| 160 | 0-15 | 0.28 | 0.25 | 204 | 180 | 39 | 35 | 325 | 327 | 8.71 | 8.65 |
| | 15-30 | 0.16 | 0.16 | 174 | 163 | 15 | 17 | 233 | 232 | 8.80 | 8.63 |
| Initial value | 0-15 | 0.18 | 0.17 | 164 | 169 | 33 | 33 | 339 | 347 | 8.56 | 8.43 |
| | 15-30 | 0.17 | 0.15 | 142 | 146 | 17 | 18 | 247 | 270 | 8.70 | 8.42 |
| Av. value | 0-15 | 0.24 | 0.22 | 198 | 176 | 35.5 | 37.4 | 349 | 361 | 8.76 | 8.62 |
| | 15-30 | 0.16 | 0.16 | 180 | 165 | 15.8 | 17.4 | 249 | 246 | 8.81 | 8.69 |

### 5.2.3 Irrigation and nitrogen management in mustard

The aim of this study was to provide a multiple option of doses of nitrogen/FYM under varying number of irrigations in mustard, the most profitable crop in the semi-arid Agra region, on newly constructed terraces on shallow Yamuna ravines. This study involving seven treatments ($T_1$: Pre-sowing irrigation + 40 kg N $ha^{-1}$, $T_2$: Irrigation at pre-sowing + branching + 40 kg N $ha^{-1}$, $T_3$: Irrigation at pre-sowing + branching + flowering + 40 kg N $ha^{-1}$, $T_4$: Irrigation at pre-sowing + branching + flowering + pod filling + 40 kg N $ha^{-1}$, $T_5$: Irrigation at pre-sowing + branching + flowering + pod filling + 60 kg N $ha^{-1}$, $T_6$: Irrigation at pre-sowing + branching + flowering + pod filling + 60 kg N $ha^{-1}$+ 6 t FYM $ha^{-1}$ and $T_7$: Irrigation at pre sowing + branching + flowering+pod filling+60 kg N $ha^{-1}$+6 t FYM $ha^{-1}$ + insecticide + fungicide) was conducted in randomized block design replicated thrice in Agra watershed during 1990-93.

**Growth and yield attributes:** Results (Table 5.12) indicated that increase in number of irrigations and nitrogen level and addition of 6 t FYM $ha^{-1}$registered marked influence on growth and yield traits of mustard on terraced and bunded shallow Yamuna ravines. Among different treatments, combining key production factors *i.e.* irrigation at pre-sowing + branching + flowering + pod filling + 60 kg N $ha^{-1}$+ 6 t FYM $ha^{-1}$ in $T_6$ registered the maximum values of plant height (173.9 cm), primary, secondary and tertiary branches (8.3, 19.0 and 30.7, respectively), silique $plant^{-1}$ (812), seed $siliqua^{-1}$ (13.1), and test weight (5.96 g) of mustard crop. However, statistical comparisons of growth and yield attributes under some treatments have statistically at par values with $T_6$.

Mustard seed yield increased from 967 to 2268 kg $ha^{-1}$on increasing the levels of irrigation and N applications and use of FYM which registered an increase of 58 to 135% or 559 to 1301 kg mustard grain $ha^{-1}$ over the use of pre sowing irrigation + 40 kg N $ha^{-1}$ ($T_1$). Little influence of insecticide and fungicide applications was observed on mustard seed yield due to no/mild infestation of insect pests and diseases during the experimentation period (Table 5.13).

**Economics:** Alike mustard seed yield, $T_6$ also registered the highest additional gross (Rs. 10304 $ha^{-1}$) and net return (Rs. 7368 $ha^{-1}$) among different treatments (Table 5.13). The decrease in additional net return in comparison to $T_6$ corresponded to Rs. 4068, 2285, 999, 9 and 1455 $ha^{-1}$ under $T_1$, $T_2$, $T_3$, $T_4$ and $T_6$, respectively.

**Table 5.12: Average growth and yield attributes of mustard as influenced by different Nitrogen and irrigation levels (1990-93)**

| Treatment | Plant height (cm) | Number of branches $plant^{-1}$ | | | Silique $plant^{-1}$ | Seed $siliqua^{-1}$ | 1000 seed weight (g) |
|---|---|---|---|---|---|---|---|
| | | Primary | Secondary | Tertiary | | | |
| $T_1$ | 114.5 | 6.1 | 9.9 | 15.2 | 315 | 11.0 | 5.04 |
| $T_2$ | 151.9 | 6.6 | 12.7 | 22.1 | 363 | 11.6 | 5.51 |
| $T_3$ | 151.5 | 7.0 | 14.9 | 25.3 | 435 | 11.8 | 5.58 |
| $T_4$ | 160.0 | 7.5 | 15.5 | 25.6 | 512 | 12.0 | 5.68 |
| $T_5$ | 168.5 | 7.8 | 18.8 | 28.7 | 706 | 12.6 | 5.80 |
| $T_6$ | 173.9 | 8.3 | 19.0 | 30.7 | 812 | 13.1 | 5.96 |
| $T_7$ | 168.7 | 8.2 | 18.9 | 29.1 | 771 | 12.8 | 5.78 |
| CD(P=0.05) | 5.1 | 0.5 | 1.5 | 6.0 | 72 | 0.7 | 0.09 |

Table 5.13: Average seed yield of mustard, additional cost and additional net return as influenced by different Nitrogen and irrigation levels (1990-93)

| Treatment | Yield (kg ha$^{-1}$) | % increase over $T_1$ | Additional seed yield (kg ha$^{-1}$) | Additional gross return (Rs. ha$^{-1}$) | Additional cost (Rs. ha$^{-1}$) | Additional net return (Rs. ha$^{-1}$) |
|---|---|---|---|---|---|---|
| $T_1$ | 967 | - | - | - | - | - |
| $T_2$ | 1526 | 58 | 559 | 5143 | 380 | 4755 (-4068) |
| $T_3$ | 1762 | 82 | 795 | 7314 | 776 | 6538 (-2285) |
| $T_4$ | 1944 | 101 | 977 | 8988 | 1164 | 7824 (-999) |
| $T_5$ | 2104 | 118 | 1137 | 10460 | 1646 | 8814 (-9) |
| $T_6$ | 2268 | 135 | 1301 | 11969 | 3146 | 8823 (-) |
| $T_7$ | 2087 | 116 | 1220 | 10304 | 2936 | 7368 (-1455) |
| CD(P=0.05) | 171 | - | - | - | - | - |

Figures in parenthesis indicate the decrease in additional net return in comparision to $T_6$ treatment.

**Crop moisture use:** Total moisture use increased from 122.9 mm in $T_1$ (pre sowing irrigation) to 308.9 mm in $T_5$ (irrigation at pre-sowing + branching + flowering + pod filling) registering an enhancement of 151.3% in total moisture use. Also, there was just 4.9 mm in $T_5$ and $T_6$. However, moisture use efficiency registered a declining/ haphazard trend after increasing the irrigation beyond two numbers *i.e.* pre-sowing and branching (Table 5.14).

Table 5.14: Total moisture use (mm) and moisture use efficiency (kg grain ha$^{-1}$ mm) as influenced by different nitrogen and irrigation levels in mustard crop (1990-93)

| Treatment | Total moisture use | Moisture use efficiency |
|---|---|---|
| $T_1$ | 122.9 | 7.91 |
| $T_2$ | 186.7 (51.9) | 8.30 |
| $T_3$ | 248.1 (101.9) | 7.91 |
| $T_4$ | 299.4 (143.6) | 6.53 |
| $T_5$ | 308.9 (151.3) | 6.83 |
| $T_6$ | 304.0 (147.8) | 7.58 |
| $T_7$ | 300.4 (144.4) | 6.97 |

*Figures in the parenthesis indicate per cent increase in moisture use over control ($T_1$).

### 5.2.4 Nitrogen management in rainfed/ minimal irrigated mustard

Green gram-mustard is a recommended cropping system for rain fed reclaimed Yamuna ravines. Nitrogen is essential for establishment/ enhanced crop productivity both under rainfed and irrigated situations. Meanwhile, the soil moisture availability greatly influences the nutrient uptake both under rain fed and irrigated conditions since crop yields are directly related to amount of nutrients absorbed. Therefore total moisture use, moisture use efficiency, crop root penetration, growth, yield attributes and productivity of mustard crop as influenced by six nitrogen doses (0, 20, 40, 80, 120 and 160 kg ha$^{-1}$) was studied under rain fed and minimal irrigation conditions during 1986-88 in an experiment conducted in randomized block design replicated four times on sandy soil in green gram-mustard system. This study also aimed to evaluate the nutrient uptake behaviour of crops under rain fed/limited water availability in view of meagre studies on this line.

**Growth yield attributes and productivity of mustard:** Nitrogen application under rain fed conditions significantly increased the total moisture use (6.8 to 38.8 mm), grain yield (36 to 758 kg ha$^{-1}$), moisture use efficiency (0.61 to 3.71 kg ha$^{-1}$ mm), root penetration (4 to 26.8 cm), branches plant$^{-1}$ (0.4 to 3.9), silique plant$^{-1}$ (14.0 to 58), grains siliqua$^{-1}$ (2.22 to 12.2) and 100 grains weight ( 1.8 to 9.6 kg) under rain fed conditions but variations among 80, 120 and 160 kg N ha$^{-1}$ were statistically at par (Table 5.15 and 5.16). However, application of 80 kg N ha$^{-1}$ to mustard cropresulted in the highest mustard grain yield (1101 kg ha$^{-1}$) and additional returns (5504 kg ha$^{-1}$) under rain fed conditions. Results also showed that 80 kg N $ha^{-1}$ also significantly enhanced the total moisture use (184.2 mm), N content (12.82%), plant height (135 cm), silique $plant^{-1}$ (173), grains $siliqua^{-1}$(40.0) and grain yield (1231 kg $ha^{-1}$) under minimal irrigation conditions but variations among 80, 120 and 160 kg N $ha^{-1}$ were again at par. However, among N doses, 80 kg N $ha^{-1}$registered significantly higher and the highest moisture use efficiency (6.26 kg $ha^{-1}$ $mm^{-1}$), root penetration (37.8 cm), branches $plant^{-1}$(13.8), mustard grain yield (1231 kg $ha^{-1}$) and additional returns (Rs. 6428 $ha^{-1}$) under minimal irrigation conditions.

**Nutrient content and uptake:** Results showed that N, P and K content in stalk and grain reduced or maintained the status quowith application of first increment of N (20 kg $ha^{-1}$) and thereafter it normally increased with application of successive N levels (Table 5.17). Absorption pattern of nutrients (periodic contents of N and P) indicated that major uptake of N and P took place up to flowering/60 days stage while potash content in plants continued to increase till maturity. Applications of nitrogen at 80 kg $ha^{-1}$ resulted in maximum total uptake of N, P and K *i.e.* (48.3 and 60.6, 9.38 and 10.38 and 63 and 69.6 kg $ha^{-1}$ under rain fed and minimal irrigation conditions, respectively). This can be ascribed to the highest grain yield at 80 kg N $ha^{-1}$both under rain fed and minimal irrigation conditions.

**N use efficiency:** Also, 80 kg N $ha^{-1}$ increased the N use efficiency by 9.47 and 10.79 kg grain $kg^{-1}$ N which corresponded recovery of applied N by 49.3 and 62.1% under rain fed and minimal irrigation conditions, over control, respectively (Table 5.18). However, uptake of nutrients, N use efficiency and N recovery registered a sharp decline at 120 and 160 kg N $ha^{-1}$ under both rain fed and minimal irrigation conditions (Nitant and Om Prakash, 1989).

**Table 5.15: Effect of Nitrogen levels on growth, yield attributes and yields of mustard**

| Nitrogen level (kg $ha^{-1}$) | Plant height (cm) | Branches $plant^{-1}$ | Siliqua $plant^{-1}$ | Grains $siliqua^{-1}$ | 100 grains weight (g) | Yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|
| | | | **Rain fed condition** | | | |
| 0 | 90.0 | 8.5 | 84 | 16.2 | 14.4 | 343 |
| 20 | 102.0 | 8.9 | 98 | 18.4 | 16.2 | 454 |
| 40 | 110.4 | 10.2 | 102 | 22.4 | 19.4 | 660 |
| 80 | 129.8 | 12.4 | 142 | 28.4 | 24.4 | 1101 |
| 120 | 130.0 | 12.2 | 140 | 28.4 | 24.0 | 1065 |
| 160 | 130.0 | 12.1 | 132 | 27.3 | 23.9 | 909 |
| CD @ 5% | 56.4 | 2.03 | 27.7 | 6.0 | 4.9 | 216 |
| | | | **Irrigated condition** | | | |
| 0 | 97.0 | 7.0 | 95 | 16.0 | 13.2 | 368 |
| 20 | 101.0 | 8.8 | 97 | 22.0 | 15.2 | 481 |
| 40 | 112.0 | 10.6 | 129 | 28.0 | 18.8 | 769 |
| 80 | 135.0 | 13.8 | 173 | 40.0 | 30.2 | 1231 |
| 120 | 124.0 | 12.0 | 159 | 38.0 | 28.8 | 991 |
| 160 | 130.0 | 11.8 | 163 | 38.0 | 22.8 | 916 |
| CD @ 5% | 11.0 | 1.6 | 23 | 6.7 | 13.2 | 220 |

**Table 5.16: Effect of Nitrogen levels on total moisture use (TMU), moisture use efficiency (MUE) and root penetration (RP) of mustard**

| Nitrogen level (kg ha$^{-1}$) | TMU (mm) | Grain Yield (kg ha$^{-1}$) | MUE (kg grain ha$^{-1}$ mm$^{-1}$) | RP (cm) | N content (%) | Additional return (Rs. ha$^{-1}$) |
|---|---|---|---|---|---|---|
| **Rainfed condition** | | | | | | |
| 0 | 151.0 | 343 | 2.27 | 12.0 | 1.22 | - |
| 20 | 157.8 | 454 | 2.88 | 16.0 | 1.20 | 748 |
| 40 | 167.0 | 660 | 3.95 | 22.8 | 1.84 | 2304 |
| 80 | 184.2 | 1101 | 5.98 | 38.8 | 2.68 | 5504 |
| 120 | 187.1 | 1065 | 5.69 | 38.6 | 2.74 | 4984 |
| 160 | 189.8 | 909 | 4.79 | 38.2 | 2.80 | 3408 |
| CD (P=5%) | 9.3 | 216 | 1.56 | 13.8 | 0.37 | |
| **Irrigated condition** | | | | | | |
| 0 | 150.4 | 368 | 2.45 | 15.4 | 1.38 | - |
| 20 | 161.9 | 481 | 2.97 | 18.2 | 1.32 | 908 |
| 40 | 178.3 | 769 | 4.32 | 22.8 | 1.98 | 2932 |
| 80 | 196.7 | 1231 | 6.26 | 37.8 | 2.82 | 6428 |
| 120 | 192.5 | 991 | 5.15 | 30.2 | 2.84 | 4144 |
| 160 | 192.2 | 916 | 4.77 | 29.4 | 2.90 | 3304 |
| CD (P=5%) | 10.8 | 220 | 0.98 | 5.6 | 0.37 | |

TMU: total moisture use, RP: root penetration

**Table 5.17: Nutrient uptake (kg ha$^{-1}$) by mustard under varying Nitrogen rates**

| Nitrogen level (kg ha$^{-1}$) | Rain fed condition | | | Minimal irrigation condition | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| 0 | 8.86 | 1.49 | 11.78 | 10.9 | 1.63 | 14.3 |
| 20 | 12.04 | 1.70 | 26.31 | 15.1 | 2.45 | 22.8 |
| 40 | 27.73 | 3.56 | 32.01 | 27.8 | 4.73 | 34.9 |
| 80 | 48.30 | 9.38 | 63.02 | 60.6 | 10.38 | 69.6 |
| 120 | 42.96 | 8.43 | 49.84 | 45.4 | 8.39 | 51.9 |
| 160 | 39.23 | 7.85 | 47.79 | 42.5 | 8.82 | 51.6 |
| CD @ 5% | 19.3 | 4.09 | 21.3 | 22.0 | 4.02 | 23.8 |

**Table 5.18: Nitrogen use efficiency and Nitrogen (%) recovery from applied fertilizer by mustard under rainfed and minimal irrigation conditions**

| Nitrogen rate (kg ha$^{-1}$) | N use efficiency (kg grain kg$^{-1}$ N) | | N recovery (%) | |
|---|---|---|---|---|
| | Rainfed | Minimal irrigation | Rainfed | Minimal irrigation |
| 0 | - | - | - | - |
| 20 | 5.55 | 5.68 | 15.9 | 21.0 |
| 40 | 7.93 | 8.13 | 34.7 | 42.2 |
| 80 | 9.47 | 10.79 | 49.3 | 62.1 |
| 120 | 6.02 | 5.19 | 28.4 | 28.7 |
| 160 | 3.54 | 3.43 | 20.0 | 19.8 |

### 5.2.5 Urea fertilized green manure

Three popular green manure crops (GM) *viz.* sunhemp, dhaincha and cluster bean, were grown (0, 10 and 20 kg ha$^{-1}$) and evaluated during 2001-06 maintaining two control ($N_{120}$ and no GM and no N) in randomized block design replicated thrice. Urea was applied to achieve higher green biomass production and also to narrow down the C:N ratio for enhanced decomposition of residues, moisture conservation and sustained productivity of wheat crop on class III land. The wheat crop was fertilized with 125 kg N ha$^{-1}$ both with and without green manure crops. The 50 kg N ha$^{-1}$ was applied as top dressing in wheat in all the treatments including without green manure treatment. Phosphorus was applied (60 kg ha$^{-1}$) in all the treatments as basal dose at sowing.

**Green biomass:** Results showed that green manure crops fertilized with 20 kg N ha$^{-1}$ registered higher green biomass over use of 10 kg N ha$^{-1}$ (0.6, 0.6 and 0.4 t ha$^{-1}$ in sun hemp, dhaincha and cluster bean, respectively. However the maximum green biomass (11.2 t ha$^{-1}$) was registered under sun hemp fertilized with 20 kg N ha$^{-1}$.

**Soil moisture (0-15 cm):** Data (Table 5.21) revealed that higher soil moisture in 0-15 cm soil depth was recorded under sun hemp fertilized with 20 kg N ha$^{-1}$ (16.6 t ha$^{-1}$) while minimum soil moisture in 0-15 cm layer was noticed under $N_{120}$ ($T_1$).

**Crop productivity:** The highest mean wheat grain yield (4860 kg ha$^{-1}$) was obtained under dhaincha fertilized with 20 kg N ha$^{-1}$. Similarly the highest mustard grain yield (2094 kg ha$^{-1}$) was also registered under dhaincha green manure fertilized with 20 kg N ha$^{-1}$(Table 5.19) (Nitant and Inderpal, 2004).

**Table 5.19: Green biomass, soil moisture and yield of wheat and mustard under green manuring (2001-05)**

| Treatment | Average green biomass (t ha$^{-1}$) | Average moisture content (%) (0-15 cm) (Nov. 04 to Nov. 06) | Wheat grain yield (kg ha$^{-1}$) | Mustard grain yield (kg ha$^{-1}$) | Nitrogen added to soil (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| $T_1$: $N_{120}$ | - | 10.0 | 2880 | 1220 | 72.6 |
| $T_2$: Sunhemp $N_{10}$ | 10.6 | 15.2 | 3780 | 1338 | 75.8 |
| $T_3$: Sunhemp $N_{20}$ | 11.2 | 16.6 | 4210 | 1976 | 69.8 |
| $T_4$: Dhaincha $N_{10}$ | 10.2 | 14.8 | 3828 | 1425 | 74.8 |
| $T_5$: Dhaincha $N_{20}$ | 10.8 | 15.8 | 4860 | 2094 | 67.8 |
| $T_6$: Cluster bean $N_{10}$ | 7.8 | 15.0 | 4384 | 1763 | 70.2 |
| $T_7$: Cluster bean $N_{20}$ | 8.2 | 15.6 | 4425 | 1953 | - |
| $T_8$: Control (No GM) + (No N) | - | 10.4 | 1022 | 392 | - |

- means no sample

### 5.2.6 Nitrogen fertilization in green manure-mustard system

The efficiency of applied N in mustard crop in $CaCO_3$ rich eroded soils hardly exceeds 35% even with best agronomic/conservation measures due to rapid loss of N from the soil/plant system. Besides, mustard responds to other nutrients like Zn and sulphur, which are not yet applied by the farmers. However, residues of green manures also contain nutrients like Zn and S. Therefore, present experiment conducted during 1998-2001 in randomized block design replicated thrice involved twelve treatments ($N_0$ (control), $N_{40}$, $N_{80}$, $N_{120}$, $SN_{40}$, $SN_0$, $SN_{40}$, $SN_{120}$, $DN_0$, $DN_{40}$, $DN_{80}$, $DN_{120}$) maintaining a control ($N_0$). The study investigated the effect of green manure on N use, total crop moisture use, moisture use efficiency, organic carbon, pH and crop yield.

**Crop moisture use:** Results revealed that use of N with GM improved both total moisture use (TMU) and moisture use efficiency (MUE) over no nitrogen/control. Data (Table 5.22) further revealed that each successive increment in N dose recorded higher TMU and WUE upto 120 kg N $ha^{-1}$ under sole use of N fertilizers and combining GM and N fertilizers was in order of dhaincha GM + N> sun hemp GM + N> sole use of N fertilizer. The highest TMU of 216.4 mm was recorded under sun hemp GM + 80 kg N $ha^{-1}$ while the highest MUE was recorded under sun hemp GM + 120 kg N $ha^{-1}$.

**Crop productivity:** Data (Table 5.22) showed that maximum average mustard grain yield of 1656 kg $ha^{-1}$ was recorded under sun hemp GM + 80 kg N $ha^{-1}$.

**Organic carbon and pH:** The organic carbon content and soil pH were most favorably changed to 0.54% and 7.4 under sun hemp + 80 kg N $ha^{-1}$, respectively. Thus, green manure + N application resulted in sustained higher productivity and increased N use efficiency under mustard crop in Semi-Arid Agra region (Table 5.20).

**Table 5.20: Grain yield, total moisture use and organic C content under different treatments (Average of three years)**

| Treatment N (kg $ha^{-1}$) + GM | Yield (kg $ha^{-1}$) | TMU (mm) | MUE (kg grain $mm^{-1}$) | OC (%) | pH |
|---|---|---|---|---|---|
| $N_0$ (Control) | 285 | 150.8 | 1.71 | 0.28 | 8.4 |
| $N_{40}$ | 731 | 170.2 | 4.29 | 0.32 | 8.4 |
| $N_{80}$ | 1243 | 196.4 | 6.33 | 0.34 | 8.3 |
| $N_{120}$ | 1251 | 196.0 | 6.38 | 0.36 | 8.3 |
| $SN_{40}$ | 466 | 162.4 | 2.87 | 0.40 | 8.0 |
| $SN_0$ | 1295 | 182.8 | 7.08 | 0.46 | 7.8 |
| $SN_{40}$ | 1656 | 216.4 | 7.65 | 0.54 | 7.4 |
| $SN_{120}$ | 1640 | 214.2 | 7.66 | 0.50 | 7.4 |
| $DN_0$ | 392 | 158.4 | 2.47 | 0.38 | 8.0 |
| $DN_{40}$ | 1264 | 178.2 | 7.09 | 0.46 | 7.8 |
| $DN_{80}$ | 1522 | 212.4 | 7.24 | 0.48 | 7.6 |
| $DN_{120}$ | 1540 | 210.8 | 7.31 | 0.48 | 7.6 |

$N_{40}$ mean 40 kg N $ha^{-1}$ and likewise SN means sun hemp and DN means dhaincha.

### 5.2.7 Substitution of nitrogen through *Leucaena* green leaves

The poor water/nutrient holding capacity of sandy loam soils of reclaimed Yamuna ravines inter links with low soil organic matter/clay content, therefore, a field study involving six treatments ($T_1$: Control/no N application, $T_2$: 100 kg N $ha^{-1}$ through urea without *Leucaena* rows, $T_3$: 100 kg N $ha^{-1}$ through urea, $T_4$: 25 kg N $ha^{-1}$ through *Leucaena* leaves + 75 kg N $ha^{-1}$ through urea, $T_5$: 50 kg N $ha^{-1}$ through *Leucaena* leaves + 50 kg N $ha^{-1}$ through urea and $T_6$: 100 kg N $ha^{-1}$ through *Leucaena* leaves) was conducted in randomized block design replicated four times in order to assess the effect of subabul leaf biomass incorporation as a substitute of N fertilizer in pearl millet and wheat crops, its effect on soil fertility and net returns. Green *Leucaena* leaves containing about 3% nitrogen on dry weight basis were incorporated into the soil before sowing of wheat crop.

**Crop productivity:** Results showed that maximum wheat grain yield (3418 kg $ha^{-1}$) was recorded under 25 kg $ha^{-1}$ through *Leucaena* leaves + 75 kg N $ha^{-1}$ supplemented through urea ($T_4$) (Table 5.21). This showed that well managed *Leucaena* plants pruned at 75 cm height in alley cropping did not exert any suppressing effect on growth and yield of wheat. Among treatments involving substitution of N, 25% substitution of N

**Table 5.21: Grain yield (kg ha$^{-1}$) of wheat as influenced by source of Nitrogen (1994-97)**

| Treatment | 1994-95 | 1995-96 | 1996-97 | 1997-98 | Av. yield of pearl millet | Av. yield of wheat |
|---|---|---|---|---|---|---|
| $T_1$: Control (without N application) | 895 | 903 | 733 | 950 | 919 | 870 |
| $T_2$: 100 kg N through urea (without *Leucaena* rows) | 4035 | 2423 | 2643 | 3437 | 2048 | 3137 |
| $T_3$: 100 kg N throughurea | 4010 | 2135 | 2495 | 3556 | 1985 | 3049 |
| $T_4$: 25 kg N through *Leucaena* leaves + 75 kg N through urea | 4428 | 2535 | 3276 | 3843 | 1987 | 3418 |
| $T_5$: 50 kg N through *Leucaena* leaves + 50 kg N through urea | 3940 | 1630 | 2513 | 3625 | 1999 | 2937 |
| $T_6$: 100 kg N through *Leucaena* leaves | 3460 | 1340 | 2035 | 3281 | 2055 | 2529 |
| Sem (I) | 260 | 40 | 126 | 132 | - | - |
| CD @ 5% | 559 | 185 | 269 | 282 | - | - |

through *Leucaena* leaves resulted in significantly higher wheat grain yield (3418 kg ha$^{-1}$) than 50% (2937 kg ha$^{-1}$) and 100% (2529 kg ha$^{-1}$) substitution of N through *Leucaena* leaves. The plant height and yield contributing character of wheat under 25% substitution of N also registered higher values over 50 and 100% substitution of N by *Leucaena* leaves. Residual effect of *Leucaena* leaves biomass incorporation in wheat crop was also observed on pearl millet crop. Substitution of 100% nitrogen through *Leucaena* leaves resulted in higher grain yield of pearl millet (2055 kg ha$^{-1}$) than 25% substitution of N (1987 kg ha$^{-1}$). Organic carbon (0.29%), available N (164.6 kg ha$^{-1}$), P (23.4 kg ha$^{-1}$) and K (17.2 kg ha$^{-1}$) also increased under 100% substitution of fertilizer N through *Leucaena* biomass after 4 years. The highest net returns (Rs. 16172 ha$^{-1}$, base year-2002) and benefit: cost ratio of 1.98 were obtained under 25% substitution of N by *Leucaena* leaves (Om Prakash and Bhushan, 2003).

### 5.2.8 Green manure-wheat/mustard system

Green manuring, a traditional practice having high social acceptability and cost effectiveness, was very effective in achieving the sustained higher productivity and soil fertility/health build up in a study in semi-arid Agra region in Indo-gangetic alluvial plain zone. The technology involves sowing seeds of dhaincha (25-30 kg ha$^{-1}$) or sun-hemp (50-60 kg ha$^{-1}$) with basal application of 20 kg N ha$^{-1}$ at the onset of monsoon and under-ploughing green biomass of sun-hemp at 35-50 and of dhaincha at 60-75 days crop stage. The wheat and mustard in sequence are raised following recommended package of practices. Green manure has a potential to produce about 78-112 q green biomass ha$^{-1}$ which on incorporation in soil improves residual moisture by 4.8 to 6.6% in crop root zone (0-15 cm) and adds about 74.8 kg N ha$^{-1}$ in soil over no green manure practice. Results of a study with green manure showed that application of 10 kg N ha$^{-1}$ to sun-hemp green manure crop + application of 80 kg N ha$^{-1}$recorded the highest wheat grain yield and registered maximum improvement in 1000 grain weight. The dhaincha green manure improves total soil moisture use (216.4 mm) and moisture use efficiency (7.65 kg grain per mm of water) of mustard crop in green manure-mustard system by encouraging deep crop root penetration in soil (up to 41.2 cm). The practice improves soil organic carbon (from about 0.20 to 0.54%), ameliorates the pH (8.4 to 7.4), promotes soil and water conservation and improves soil physical properties. The technology enhances wheat grain yield by 900-1980 kg ha$^{-1}$ and of mustard by 118-874 kg ha$^{-1}$ over normally fertilized wheat and mustard crop @ 120 and 80 kg N $ha^{-1}$, respectively. Green manure-wheat/mustard fetched an average net return of Rs. 30000-32000 which is higher than use of recommended chemical fertilizers alone in pearl millet/fallow-mustard system (farmer's practice). The technology especially suits to light textured and poorly fertile soils of reclaimed Yamuna ravines in Semi-Arid regions.

**Table 5.22: Cowpea yield (kg $ha^{-1}$) as affected by various doses of $P_2O_5$ fertilizers (1971-73)**

| Doses of $P_2O_5$ (kg $ha^{-1}$) | Grain yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) |
|---|---|---|
| 0 | 225 | 2169 |
| 20 | 417 | 2500 |
| 40 | 369 | 2659 |
| 60 | 465 | 2962 |
| 80 | 641 | 3199 |
| 100 | 536 | 2967 |
| 120 | 482 | 2770 |

### 5.2.9 Response of cowpea to different levels of Phosphorus

Cowpea on account of its quick growth potential provides more ground cover. This attracts the attention of soil and water conservationist to protect the soil from rain drop impact and splash erosion. Its growth close to down offers certain obstructions to runoff flow while its deep and ramified root system exerts beneficial effect on soil binding apart from soil fertility build up due to nitrogen fixation and easy to composition of crop residues (narrow C:N ratio). However, cowpea growth is not fully realized on nutrient poor reclaimed Yamuna ravines. Therefore, to achieve higher root and shoot growth of cowpea and to economize phosphorus dose on reclaimed Yamuna ravines, a field experiment was conducted during 1971-73 involving seven doses of $P_2O_5$ (0, 20, 40, 60, 80, 100 and 120 kg $ha^{-1}$) in randomized block design replicated thrice. The results show that 80 kg $P_2O_5$ $ha^{-1}$ registered the highest and significantly higher grain yield of cowpea. Use of 80 kg $P_2O_5$ $ha^{-1}$ also registered the highest straw yield but variations were at par with 60 and 100 kg $P_2O_5$ $ha^{-1}$. The results further show that 80 kg $P_2O_5$ $ha^{-1}$ also registered the highest values of depth of main root, dry weight of root, volume of root and lateral spread of roots at flowering and harvesting stages.

**Table 5.23: Effect of different doses of phosphoric fertilizers on root development of cowpea.**

| Doses of $P_2O_5$ $ha^{-1}$ | Depth of main root (mm) | | Digging of main root (mm) | | Dry weight of roots (g $plant^{-1}$) | | Volume of roots ($cm^3$ $plant^{-1}$) | | Lateral spread of roots (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | * | ** | * | ** | * | ** | * | ** | * | ** |
| 0 | 27.2 | 41.5 | 3.69 | 4.1 | 1.10 | 1.20 | 1.35 | 1.68 | 26.4 | 34.4 |
| 20 | 29.5 | 43.8 | 4.23 | 4.43 | 1.63 | 1.43 | 1.82 | 2.12 | 28.9 | 35.8 |
| 40 | 31.5 | 46.2 | 4.58 | 4.62 | 2.05 | 1.85 | 2.59 | 2.51 | 32.0 | 37.2 |
| 60 | 32.0 | 47.5 | 5.23 | 5.39 | 2.15 | 2.09 | 2.71 | 3.26 | 32.9 | 40.4 |
| 80 | 36.5 | 50.3 | 5.34 | 5.62 | 2.55 | 2.35 | 3.12 | 3.57 | 38.4 | 40.8 |
| 100 | 33.8 | 48.6 | 5.04 | 5.25 | 1.79 | 1.89 | 2.16 | 2.73 | 32.1 | 38.3 |
| 120 | 32.8 | 45.7 | 4.46 | 4.87 | 1.80 | 1.41 | 2.09 | 2.33 | 32.2 | 36.0 |
| S Em (±) | 1.2 | 1.3 | 0.41 | 0.34 | 0.17 | 0.26 | 0.52 | 0.60 | 2.30 | 1.3 |
| CD @ 5% | 3.7 | 4.1 | NS | NS | NS | NS | NS | NS | NS | 4.1 |

*At flowering stage, **At harvesting stage

### 5.2.10 Nutrient management in lentil

This study was conducted in Jalalpur and Dhanina villages of NWDPRA watershed during 2009-10. Lentil (Cv. K-75) was sown rain fed on fields of 12 farmers which were having wide variations in crop history and soil texture (light to heavy)/fertility/water holding potential in the first fort night of November.

Results (Table 5.24) revealed that performance of farmer's practice and no fertilizer treatments was almost at par. Numerically higher grain yield of lentil in no fertilizer treatment than farmer's practice may be attributed due to high yielding seed of lentil provided to the farmers which was used in no fertilizer treatment. Farmer's used their own old variety in farmer's practice treatment. Data (Table 5.24) indicated that all nutrient management treatments invariably improved the grain and straw yield of lentil over farmer's practice which ranged from 10.58% in $T_3$ (PSB) to 46.85% in $T_7$ (Use of PSB + *Rhizobium* + RDF). Similarly, improvement in straw yield of lentil due to nutrient management treatments over farmer's practice ranged from 8.43% in $T_3$ to 41.11% in $T_7$. Seed treatment with *Rhizobium* was superior to PSB while *Rhizobium* + PSB were superior to independent use of either *Rhizobium* or PSB. Similarly, use of *Rhizobium* + PSB + RDF was superior to RDF in producing higher grain and straw yield of lentil.

### 5.2.11 Nutrient management in gram

This on farm study (OFR) was also conducted in Jalalpur and Dhanina villages of NWDPRA watershed in Agra district during 2009-10 on the fields of 9 farmers having wide variability in cropping history/soil characteristics. Four high yielding varieties of gram (Cv. Udai, Vijai, Pusa 362 and J 6-16) were evaluated against the unidentified old varieties of farmers (farmer's practice) under following nutrient management treatments (Table 5.25).

**Table 5.24: Effect of nutrient management treatments on grain, straw and biological yield (kg ha$^{-1}$) of lentil and harvest index in Semi-Arid Agra region**

| Treatment | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | Biological yield (kg ha$^{-1}$) | Harvest index (kg ha$^{-1}$) |
|---|---|---|---|---|
| $T_1$: Farmer's practice | 887.17 | 1064.33 | 1951.50 | 45.46 |
| $T_2$: No fertilizer | 896.83 | 1053.33 | 1950.16 | 45.99 |
| $T_3$: Seed treatment with Phosphorus Solubilizing Bacteria (PSB) | 981.00 | 1135.08 | 2116.08 | 46.36 |
| $T_4$: Seed treatment with *Rhizobium* | 1073.58 | 1227.00 | 2300.58 | 46.67 |
| $T_5$: Seed treatment with PSB + *Rhizobium* | 1115.58 | 1268.33 | 2383.92 | 46.80 |
| $T_6$: Use of recommended dose of fertilizers (RDF) | 1185.58 | 1323.00 | 2508.58 | 47.26 |
| $T_7$: Use of PSB + *Rhizobium* + RDF | 1302.83 | 1450.83 | 2753.67 | 47.31 |

**Table 5.25: Mean performance of four gram varieties under different nutrient management treatments in respect of grain, straw and biological yield (kg ha$^{-1}$) and harvest index in Semi-Arid region of Agra**

| Treatment | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | Biological yield (kg ha$^{-1}$) | Harvest index (kg ha$^{-1}$) |
|---|---|---|---|---|
| $T_1$: Farmer's practice | 561.22 | 691.33 | 1252.56 | 44.83 |
| $T_2$: No fertilizer | 579.78 | 711.11 | 1290.84 | 44.94 |
| $T_3$: Seed treatment with Phosphorus solubilizing bacteria (PSB) | 640.33 | 779.44 | 1419.78 | 45.18 |
| $T_4$: Seed treatment with *Rhizobium* | 706.11 | 845.33 | 1551.44 | 45.60 |
| $T_5$: Seed treatment with PSB + *Rhizobium* | 826.22 | 975.00 | 1801.22 | 45.92 |
| $T_6$: Use of recommended doses of fertilizers (RDF) | 876.00 | 1026.89 | 1902.89 | 46.09 |
| $T_7$: Use of PSB + *Rhizobium* + RDF | 960.78 | 1116.67 | 2077.44 | 46.29 |

Results (Table 5.25) revealed that yield performance under farmer's practice and no fertilizer treatment was almost at par. Numerically higher grain yield of gram in no fertilizer treatment than farmer's practice may be attributed due to high yielding seed of gram provided to the farmers in no fertilizer treatment while farmer's used their own old variety in farmer's practice treatment. Data indicated that all nutrient management options invariably improved the lentil grain yield over farmer's practice which ranged from 10.58% in $T_3$ (PSB) to 46.85% in $T_7$ (PSB + *Rhizobium* + RDF). Similarly, nutrient management treatments also improved straw yield of lentil over farmer's practice which ranged from 8.43% in $T_3$ to 41.11% in $T_7$. Seed treatment with *Rhizobium* was superior to PSB while *Rhizobium* + PSB were superior to independent use of either *Rhizobium* or PSB. Similarly, *Rhizobium* + PSB + RDF were superior to RDF in producing higher grain and straw yield of gram.

### 5.2.12 Restoration of soil fertility of newly terraced ravine land

Land development involves earth-moving processes (cut portion with low fertility/nutrients/ organic carbon and vice versa in filled portion), therefore exposed sub soil/ cut portion is poor in crop productivity during initial years after land development. This study assesses the susceptibility of different crops to various depth of cut of soil and to find out the corrective measures to avert the loss in productivity. The experiment was conducted on farmers' field on newly terraced land. The difference in crop production on eroded fields (cut section) as compared to control plots revealed the loss of productivity due to top soil removal. Organic carbon and available nitrogen phosphorus and potassium were lower in cut portions than in the filled portion. The Ao horizon rich in organic carbon and nutrients is the zone of biological activity. Therefore, to restore the fertility of cut portion at par with Ao horizon, the zone of biological activity, different levels of FYM (5-10 t $ha^{-1}$) and chemical fertilizers and high yielding variety of wheat (Lok 1) and mustard (T 59) were evaluated in Agra watershed based on soil analysis and nutrient requirement of different crops. Results of four year study (1988-91) reveal that grain yield of wheat and mustard registered a considerable increase from 2212 to 3548 kg $ha^{-1}$ (60.4%) and from 956 to 1632 kg $ha^{-1}$ (70.7%) over farmer's practice, respectively. Thus 1336 and 676 kg $ha^{-1}$ additional grain yield of wheat and mustard was realized under use of FYM + fertilizers + high yielding varieties which fetched an additional net return of Rs. 2626 and Rs. 4089 $ha^{-1}$ over the farmer's practice, respectively (Table 5.26).

**Table 5.26: Grain yield (kg $ha^{-1}$), gross and net return (Rs. $ha^{-1}$) and additional yield (kg $ha^{-1}$) under demonstration of FYM + fertilizers + high yielding crop varieties and farmer's practice / non-demonstration in Agra watershed**

| Year | Grain yield (kg $ha^{-1}$) | Gross return under improved agro-techniques (Rs. $ha^{-1}$) | Net return over local practice (Rs. $ha^{-1}$) | Additional grain yield (kg $ha^{-1}$) |
|---|---|---|---|---|
| | | Wheat | | |
| 1988 | 3323 (2099) | 8528 (5346) | 3698 | 1224 |
| 1989 | 3500 (2178) | 10125 (6333) | 5295 (2552) | 1322 |
| 1990 | 3723 (2049) | 10770 (5958) | 5770 (1958) | 1674 |
| 1991 | 3645 (2520) | 14740 (10190) | 9740 (5990) | 1125 |
| **Mean** | **3548 (2212)** | **11041 (5957)** | **6126 (3500)** | **1336** |
| | | Mustard | | |
| 1988 | 1722 (963) | 10332 (5778) | 7757 (3653) | 759 |
| 1989 | 1565 (750) | 10173 (4875) | 7598 (2750) | 815 |
| 1990 | 1840 (1209) | 11960 (7858) | 9360 (5658) | 613 |
| 1991 | 1400 (900) | 11200 (7200) | 8600 (4900) | 500 |
| **Mean** | **1632 (956)** | **10916 (6428)** | **8329 (4240)** | **676** |

Results of an another study in green gram–mustard sequence on newly developed bench terraces (Table 5.27) reveal that different treatments registered significant variations in the grain yield but $T_4$ recorded the highest and significantly higher yield performance which establishes the superiority of *Leucaena* mulch over FYM on reclaimed Yamuna ravines. This can be ascribed to leguminous residue of *Leucaena* having narrow C:N ratio quickly mineralized and gave immediate nutrient benefits while nutrient release from FYM is relatively slower. This treatment outperformed the recommended fertilizer dose which indicates possibilities of favorable influence of leguminous mulch on physical soil conditions and more *in situ* soil water retention.

In mustard crop, results depict that recommended dose of fertilizers + irrigation in six splits at the stages when soil experienced moisture deficit registered significantly higher grain yield registering 158.54, 46.68 and 26.19% higher values that corresponded to 9.75, 5.06 and 3.84 q $ha^{-1}$ over $T_1$, $T_2$ and $T_4$, respectively. Further recommended dose of fertilizers + *Leucaena* mulch @ 5 t $ha^{-1}$ recorded significantly higher mustard grain yield over recommended fertilizers + two irrigations which pin points that effect of *in situ* rain water conservation by leguminous residue mulch far exceeded the influence of two irrigations on newly developed bench terraces in mustard crop. Thus, lower soil profile moisture on irrigation in six splits and *Leucaena* mulch can be linked to immediate and more utilization of moisture by crop and its favorable effect on germination, growth, flowering, pod setting and pod filling. Thus, recommended doses of fertilizers along with six split irrigations through sprinkler should be used in mustard crop on newly developed bench terraced in Yamuna ravines.

**Table 5.27: Grain yield (q $ha^{-1}$) of green gram and mustard under different irrigation and fertilizer treatment**

| Treatment | Mustard (q $ha^{-1}$) | Treatment | Green gram (q $ha^{-1}$) |
|---|---|---|---|
| $T_1$: Control | 6.15 | $T_1$: Control | 3.16 |
| $T_2$: Recommended NPK + $I_1$, $I_2$ | 10.84 | $T_2$: Recommended NPK | 3.63 |
| $T_3$: $T_2$+($I_{1/3}$+$I_{1/3}$+$I_{1/3}$, $I_{1/3}$+$I_{1/3}$+$I_{1/3}$) | 15.90 | $T_3$: $T_2$+5 t FYM $ha^{-1}$ | 4.24 |
| $T_4$: $T_2$+*Leuceana* mulch @ 5 t $ha^{-1}$ | 12.06 | $T_4$: $T_2$+*Leuceana* mulch @ 5 t $ha^{-1}$ | 5.08 |
| *CD (P=0.05)* | 0.68 | *CD (P=0.05)* | 0.20 |

### 5.2.13 Long term fertility management

A long-term fertility experiment was conducted during 1978 to 2001 on sandy loam soil of reclaimed Yamuna ravines to assess the effect of manures and fertilizers on the grain yield of pearl millet-wheat system and its impact on soil fertility. Nine treatments ($T_1$: control, $T_2$: recommended NPK, $T_3$: N on soil test basis, $T_4$: NP on soil test basis, $T_5$: NPK on soil test basis, $T_6$: Farm yard manure 5 t $ha^{-1}yr^{-1}$, $T_7$: 15 t FYM $ha^{-1}$ every third year, $T_8$: recommended NPK + 5 t FYM $ha^{-1}yr^{-1}$ and $T_9$: recommended NPK + 15 t FYM $ha^{-1}$ every third year) were replicated thrice in randomized block design. Results showed that application of fertilizer based on recommended doses or on the basis of soil test were statistically at par in producing grain yield of crops. Recommended fertilizers in combination with 5 t FYM $ha^{-1}yr^{-1}$ registered the highest grain yields of 1524 and 2825 kg $ha^{-1}$ of pearl millet and wheat, respectively. Organic carbon content was increased from 0.16 to 0.28% due to the application of recommended NPK + FYM. The available N, $P_2O_5$ and $K_2O$ were also increased over the control on application of organic manures and fertilizers. Higher water stable aggregates were also recorded in this treatment (Fig. 5.1). The infiltration rate was also higher *i.e.* 3.0 cm $hr^{-1}$ in this treatment *i.e.* recommended NPK + 5 t FYM $ha^{-1}$ $yr^{-1}$(Gawande, 2001).

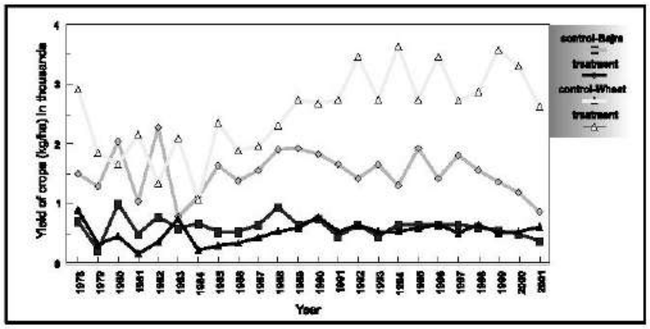



**Fig. 5.1: Effect of long-term fertility management on sustainability and yield of crops.**

## 5.3 Residual Soil Moisture Conservation/ Supplementary Irrigation for Higher and Sustainable Production

### 5.3.1 Surface mulching/conservation irrigation in mustard

The present study was carried out to evaluate the effect of mulching on soil moisture conservation and yield of mustard under situation of with and without supplemental irrigation in green gram-mustard system on reclaimed Yamuna ravines.

**Conservation of soil moisture under dust mulch:** The mustard crop was sown by middle of October after harvesting of green gram in middle September when climatic conditions are available. During this one month period moisture was lost through evaporation. Data reveal that during these 3 weeks 43 mm soil moisture was lost in plots which were immediately not cultivated after harvest of green gram. In dust mulch plots, loss of soil moisture during this period corresponded to 28 mm, thus 16.5% soil moisture was conserved in dust mulch plot at time of sowing of mustard.

**Fluctuation in soil temperature:** Fluctuation in soil temperature was also monitored at two soil depths (0-5 and 5-10 cm) under control and grass mulch plotsat seedling emergence and flowering stage of mustard crop. Results show that during day time higher temperature was recorded in un-mulch plots than grass mulch plots while during night hours the case was reverse. At 0-5 cm depth the difference in highest temperature was 5.5°C.

**Crop water use:** The crop in control plot utilized 70 mm of soil moisture for its maturity but maximum crop water utilization was observed where irrigation was provided at flowering (146 mm) (Table 5.28).

**Crop yield:** Maximum mustard grain yield (2429 kg $ha^{-1}$) was recorded in plots where pre-sowing irrigation + irrigation at flowering was applied (Table 5.28). In control plot, mustard grain yield was 763 kg $ha^{-1}$ which was increased to 1011 kg $ha^{-1}$ on use of dust mulch, thus registering an increase of 32%. Mustard grain yield was further increased to 1251 kg $ha^{-1}$ on use of grass mulch at harvest of green gram. Thus mustard grain yield enhancement due to use of grass mulch yield corresponded to 64% over the control. This can be ascribed to more moisture conservation and decline in soil temperature due to surface mulching (Bhushan, 1989).

**Table 5.28: Grain yield of mustard and crop moisture use as affected by surface mulching**

| Treatment | Grain yield (kg $ha^{-1}$) | Crop moisture use (mm) |
|---|---|---|
| A. Control | 763 | 70 |
| B. A + pre irrigation | 1485 | 109 |
| C. B + irrigation at flowering | 2429 | 146 |
| D. Dust mulching after harvesting of green gram | 1011 | 76 |
| E. D+Grass mulch till sowing of mustard | 1251 | 79 |
| F. D + grass mulch till harvest of mustard | 1333 | 96 |
| G. D + PRI IRRI | 1437 | 104 |
| H. D + PRI + Grass mulching | 1544 | 106 |

### 5.3.2 Land modification system for enhanced rain water conservation

Uneven distribution of rainfall is a common feature in semi-arid Agra region which greatly influences the success of pearl production. Therefore, land modification for higher rain water conservation to provide stability in yield of pearl millet crop, a three years study on land modification systems which was then combined with surface mulching was conducted at Agra centre. Results show that land modification system (sowing of pearl millet on ridges) provided 10-20% higher grain yield of pearl millet crop (Table 5.29). Use of surface mulch at the flag end of monsoon produced about 20% higher grain yields over unmulched control.

**Table 5.29: Average yield of pearl millet as affected by planting methods and surface mulching (1988-86)**

| Treatment | Pearl millet grain yield (kg ha$^{-1}$) | % increase over control |
|---|---|---|
| $T_1$: Flat & uniform sowing (40 cm) | 1227 | - |
| $T_2$: Flat & paired row sowing (20-60 cm) | 1304 | 6.3 |
| $T_3$: Sowing on ridges (40 cm) | 1469 | 19.7 |
| $T_4$: $T_1$ + earthing up after 3 weeks | 1335 | 8.8 |
| $T_5$: $T_2$ + earthing up after 3 weeks | 1344 | 9.5 |
| $T_6$: Sowing two rows on raised bed | 1347 | 9.8 |
| $T_7$: Sowing paired rows on raised bed | 1418 | 15.6 |
| With surface mulching | 1740 | 18.5 |
| Without surface mulching | 1468 | |

### 5.3.3 Efficacy of vegetative barriers at 3% slope

A study on runoff plots (30 m x 5 m) at 3% slope equipped with multi-slot devisers on sandy loam soil texture (sand silt and clay 77.0, 10.5 and 12.5%, respectively) with 15 to 25% $CaCO_3$ content aimed to evaluate the efficacy of vegetative barriers in controlling the soil erosion was conducted involving seven treatments ($T_1$: Green gram pure, $T_2$: $T_1$+ one row of *C. ciliaris* at 20 m, $T_3$: $T_1$ + one row of *C. ciliaris* at 30 m, $T_4$: $T_1$ + two rows of *C. ciliaris* at 20 m, $T_5$: Green gram + one row of *Agave* at 30 m, $T_6$: *C. ciliaris* pure, $T_7$: Cultivated fallow). Green gram was raised in all the plots except cultivated fallow ($T_7$). Results depict that maximum erosion losses (runoff 264.48 mm and soil loss 19.31 t ha$^{-1}$) were recorded under cultivated fallow and minimum under pure stand of *C. ciliaris* (runoff 60.71 mm and soil loss 1.4 t ha$^{-1}$). Barriers of two rows of *C. ciliaris* proved best which reduced runoff to almost half (57%) while soil loss was reduced to almost one fourth (23%) than cultivated fallow. Grain yield of green gram was also maximum on imposition of two rows of *C. ciliaris* barrier (Table 5.30).

**Table 5.30: Runoff (mm) and soil loss (t ha$^{-1}$) as influenced by different sets of vegetative barriers at 3% runoff plots (mean annual rainfall: 586 mm)**

| Treatment | Runoff | | | | Soil loss | | | |
|---|---|---|---|---|---|---|---|---|
| | 1996 | 1997 | 1999 | Average | 1996 | 1997 | 1999 | Average |
| $T_1$: Green gram pure | 70 | 78 | 217.2 | 121.23 | 3.11 | 0.86 | 18.5 | 7.49 |
| $T_2$: $T_1$ + one row of *C. ciliaris* at 20 m | 77 | 84 | 192.4 | 117.80 | 3.41 | 0.78 | 8.9 | 4.36 |
| $T_3$: $T_1$ + one row of *C. ciliaris* at 30 m | 63 | 43 | 173.9 | 93.30 | 1.88 | 0.42 | 8.4 | 3.56 |
| $T_4$: $T_1$ + two rows of *C. ciliaris* at 20 m | 49 | 62 | 169.8 | 93.60 | 0.92 | 0.27 | 4.4 | 1.86 |
| $T_5$: Green gram + one row of *Agave* at 30 m | 47 | 62 | 150.9 | 86.63 | 0.86 | 0.44 | 8.9 | 3.40 |
| $T_6$: *C. ciliaris* pure | 34 | 8 | 146.0 | 60.70 | 0.35 | 0.04 | 1.4 | 0.60 |
| $T_7$: Cultivated fallow | 88 | 77 | 264.5 | 143.16 | 4.38 | 0.92 | 19.3 | 8.20 |

Results of another study on horizontal interval of vegetative barrier indicated that minimum soil loss and runoff was registered under pure *C. ciliaris* while maximum runoff and soil loss was observed under cultivated fallow.

Among different vegetative barriers evaluated in green gram, one row of *Agave* at 30 m registered maximum reduction in runoff and soil loss over the pure stand of green gram and this corresponded to 49.93% (60.5 mm) and 91.99% (6.89 t $ha^{-1}$), respectively. Thus, both *Agave americana* and *C. ciliaris* at 30 m brought the soil loss within the permissible limits.

### 5.3.4 Supplementary irrigation in castor and mustard

The factors like deep and poor quality ground water, semi-arid climate beset with aberrant rainfall (uneven distribution, late onset and early withdrawal of monsoon) and light textured sandy loam soils endowed with poor water/nutrient holding potential, low clay/organic matter content and presence of $CaCO_3$ nodules etc., often lead to subsistent/low productivity/ failure of rainy season crops due to deficit of soil moisture under droughts of variable duration and intensity. Therefore, a study to assess the possibility/feasibility of supplementary irrigation with harvested water was conducted at Agra Centre in castor and mustard crops during 1993-96.

The castor (Cv. GAUCH 1) and mustard (Cv. Varuna) were given 5 cm of irrigation at kernel and grain formation stage, respectively, while pre-sowing irrigation was also applied to mustard crop.

The average grain yield of castor and mustard crops increased on increase in level of irrigation. The grain yield of mustard and castor increased by 35 and 68% on supplementary irrigation and corresponded to 371 and 548 kg $ha^{-1}$ over the un-irrigated/rain fed control, respectively (Om Prakash *et. al.*, 1998).

**Table 5.31: Plant height, yield attributes, cotton yield (kg $ha^{-1}$), cost of cultivation, net return (Rs. $ha^{-1}$) and B:C ratio as affected by different sets of life-saving irrigation and plant geometry (2003-05)**

| Treatment | Plant height (cm) 75 DAS | Main branches $plant^{-1}$ | Balls $plant^{-1}$ | Lint yield (kg $ha^{-1}$) | Cost of cultivation (Rs. $ha^{-1}$) | Net return (Rs. $ha^{-1}$) | B:C ratio |
|---|---|---|---|---|---|---|---|
| **Life-saving irrigation** | | | | | | | |
| $I_1$ | 124.2 | 15.2 | 41.8 | 1400 | 16760 | 25957 | 2.6 |
| $I_2$ | 115.1 | 13.7 | 32.7 | 1203 | 16760 | 22265 | 2.3 |
| $I_3$ | 149.9 | 14.8 | 36.8 | 1287 | 17260 | 23723 | 2.4 |
| **Planting geometry** | | | | | | | |
| 60 x 30 cm | 147.1 | 12.1 | 31.1 | 1171 | 17187 | 20663 | 2.2 |
| 60 x 45 cm | 126.0 | 13.4 | 36.9 | 1283 | 16927 | 23715 | 2.4 |
| 60 x 60 cm | 116.0 | 14.8 | 43.2 | 1437 | 16667 | 28233 | 2.7 |

| Treatment | Spacing | | | Average |
|---|---|---|---|---|
| LSI | 30 | 45 | 60 | - |
| $I_1$ | 1510 | 1611 | 1762 | 1628 |
| $I_2$ | 1345 | 1477 | 1661 | 1494 |
| $I_3$ | 1450 | 1565 | 1671 | 1562 |
| Average | 1435 | 1551 | 1698 | - |

### 5.3.5 Harnessing total crop moisture use for higher net returns by growing cotton

This experiment involving three life saving irrigations (at 21, 42 and 21 + 42 DAS) and three spacing of cotton (60cm x 30 cm, 60cm x 45 cm and 60cm x 60 cm) was conducted in split plot design replicated thrice for 3 years (2003 to 2005) (Table 5.31). The study envisages that *in-situ* soil moisture conservation/utilization of pre-monsoon rains by growing deep rooted cotton may improve the total crop moisture use/water use efficiency and thereby led to higher sustained production of cotton in cotton-wheat system (Table 5.32). The study further assumes that cotton can tolerate soil moisture stress better than the dominantly grown pearl millet crop and thereby can fetch higher monetary benefits under cotton-wheat sequence than pearl millet-wheat system. Results (average of three years) reveal that cotton sown in the third week of April at 60 cm x 60 cm spacing and irrigated at 21 DAS in summers maximized the total net return (Rs. 38527 $ha^{-1}$ at 2004-05 prices) from cotton-wheat which was Rs. 25997 $ha^{-1}$ higher than pearl millet-wheat system (Rs. 12530 $ha^{-1}$) (Table 5.33) (Om Prakash and Yadav, 2005).

**Table 5.32: Grain yield of wheat as influenced by cropping systems**

| Cropping system | Wheat yield ( kg $ha^{-1}$) | | | |
|---|---|---|---|---|
| | 2003-04 | 2004-05 | 2005-06 | Average |
| Cotton-wheat | 4038 | 3803 | 3770 | 3870 |
| Pearl millet-wheat | 3588 | 3382 | 3450 | 3473 |

**Table 5.33: Wheat yield (kg $ha^{-1}$) under cotton/pearl millet-wheat cropping system (average 2004-05)**

| Cropping system | Average yield (kg $ha^{-1}$) cotton/pearl millet | Average yield (kg $ha^{-1}$) wheat | Cost of cultivation (Rs. $ha^{-1}$) | Net return (Rs. $ha^{-1}$) | B:C ratio |
|---|---|---|---|---|---|
| Cotton-wheat | 1437/5234* | 3931 | 36750 | 38527 | 2.05 |
| Pearl millet-wheat | 2289 | 3485 | 26950 | 12530 | 1.46 |

*Pearl millet equivalent

### 5.3.6 Effect of water quality on water use efficiency of crops

This project started during 2005-06 in Agra watershed on farmers' fields having marked variations in water quality aimed to determine effect of water quality on grain yield and water use efficiency (WUE) of crops. The experiment involved five treatments $T_1$: farmers practice, $T_2$: 25% more seed rate and fertilizer over recommended fertilizer dose + line sowing, $T_3$: $T_2$+ 10 t FYM $ha^{-1}yr^{-1}$ and $T_4$: $T_2$ + gypsum (100% RSC neutralization value for irrigation water) imposed in pearl millet and one additional treatment of green manure ($T_5$) under green manure-wheat system. In general, the grain yield and WUE of crops declined as the quality of water deteriorated. The highest grain yield of wheat (46.25 q $ha^{-1}$) was recorded at site I having RSC value 1.65 + FYM treatment. Water use efficiency was also highest (14.31 kg $ha^{-1}$mm) under this treatment. As the water quality deteriorated at site II (RSC value 4.14) and site III (RSC value 5.26), the wheat grain yield also declined considerably. WUE of wheat crop ranged from 12.60 to 14.31 kg $ha^{-1}$mm at site I (RSC value 1.65) being highest in treatment $T_3$ (FYM) followed by green manure ($T_5$) (WUE-14.08 kg $ha^{-1}$ $mm^{-1}$). As quality of water deteriorated, WUE at site II (11.84-12.43 kg $ha^{-1}$ $mm^{-1}$) and site III (11.81-12.79 kg $ha^{-1}$ $mm^{-1}$) also declined considerably. The highest pearl millet grain yield (47.86 q $ha^{-1}$) was recorded at site I under treatment of 25% more seed rate and fertilizer over recommended dose. The WUE was also highest (21.72 kg $ha^{-1}$ $mm^{-1}$) under $T_2$treatment at site I. Nevertheless, all the treatments recorded higher grain yield incomparison to control at site I. The effect of poor quality of water was evident as infiltration rate (1.7 cm $hr^{-1}$) at site I under treatment of gypsum was higher than the infiltration rate (1.2 cm $hr^{-1}$) under treatment of gypsum at site II.

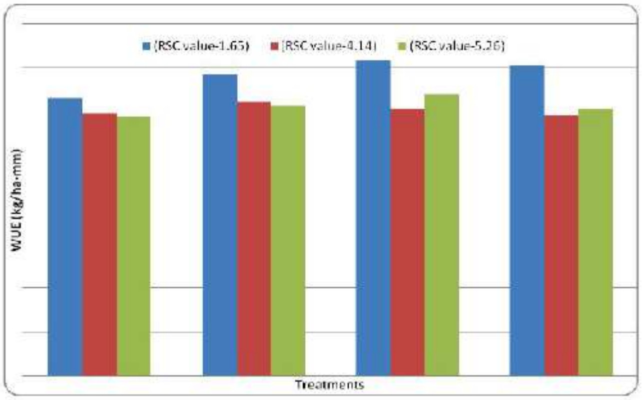



**Fig. 5.2: Effect of RSC on water use efficiency of pearl millet crop**

### 5.3.7 Improvement in indigenous moisture conservation/runoff management methods (NATP project)

This participatory on farm research aimed to improve the indigenous methods of moisture conservation/runoff management to increase the overall moisture availability and crop water use and thereby enhancing the productivity through harnessing benefit of such conserved soil moisture by adopting integrated approach of efficient soil moisture utilization by selection of appropriate crops, optimizing sowing time and method, ensuring crop stand establishment and considering the need/prospects of irrigation to make rain fed farming economical/profitable. This study involved three experiments (two under upland conditions and one under age old practice of submergence bundhis).

**Conservation furrow/diking in green gram-mustard system**

This experiment titled "Evaluation and improvement of moisture conservation and runoff management in the fallow-mustard cropping system in the semi-arid alluvial soils" was conducted in seven villages of Agra district with four treatments ($T_1$: Intermittent cross harrowing of *kharif* fallow followed by mustard, $T_2$: Conservation furrow at 3 m interval in *kharif* fallow followed by sweep cultivation, $T_3$: Conservation furrow at 3 m interval and raising green gram for grain followed by sweep cultivation and $T_4$: Conservation furrow at 3 m interval and raising green gram for green manure followed by sweep cultivation).

**Crop productivity:** Results showed that conservation furrow at 3 m interval in the line sown green gram registered maximum grain yield and net return. Conservation furrow in green gram also improved residual moisture conservation which enabled farmers to cultivate 2$^{nd}$ crop of mustard in rotation which raised the cropping intensity to 200%. Thus, it clearly suggests toreduce/stop the fallowing/cultivated fallow which aggravates runoff generation and soil erosion. Conservation furrow at 3 m interval also suited well to pearl millet crop in pearl millet-wheat system whereas even total crop failure was noticed under indigenous methods of cultivation. Conservation furrow increased soil moisture utilization and produced additional pearl millet grain yield of 88 kg ha$^{-1}$and net return of Rs. 366 ha$^{-1}$over line sowing. Combining line sowing and conservation furrow produced synergistic effect in enhancing soil moisture utilization and pearl millet grain yield. Results appended in Table 5.36 indicated that fallow + diking registered higher grain yield of mustard over only fallow treatment but green gram + diking recorded higher mustard grain yield over fallow + diking treatment. The treatment (green manure) did not registered any definite trend i.e. it outperform green gram + diking treatment at some instances while it recorded lower values than green gram + diking treatment in producing the mustard grain yield at other places. The failure of green gram crop under the set of these two treatments in some years can be ascribed to soil moisture excess/sensitivity of pulses to water logging. Results further showed that application of pre sowing irrigation in mustard registered much higher grain yield over without pre sowing irrigation treatment (Table 5.37), however, green gram + diking + pre sowing irrigation in mustard registered the highest mustard grain yield of 1111 kg ha$^{-1}$.

**Sowing time:** Farmers have shown encouraging response to improve upon need based economic crops and cropping sequences for enhanced and sustainable productivity under rainfed farming. Early sowing of pearl millet in lines produced good yield in 2001, whereas, those in broadcasting failed to produce any yield because of severe drought. In 2002, conservation furrow at 3 m interval + gurr at knee height stage in the line sown pearl millet crop produced much higher grain yield as against pearl millet productivity under indigenous methods even on supplementary irrigation. Results further show that intercropping either by broadcasting or in line sowing did not succeed which suggests that pearl millet should be sown as sole crop in regular lines as early as possible with onset of monsoon. Grain yield of pearl millet across the Agra district establishes that there is reduction in yield on delay in sowing beyond June 26. Results further indicated that sowing of pearl millet up to 10th of July produces good grain yield on farmer's field but further delay in sowing reduces the yield drastically.

**Table 5.34: Grain yield of green gram at different locations in Agra district**

| Name of village | Name of farmer | Grain yield (kg ha$^{-1}$) $T_3$ (ITK) |
|---|---|---|
| Fatehpur Sikri | Soharan Singh | 750 |
| | Lakhan Singh | 620 |
| Bandrauli | Guddu | 550 |
| | Harishanker | 480 |
| Biloni | HariOm | 675 |
| | Kuldeep | 350 |
| Rahan Kala | Ajaybeer Singh | 560 |

**Table 5.35: Grain yield (kg ha$^{-1}$), cost of cultivation, gross income and net return of green gram crop in Agra district**

| Name of village | Name of farmer | Grain yield (kg ha$^{-1}$) | Gross income | Cost of cultivation (Rs. ha$^{-1}$) | Net return (Rs. ha$^{-1}$) |
|---|---|---|---|---|---|
| Fatehpur Sikri | Soharan Singh | 750 | 12750 | 5115 | 7635 |
| | Lakhan Singh | 620 | 10540 | 4505 | 6035 |
| Bandrauli | Guddu | 550 | 9350 | 4030 | 5320 |
| | Harishanker | 480 | 7160 | 3530 | 3630 |
| Biloni | HariOm | 675 | 11475 | 4805 | 6670 |
| | Kuldeep | 350 | 5950 | 4265 | 1685 |
| Rahan Kala | Ajaybeer Singh | 560 | 9520 | 3890 | 5630 |
| | Mahtab | 640 | 10880 | 4100 | 6780 |

Market rate of green gram: Rs. 1700 q$^{-1}$

**Table 5.36: Grain yield (kg ha$^{-1}$) of mustard under different treatments**

| Name of village | Name of farmer | $T_1$ (Fallow-mustard) | $T_2$ (Fallow+ diking-mustard | $T_3$ Green gram-mustard | $T_4$ Green manure-mustard |
|---|---|---|---|---|---|
| Fatehpur Sikri | Devendra | 350 | 440 | F | F |
| | Kesav | 820* | 860* | 1020* | 960* |
| Bandrauli | Puran Chand | 760* | 840* | 916* | 942* |
| | Banvarilal | 850* | 880* | 1012* | 996* |
| | VishambharSingh | 320 | 430 | F | F |
| Biloni | Lajja Ram | 1048* | 1028* | 1240* | 1232* |
| | Kirpa Ram | 220 | 328 | F | F |
| Mahuasala | Jagdish | 1060* | 1092* | 1196* | 1212* |
| | SNL Shrivastav | 1156* | 1228* | 1340* | 1280* |
| Gopipura | Virendra Singh | 928* | 960* | 1052* | 1228* |
| | Ram Nivas | 480 | 692 | F | F |

**Note:** Green gram in $T_4$ was used for grain picking instead of green manure as there was no sufficient moisture *with pre sowing irrigation and F means crop failed due to no irrigation source/drought

**Table 5.37: Effect of diking and green gram crop on mustard grain yield (2002-03)**

| Treatment | Grain yield (kg ha$^{-1}$) | Increase in grain yield due to conservation diking/green gram | |
|---|---|---|---|
| | | Kg ha$^{-1}$ | Per cent increase |
| Fallow - mustard (without pre sowing irrigation) | 343 | - | - |
| Fallow - mustard (with pre sowing irrigation) | 946 | - | - |
| Fallow + diking-mustard (without pre sowing irrigation) | 473 | 130 | 38 |
| Fallow + diking-mustard (with pre sowing irrigation) | 984 | 38 | 4 |
| Green gram - mustard (with pre sowing irrigation) | 1111 | 165 | 17 |

The 2[nd] experiment titled "Evaluation and improvement of moisture conservation and runoff management for long slopes under pearl millet-wheat system" was conducted in seven villages of Agra district involving three treatments ($T_1$: Farmer's practice *i.e.* broad casting of mixed crops + gurr, $T_2$: Line sowing of pure pearl millet + gurr and $T_3$: Line sowing of pure pearl millet + conservation furrow at 3 m interval + gurr). Results showed that $T_3$ registered higher pearl millet grain yield over line sowing + gurr ($T_2$) and farmers practice ($T_1$) (Table 5.39).

**Table 5.38: Grain yield of pearl millet under different treatments on various locations (2003).**

| Name of village | Name of farmer | Grain yield (kg ha$^{-1}$) | | | Date of sowing |
|---|---|---|---|---|---|
| | | $T_1$ (ITK) | $T_2$ (IITK) | $T_3$ (IITK) | |
| Fatehpur Sikri | Kesav | 1820 | 2350 | 2480 | 1-08-03 |
| | Lakhan Singh | 1540 | 2080 | 2120 | 4.08.03 |
| Bandrauli | Sunil | 1600 | 2150 | 2230 | 1.08.03 |
| | Rambabu | 1970 | 2285 | 2380 | 2.08.03 |
| Biloni | HariOm | 1800 | 2325 | 2420 | 3.08.03 |
| Mahuasala | Ashok Pratap | 1140 | 1530 | 1620 | 8.08.02 |

**Table 5.39: Average grain yield of pearl millet, gross income, cost of cultivation, net return and B:C ratio under different moisture conservation/runoff management (2003).**

| Treatment | Average grain yield (kg ha$^{-1}$) | Gross income yield (Rs. ha$^{-1}$) | Cost of cultivation (Rs. ha$^{-1}$) | Net return yield (Rs. ha$^{-1}$) | B:C ratio |
|---|---|---|---|---|---|
| $T_1$: Farmer's practice | 1645 | 8856 | 6111 | 3395 | 1.44 |
| $T_2$: Line sowing + gurr | 2120 | 11415 | 6231 | 5183 | 1.83 |
| $T_3$: $T_2$ + conservation diking | 2208 | 11912 | 6363 | 5549 | 1.87 |

**Improving ground water/reducing submerged area under influence of bundhies**

This study titled "Evaluation and improvement of moisture conservation and runoff management in the age old practice of submergence bundhies" involved four treatments ($T_1$: Farmer's practice *i.e.* cross harrowing followed by tine cultivator and sowing of *rabi* crop by seed drill, $T_2$: cross harrowing followed by sweep cultivation and sowing by seed drill, $T_3$: Zero tillage and sowing by seed drill and $T_4$: $T_2$ + dust mulch through inter-culture operations was enabled the promotion of *rabi* cultivation in upland areas and *kharif* cultivation in submergence area. In this study, 27 recharge sumps (3 m x 2 m x 2 m) were constructed before June, 2003 wherein five open wells were located. Monthly monitoring of water table of open wells showed that there was rise in water table level in the range of 2-4 m which can be useful in increasing the command area of open wells (Yadav *et. al.*, 2002).

## 5.4 Resource Conservation and Sustainable Production under Different Crops and cropping Systems

### 5.4.1 Double cropping for stable production under rain fed conditions

Results of seven crop rotations (pearl millet/green gram/maize/cowpea/soybean/cluster bean/pigeonpea-wheat) evaluated under rain fed conditions show that land fallow during rainy season and sole cropping of cereals/millets do not provide adequate stability in the agricultural production in semi-arid Agra region. The study clearly establishes that wheat preceded by cereals such as pearl millet or maize is both unstable and un-economical. However, double cropping using short duration variety of green gram (60 days) that adjusts well with available growing season when sown with onset of monsoon in the first week of July followed by raising a low water requiring mustard crop provided the most stable agricultural production under different sets of rainfall aberrations in distribution/commencement or withdrawal of monsoon rains over the several years. In another study involving different crop rotations (cluster bean-wheat, pearl millet-wheat and fallow-wheat) to quantify the effect of rainy season land use on productivity of succeeding wheat crop showed that cluster bean-wheat was the best in enhancing the wheat productivity (2.45 t $ha^{-1}$) and net return (Rs. 31,226 $ha^{-1}$ $yr^{-1}$) followed by pearl millet-wheat (2.1 t $ha^{-1}$). The study recommends that in cluster bean-wheat rotation, N requirement of wheat can be reduced by 40 kg N $ha^{-1}$ *i.e.* the highest net return in wheat crop was obtained at 80 kg N $ha^{-1}$ instead of 120 kg N $ha^{-1}$. Use of 80 kg N $ha^{-1}$ in cluster bean-wheat system recorded higher net return over pearl millet-wheat or fallow wheat system (Bhushan and Om Prakash, 2001).

### 5.4.2 Maximization of mustard seed yield

A field experiment (1991-93) conducted on reclaimed Yamuna ravines showed that combined application of different production factors like irrigations, fertilizers, FYM and plant protection measures recorded the highest performance of growth parameters and yield attributes. Mustard grain yield increased by 58% with one irrigation at branching, 82% with two irrigations at branching + flowering and 101% with three irrigations at branching + flowering + pod filling stages. Seed yield further increased to 118% with application of 60 kg N $ha^{-1}$ and 135% with further application of 10 t FYM $ha^{-1}$. The highest seed yield of mustard (2268 kg $ha^{-1}$) and highest additional return (Rs. 8823 $ha^{-1}$) were recorded under irrigation at branching + flowering + pod filling + 60 kg N $ha^{-1}$ + 10 t FYM $ha^{-1}$ (Narayan and Bhushan, 1991).

### 5.4.3 Erosion-productivity relationship in pearl millet crop

The semi-arid Agra region beset with aberrant and erratic rainfall pattern is characterized by age old traditional practice of pearl millet cropping at variable slopes of shallow Yamuna ravines under rain fed conditions. However, information on resource conservation (runoff, soil loss, moisture conservation *etc.*), productivity, economics and soil fertility changes under this system lacks widely. Therefore, this study being part of a core project was started in 2010 after construction of standard runoff plots provided with multi-slot devisors and runoff collection tanks. The study aimed to quantify impact of rainfall variability on soil erosion and sustainability and resilience of pearl millet cropping. The average maximum daily rainfall during crop/experimentation period was 94.9 mm (34 mm in 2015 to 121.9 mm in 2013). The years 2014 and 2015 were drought years when no runoff, soil loss or pearl millet crop was produced. This indicates that chances of crop failure at different to 40%. The average runoff increased with increase in land slope (0.5%: 15.36 mm to 3%: 60.91 mm). Also, average soil loss increased with increase in slope from 0.5% (396 kg ha$^{-1}$) to 3% (2267 kg ha$^{-1}$). The similar trend was also recorded during other years except 2014 to 2015 (Table 5.40). The average grain yield during the experimentation period (2012 to 2016) showed a decreasing trend on increase in land slope *i.e.* 852 kg ha$^{-1}$ at 3% and 1381 kg ha$^{-1}$ at 0.5% land slope. A trend similar to average grain yield was also recorded in stover yield *i.e.* 2897 kg ha$^{-1}$ at 3% and 3746 kg ha$^{-1}$ at 0.5% runoff plots (Table 5.41). This indicates that pearl millet farming at different slopes of Yamuna ravines gradually becomes risky with increase in land slope.

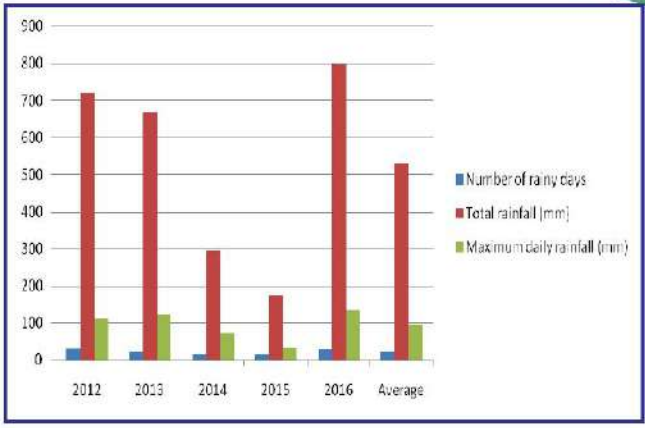



**Fig. 5.3: Number of rainy days, total rainfall (mm) and maximum daily rainfall (mm) during crop period at different land slopes of shallow Yamuna ravines during 2012 to 2016.**

**Table 5.40: Runoff (mm) and soil loss (kg ha$^{-1}$) from pearl millet crop at different land slopes of shallow Yamuna ravines**

| Runoff (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Land slope | 2012 | 2013 | 2014 | 2015 | 2016 | Total | Average |
| 0.5% | 30.0 | 26.0 | - | - | 20.8 | 76.8 | 15.36 |
| 1.0% | 59.3 | 50.7 | - | - | 41.1 | 151.1 | 30.22 |
| 2.0% | 81.5 | 74.4 | - | - | 78.1 | 234.3 | 46.86 |
| 3.0% | 118.8 | 97.0 | - | - | 108.7 | 324.5 | 60.91 |
| Soil loss (kg ha$^{-1}$) | | | | | | | |
| 0.5% | 709 | 604 | - | - | 667 | 1980 | 396 |
| 1.0% | 1607 | 1466 | - | - | 1370 | 4443 | 887 |
| 2.0% | 2785 | 2178 | - | - | 3355 | 8318 | 1667 |
| 3.0% | 3678 | 3120 | - | - | 4537 | 11335 | 2267 |

**Table 5.41: Grain and stover yield of pearl millet (kg ha$^{-1}$) at different land slopes of Yamuna ravines under rain fed conditions**

| Grain yield (kg ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Land slope | 2012 | 2013 | 2014 | 2015 | 2016 | Total | Average |
| 0.5% | 2558 | 2574 | - | - | 1772 | 6904 | 1381 |
| 1.0% | 2228 | 2240 | - | - | 1431 | 5899 | 1180 |
| 2.0% | 1928 | 2132 | - | - | 1163 | 5223 | 1045 |
| 3.0% | 1603 | 1685 | - | - | 974 | 4262 | 852 |
| Stover yield (kg ha$^{-1}$) | | | | | | | |
| 0.5% | 7546 | 7594 | - | - | 3589 | 18729 | 3746 |
| 1.0% | 5589 | 5780 | - | - | 4639 | 16008 | 3202 |
| 2.0% | 5456 | 5863 | - | - | 3772 | 15091 | 3018 |
| 3.0% | 5236 | 5392 | - | - | 3858 | 14486 | 2897 |




**Photo 5.1: Pearl millet crop at different stages in erosion productivity experiment**

### 5.4.4 Plant geometry of cluster bean

Results of an experiment involving two plant types of cluster bean (single stem Cv. FS-277 and branched stem Cv. B-19-1-55), three inter row spacing (30, 45 and 60 cm) and two intrarow spacing (15 and 22.5 cm) under rain fed conditions showed that branched type variety recorded significantly higher grain yield (2.142 t $ha^{-1}$) at 60 cm inter row and 22.5 cm intra-row spacing on reclaimed ravine lands (Sharma *et. al.*, 1978).

**Table 5.42: Yield of Cluster bean varieties as influenced by plant population**

| Treatment | Intra row spacing (cm) | | | |
|---|---|---|---|---|
| | 15 | 22.5 | Average | |
| Single stemmed (FS-277) | 2026 | 1801 | 1914 | |
| Branched type (B19-1-55) | 1944 | 2108 | 2026 | |
| Average | 1985 | 1955 | - | |
| S Em (±) | 30 | - | - | |
| CD at 5% | 86 | - | - | |
| | Inter row spacing (cm) | | | |
| Treatment | 30 | 45 | 60 | Average |
| Single stemmed (FS-277) | 1902 | 2060 | 1779 | 1914 |
| Branched type (B19-1-55) | 1922 | 2014 | 2142 | 2026 |
| Average | 1912 | 2037 | 1960 | - |
| S Em (±) | - | 24 | - | - |
| CD at 5% | - | 70 | - | - |
| Intra row spacing (cm) | - | - | - | - |
| 15 cm | 1954 | 1950 | 2051 | 1985 |
| 22.5 cm | 1870 | 2124 | 1870 | 1955 |
| Average | 1912 | - | - | - |
| S Em (±) | 24 | - | - | - |
| CD at 5% | 70 | - | - | - |

### 5.4.5 Resource conservation under pure/sole cropping

A runoff plot study initiated in 1989 on 2% slope to assess run off and soil loss under commonly cultivated crops in Agra region showed that pure stand of *C. ciliaris* registered minimum while castor recorded maximum values of runoff, soil loss and splash erosion (Table 5.43). Determination of soil loss by using USLE equation requires crop cover values (C values), therefore based on soil loss data from cultivated fallow plots, 'C' value was estimated for major crops grown in the Agra region. Among different vegetation cover; 'C' value was lowest for *C. ciliaris* (0.08) and maximum for castor (0.45). It is established that the lower the value of 'C' factor, lower will be the soil loss. Therefore, growing of pulse crops (green gram, cluster bean and cowpea) would reduce soil loss more than wide spaced crops (castor and pearl millet). Thus, among major *kharif* crops, 'C' value ranged between 0.20 (cowpea) and 0.45 (castor) (Anonymous, 1996).

**Table 5.43: Average runoff, soil loss and splash erosion on 2% slope (average of 4 years).**

| Land use | Runoff (%) | Soil loss (t $ha^{-1}$) | Splash (g) | 'C' value |
|---|---|---|---|---|
| *C.ciliaris* | 9.6 | 0.80 | 12.00 | 0.08 |
| Green gram | 23.8 | 2.92 | 19.75 | 0.29 |
| Cowpea | 25.4 | 2.10 | 18.89 | 0.20 |
| Sesame | 24.2 | 3.44 | 22.86 | 0.33 |
| Clusterbean | 24.8 | 3.57 | 27.23 | 0.37 |
| Pearl millet | 24.8 | 4.24 | 22.94 | 0.44 |
| Castor | 25.3 | 5.27 | 27.48 | 0.45 |

The inter-relationship between crop canopy and splash erosion/soil loss showed that canopy development was faster in cowpea and green gram which attained >50% of the canopy cover in 30 days. Runoff, soil loss and splash had inverse linear relationship with canopy. A multiple linear regression equation was fitted to predict soil loss based on canopy and rainfall amount/ intensity.

$$Y = -53.0 - 5.58X_1 + 11.21X_2 + 5.372X_3$$

Where, Y = Soil loss (t $ha^{-1}$), $X_1$ = Crop canopy (%), $X_2$ = Rainfall (mm) and $X_3$ = Rainfall intensity for 30 minute duration (mm $hr^{-1}$) (Narayan and Bhushan, 1992).

### 5.4.6 Intercropping studies for higher sustained productivity

Intercropping is a tool to efficiently utilize the land, water and other resources/production factors for sustainable and higher productivity per unit area that increases cropping intensity, rainwater and soil conservation and net benefitbesides, mitigating farming risk in rain fed production systems.

The intercropping practices developed for Agra region are briefly discussed here under.

#### A. Pearl millet + legumes

Results of a study conducted on 2% runoff plots in 1981 showed that average maximum runoff (258 mm/ 50% of rainfall) and soil loss (15.67 t $ha^{-1}$) was recorded under cultivated fallow while minimum runoff (70 mm/ 15% of rainfall) and soil loss (1.81 t $ha^{-1}$) was recorded under permanent vegetative cover of *Cenchrus ciliaris* grass.

Among various cropping systems, maximum soil loss (6.34 t $ha^{-1}$) was recorded from pure pearl millet crop but it was reduced to 4 t $ha^{-1}$ when cowpea/green gram were intercropped with pearl millet (Bhushan and Om Prakash, 1983).

**Table 5.44: Resource conservation and C value under different crops**

| Treatment | Runoff (mm) | | | | Soil loss (t ha$^{-1}$) | | | | Value of 'C' |
|---|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | 1983 | Average | 1981 | 1982 | 1983 | Average | |
| Pearl millet + Cowpea | 59 | 156 | 262 | 159 | 2.25 | 1.74 | 8.08 | 4.02 | 0.26 |
| Pearl millet + Greengram | 89 | 153 | 270 | 171 | 3.62 | 1.65 | 6.81 | 4.03 | 0.26 |
| Cowpea | 75 | 156 | 280 | 170 | 3.26 | 1.64 | 7.98 | 4.29 | 0.27 |
| Greengram | 87 | 164 | 342 | 198 | 3.86 | 2.13 | 10.65 | 5.55 | 0.35 |
| Clusterbean | 66 | 176 | 257 | 166 | 3.18 | 2.86 | 10.53 | 5.52 | 0.35 |
| Pearl millet | 56 | 130 | 313 | 166 | 5.02 | 2.97 | 11.04 | 6.34 | 0.40 |
| *C. Ciliaris* | 55 | 2 | 154 | 70 | 0.5 | 0.2 | 4.73 | 1.81 | 0.11 |
| Cultivated Fallow | 114 | 293 | 367 | 258 | 5.54 | 20.13 | 21.34 | 15.67 | 1.00 |

(Total Rainfall: 272.6 mm in1981, 631.1 mm in 1982 and 818.9 mm in 1983)

**Table 5.45: Soil erodibility factor (K) for Semi-Arid Agra region**

| Year | Rainfall factor (R) | Observed soil loss (t ha$^{-1}$) | Adjusted soil loss(t ha$^{-1}$) | Estimated value of 'K' |
|---|---|---|---|---|
| 1981 | 155 | 5.54 | 30.44 | 0.197 |
| 1982 | 509 | 20.13 | 110.61 | 0.217 |
| 1983 | 607 | 21.34 | 117.25 | 0.193 |
| **Average** | **424** | **15.67** | **86.10** | **0.202** |

### B. Pigeonpea/castor + green gram/pearl millet/sesame

Pigeonpea and castor, the wide spaced crops (normally shown at 60 cm x 20 cm set their active growth after 60-70 days after sowing (DAS) meanwhile the inter row spaces infested by weeds that compete with crop for moisture, nutrient, space, radiant energy and other growth resources. Removal of weeds by manual weeding/hoeing or herbicides increases the cost of cultivation or reduces the net income to growers and accelerates the runoff generation and soil loss from weeded area. Therefore, ten treatments (Pure castor, castor + green gram in uniform row, castor + paired rows of green gram 15 cm apart, castor + pearl millet, castor + sesame, pure pigeonpea, pigeonpea + green gram in uniform row, pigeonpea + paired rows of green gram 15 cm apart, pigeonpea + pearl millet and pigeonpea + sesame) were evaluated on reclaimed Yamuna ravines under rain fed conditions in randomized block design replicated four times during 1984-87.

**Table 5.46: Average grain yield and net returns from main and intercrops on reclaimed Yamuna ravines (1984-87)**

| Treatment | Average grain yield (kg ha$^{-1}$) | Average net profit (Rs. ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Pure castor | 1945 | 3410 |
| Castor + green gram (uniform row) | 2130 (161) | 4369 |
| Castor + paired rows of green gram 15 cm apart | 2093 (292) | 4783 |
| Castor + pearl millet | 1814 (490) | 3054 |
| Castor + sesame | 1873(66) | 3234 |
| Pure pigeonpea | 777 | 1397 |
| Pigeonpea + green gram (uniform row) | 845 (218) | 2291 |
| Pigeonpea + paired rows of green gram 15 cm apart | 795 (331) | 2657 |

*Figures in the parenthesis indicate the grain yield of intercrops.

**Note:** Four rows of green gram were sown in between two rows of castor at 120 cm apart.

Results of intercropping green gram (Cv. PS 16), pearl millet (BJ 104) and sesame (Cv. T12) with rain fed pigeonpea (Cv. T21) and castor (Cv. GAUCH 1) showed that intercropping paired rows of short duration green gram at 15 cm apart with pigeon pea or castor led to maximum increase in total productivity and net profit from system as a whole. However, castor based intercropping systems were more productive and remunerative over their pigeon pea based intercropping counter parts. This study clearly suggested that by growing green gram in paired rows as intercrop either with castor or pigeon pea was potent to enhance total productivity and net income over sole main or intercrop *i.e.* there was no reduction in seed yield of main crops or even a synergistic interaction was noticed. However, both pearl millet and sesame were found competitive and reduced the seed yield of both castor and pigeonpea (main crops) by about 6 and 27% on intercropping, respectively (Om Prakash *et. al.*, 2001).

### C. Potato + mustard/wheat

Sudden commencement of wide spread diseases/natural calamities like frost drastically reduces the potato yield, a dominant *rabi* crop in Agra region. Also, there is excessive production and glut in the market that lowers the potato prices to a level that even does not meet the cost of cultivation. In this backdrop, an intercropping study involving treatments *i.e.* pure potato (Cv. Kufri Chandramukhi), potato + wheat Cv. HD1553 (2:1 ratio), potato + mustard Cv. Varuna (2:1 ratio), potato + wheat (3:1 ratio), potato + mustard (3:1 ratio), potato + wheat (4:1 ratio) and potato + mustard (4:1 ratio) was conducted under limited water supply in randomized block design replicated four times during 1984-87 in 1983 that showed the possibility of intercropping wheat and mustard in potato without much reduction in the tuber yield of main crop.

**Table 5.47: Average yield and net returns from main and intercrops (1984-87)**

| Treatment | Average yield (kg ha$^{-1}$) | Average net profit (Rs. ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Pure potato | 25976 | 4830 |
| Potato + wheat (2:1 ratio) | 21782 (1250) | 6644 |
| Potato + mustard (2:1 ratio) | 20375 (1040) | 8706 |
| Potato + wheat (3:1 ratio) | 22542 (970) | 6107 |
| Potato + mustard (3:1 ratio) | 20451 (825) | 7313 |
| Potato + wheat (4:1 ratio) | 22279 (608) | 7153 |
| Potato + mustard (4:1 ratio) | 22978 (608) | 5379 |

*Figures in the parenthesis indicate the yield of intercrops. Rate of produce (Rs. q$^{-1}$): Potato: 55, wheat: 162 and mustard: 500

The results revealed that under limited water supply, mustard intercropped with potato in 2:1 row ratio produced the highest potato equivalent (26.75 t ha$^{-1}$) and net return (Rs. 8706 ha$^{-1}$ yr$^{-1}$) which can be ascribed to lower cost of cultivation of this treatment, higher prices of mustard and least reduction in yield of potato (16.21%) as compare to pure potato crop. In fact, mustard is a low nutrient/moisture requiring crop and there is spatial advantage of shallow and deep rooting of main and intercrop, respectively. Results further showed that intercropping of potato and mustard in 2:1 row ratio reduces water requirement of potato to 1/3 as compare to sole potato crop (Om Prakash and Bhushan, 2000).

### D. Mustard + barley/taramira/linseed

Mustard being a wide space, most profitable and a dominant *rabi* crop in semi-arid Agra region, provides an opportunity of intercropping of short duration oilseed/cereals/ pulse crops for maximization of crop yield/profit through efficient utilization of resources. Therefore, three levels of irrigation (control/no irrigation, irrigation at branching stage and irrigation at branching + flowering stages) and seven sole/intercrops (sole mustard, sole barley, sole taramira, sole linseed, mustard + barley, mustard + taramira and mustard + linseed) were evaluated in a split plot design replicated thrice during 1990-92 with use of recommended doses of fertilizers in mustard and no fertilizer in intercrops.

**Table 5.48: Effect of irrigation and intercropping on grain yield of sole/intercrops (Pooled 1990- 92)**

| Treatment | Grain yield (kg $ha^{-1}$) | | | | | | | | | Pooled MYE |
|---|---|---|---|---|---|---|---|---|---|---|
| | No irrigation (control) | | | Irrigation at branching | | | Irrigation at branching + flowering | | | |
| | Sole crop | Intercrop | MYE | Sole crop | Intercrop | MYE | Sole crop | Intercrop | MYE | |
| Sole mustard | 922 | - | 922 | 1353 | - | 1353 | 1573 | - | 1573 | 1283 |
| Sole barley | 1917 | - | 659 | 2837 | - | 1001 | 3582 | - | 1289 | 983 |
| Sole *taramira* | 794 | - | 755 | 1013 | - | 963 | 1130 | - | 1075 | 931 |
| Sole linseed | 719 | - | 938 | 872 | - | 1137 | 1010 | - | 1317 | 1131 |
| Mustard + barley | 528 | 1507 | 1045 | 711 | 2054 | 1434 | 865 | 2081 | 1750 | 1410 (427) |
| Mustard + *taramira* | 553 | 725 | 1243 | 751 | 847 | 1557 | 967 | 943 | 1864 | 1555 (624) |
| Mustard + linseed | 815 | 555 | 1539 | 1079 | 714 | 2010 | 1239 | 825 | 2315 | 1955 (824) |
| Mean | 1014 | | | 1351 | | | 1598 | | | |
| CD (P=0.05) | Irrigation: 26<br>Intercropping: 57<br>Interaction: 98 | | | | | | | | | |

MYE: Mustard Yield Equivalent

Results showed that intercropping barley/*taramira*/linseed in Indian mustard was more productive and remunerative over sole cropping of mustard (Table 5.48). Also, intercropping systems registered significantly higher mean MYE over their respective sole crops irrespective of irrigation levels which ranged from a pooled MYE of 427 kg $ha^{-1}$ in mustard + barley to 864 kg $ha^{-1}$ in mustard + linseed. Thus, the study established that intercropping is a profitable practice in Semi-Arid Agra region.

Among various intercropping systems, mustard + linseed recorded the highest and significantly higher pooled values of MYE (1995 kg $ha^{-1}$), LER (1.63), water use efficiency (10.31 kg $ha^{-1}$ $mm^{-1}$), monetary returns (Rs. 17982 $ha^{-1}$), monetary advantage (Rs. 6906 $ha^{-1}$) and additional net return (Rs. 5870 $ha^{-1}$) (Table 5.49). The yield of crops progressively increased with increase in number of irrigations and average increase corresponded to 310 and 584 kg $ha^{-1}$ under one and two irrigations over no irrigation /control, respectively. However, pooled WUE decreased significantly with increase in number of irrigation (Table 5.49). Among sole/intercropping system significant variations were noticed wherein sole barley registered minimum pooled WUE (4.93 kg $ha^{-1}mm^{-1}$) while mustard + linseed recorded the highest pooled WUE (10.31 kg $ha^{-1}mm^{-1}$). Notably, all intercropping systems registered significantly higher pooled WUE over their respective sole stand of main or intercrop which established that there was efficient utilization of resources under intercropping over sole crops.

Alike grain yield, pooled values of MR, MA and AR also registered an increasing trend on increasing number of irrigations in order of irrigation at branching + flowering>irrigation at branching>control/no irrigation (Narayan *et. al.*, 1999). The relative crowding coefficient data (Table 5.50) revealed that different intercrops registered significant variations among each other in RCC while variations in aggressivity of both main and intercrops were not significant. Data conclude that barley and *taramira* were dominant while linseed was dominated in intercropping with mustard.

Table 5.49: Land equivalent ratio (LER), water use efficiency (WUE), monitory return (MR), monitory advantage (MA) and additional net return (AR) under different irrigation levels and cropping systems (Pooled 1990-92)

| Treatment | LER | WUE (kg $ha^{-1}mm^{-1}$) | MR (Rs. $ha^{-1}$) | MA (Rs. $ha^{-1}$) | AR (Rs. $ha^{-1}$) |
|---|---|---|---|---|---|
| **Irrigation levels** | | | | | |
| Control/no irrigation | 1.22 | 7.84 | 9332 | 4026 | 3063 |
| Irrigation at branching | 1.19 | 6.98 | 12428 | 4733 | 2701 |
| Irrigation at branching + lowering | 1.19 | 6.20 | 14699 | 5494 | 3527 |
| CD (P=0.05) | NS | 0.1 | 237 | NS | NS |
| **Cropping systems** | | | | | |
| Sole mustard | 1.00 | 6.9 | 11799 | - | - |
| Sole barley | 1.00 | 4.93 | 9047 | - | - |
| Sole *taramira* | 1.00 | 5.05 | 8567 | - | - |
| Sole linseed | 1.00 | 6.39 | 10404 | - | - |
| Mustard + barley | 1.31 | 7.23 | 12967 | 2925 | 967 |
| Mustard + *taramira* | 1.45 | 8.23 | 14304 | 4422 | 2455 |
| Mustard + linseed | 1.63 | 10.31 | 17982 | 6906 | 5870 |
| CD (P=0.05) | 0.05 | 0.29 | 521 | 614 | 577 |

MYE: mustard yield equivalent

Table 5.50: Relative crowding coefficient (RCC) and aggressivity of mustard based intercropping systems (Pooled 1990-92).

| Treatment | RCC | | | Aggressivity | |
|---|---|---|---|---|---|
| | Mustard (Ka) | Intercrop (Kb) | K | Mustard (Aab) | Intercrop (Aba) |
| Mustard + barley | 1.24 | 2.94 | 3.75 | -0.18 | 0.18 |
| Mustard + *taramira* | 1.48 | 7.02 | 10.38 | -0.27 | 0.27 |
| Mustard + linseed | 8.85 | 4.11 | 30.37 | 0.02 | -0.02 |
| CD (P=0.05) | - | 1.33 | 16.43 | NS | NS |

**E. Mustard + toria**

Results of intercropping toria (T 9) between rows of mustard spaced at 40 to 120 cm indicated that there was a possibility of intercropping toria between mustard rows sown at 80-100 cm (total oilseed yield about 2.2 t $ha^{-1}$) (Om Prakash and Bhushan, 1989).

## 5.5 Agro-Forestry/Alley Cropping Studies

### 5.5.1 Ber root management for sustained higher crop productivity in agro-forestry

Pearl millet-wheat/mustard is the most predominant crop rotations in the semi-arid Agra region which is characterized by fluctuating and mostly poor/subsistent productivity of rainy season crop due to highly erratic distribution in commencement and withdrawal of rainfall (650-700 mm). Therefore, to stabilize productivity of these cropping systems, ber based agr-horti system was evaluated under five tree root management practices ($T_1$: Tree planted in bottomless bitumen drum, $T_2$: Trenches of 50 cm x 30 cm in two sides of tree, $T_3$: Tree planted in polythene lined pits, $T_4$: No root management and $T_5$: Control/no tree) in randomized block design replicated four times during 1991-96 on reclaimed Yamuna ravine. The stabilization in productivity mitigation in this study mainly relate to reduction in tree-crop interface and thereby maximization of total production/net returns from the system as a whole. The green gram/pearl millet and wheat/mustard systems were imposed in inter-row spaces of Ber (Cv. *Ponda safeda*), a drought tolerant commercial ber variety planted at 10 m x 5 m. The green gram-mustard system was evaluated during 1992-97 while pearl millet (Cv. Pioneer 7688)-wheat (Cv. HD 2338) system was studied during 1998-2001. Average mustard seed yield (Table 5.53) was the highest under pure cropping while different root management treatments invariably reduced the mustard seed yield which ranged from 178 kg ha$^{-1}$ or 11.85% under bottomless bitumen drums/trenching to 241 kg ha$^{-1}$ or 16.04% under no root management. Wheat grain yield was the highest (4243 kg ha$^{-1}$) in control plot (without ber trees) which registered a reduction on introduction of ber in agri-horticulture system and under different ber root management practices. Among root management treatments, planting of ber trees in bottomless drums registered minimum reduction in wheat grain yield (396 kg ha$^{-1}$) over pure wheat stand which corresponded to just 6.48%. As such, bottomless bitumen drum was the most effective treatment in reducing the tree-crop root interface which resulted in the highest ber fruit productivity, tree height (3.40 m), tree volume (21.8 m$^3$) and fuelwood yield (2155 kg ha$^{-1}$) apart from registering minimum reduction in yield of crops in pearl millet, wheat/mustard system. Pearl millet grain yield was highest in pure stand while reduction corresponded to 5.30, 12.6, 16.5and 33.1% under bottomless bituminous drums, trenching, polythene lining and no root management, respectively. Ber fruit yield was the highest (7347 kg ha$^{-1}$) in bottomless bitumen drum treatment followed by no root management (6827 kg ha$^{-1}$), trenching (6422 kg ha$^{-1}$) and polythene lined pits (6214 kg ha$^{-1}$) (Table 5.54 ) (Om Prakash et. al., 2001).

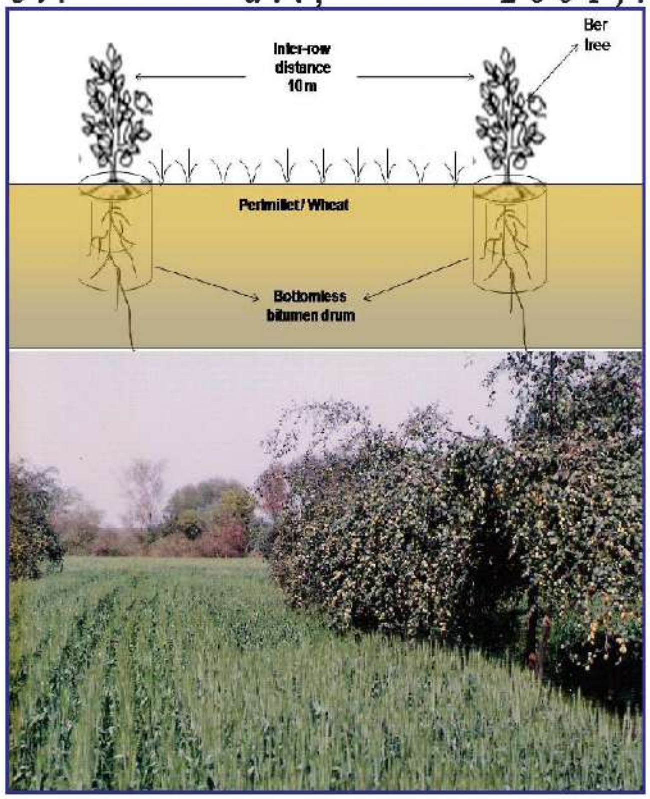



**Fig. 5.4: Sketch and field view of ber planted in bottomless bitumen drum with wheat intercrop.**

**Table 5.51: Average growth of ber trees, fruit yield and fuel wood production (kg ha$^{-1}$) under different root management treatments in agri-horticulture system (1998-01)**

| Treatment | Plant height (m) | Tree volume (m$^3$) | Fruit yield (kg ha$^{-1}$) | Fuel wood (kg ha$^{-1}$) |
|---|---|---|---|---|
| $T_1$: Tree planted in bottomless bitumen drum | 3.98 | 21.8 | 7347 | 2155 |
| $T_2$: Trenches in two sides of tree | 3.47 | 16.0 | 6422 | 1522 |
| $T_3$: Tree planted in polythene lined pits | 3.41 | 19.6 | 6219 | 1789 |
| $T_4$: No root management | 3.57 | 16.4 | 6827 | 1533 |

**Table 5.52: Cost of cultivation, net return and benefit: cost ratio under different root management options in ber based agri-horticulture system (1998-01).**

| Treatment | Gross return | Cost of cultivation | Net return | B:C ratio |
|---|---|---|---|---|
| $T_1$: Tree planted in bottomless bitumen drum | 66504 | 28140 | 38264 | 2.36 |
| $T_2$: Trenches in two sides of tree | 60097 | 27590 | 32507 | 2.18 |
| $T_3$: Tree planted in polythene lined pits | 58886 | 27940 | 30946 | 2.11 |
| $T_4$: No root management | 60002 | 27440 | 32562 | 2.19 |
| $T_5$: Control (without tree) | 39544 | 24300 | 15244 | 1.63 |

**Table 5.53: Grain yield of mustard (kg ha$^{-1}$) as influenced by different root management options in ber based agri-horticulture system (1992-97).**

| Treatment | Average grain yield |
|---|---|
| $T_1$: Tree planted in bottomless bitumen drum | 1324 |
| $T_2$: Trenches in two sides of tree | 1324 |
| $T_3$: Tree planted in polythene lined pits | 1267 |
| $T_4$: No root management | 1261 |
| $T_5$: Control (without tree) | 1502 |

**Table 5.54: Average grain yield of crops on net area basis under ber based agri- horticulture system (1998-01)**

| Treatment | Pearl millet grain yield (kg ha$^{-1}$) | Wheat grain yield (kg ha$^{-1}$) | Ber fruit yield (kg ha$^{-1}$) |
|---|---|---|---|
| $T_1$: Tree planted in bottomless bitumen drum | 2161 | 3968 | 7347 |
| $T_2$: Trenches in two sides of tree | 2028 | 3749 | 6422 |
| $T_3$: Tree planted in polythene lined pits | 1977 | 3742 | 6219 |
| $T_4$: No root management | 1833 | 3488 | 6827 |
| $T_5$: Control (without tree) | 2282 | 4243 | - |

### 5.5.2 Aonla based agro-forestry system

A study conducted during 2001-03 aimed to assess the overall impact of association of different crops on growth and yield of aonla planted at 8 m x 8 m on reclaimed Yamuna ravine. Four cropping sequence ($T_1$: Cowpea-mustard, $T_2$: Black gram-mustard, $T_3$: Green gram-mustard, $T_4$: Sun-hemp-mustard and $T_5$: Sole aonla) were grown in the tree inter spaces of aonla (Cv. Chakaiya).

Results showed that green gram grain yield of 658 kg ha$^{-1}$ and 755 kg ha$^{-1}$ green pod yield of cowpea for vegetable purpose were recorded under $T_3$ and $T_1$, respectively. A green biomass yield of 10.7, 4.8, 3.8 and 2.0 t ha$^{-1}$ was recorded from sun-hemp, cowpea, green gram and blackgram, respectively. Results further show that among various options of recycling green biomass to soil, maximum biomass was added to soil by dhaincha (green: 11.99-12.0 t ha$^{-1}$ and dry 2.99-3.0t ha$^{-1}$) followed by cowpea (green: 9.16-9.20 t ha$^{-1}$ and dry 2.29-3.00 t ha$^{-1}$) while green gram and black gram recorded very low quantity of biomass production (Table 5.55). Data (Table 5.56 & 5.57) further revealed that maximum N (74.2 kg $ha^{-1}$), P (12.6 kg $ha^{-1}$), Zn (0.46 and 0.28 ppm in 0-15 and 15-30 cm soil layer, respectively) and Fe (4.8 and 5.6 ppm in 0-15 and 15-30 cm soil layer, respectively) was recorded under recycling of dhaincha to soil. Recycling of dhaincha to soil also recorded maximum soil moisture storage in 0-25, 25-50, 50-75 and 75-100 cm soil profile during August (16.12 cm/100 cm soil profile) and September (12.75 cm/100 cm soil profile) during year 2005. Results on long term effect of association of different cropping systems with aonla on soil physical properties showed that different cropping systems registered higher organic carbon but lower bulk density and pH in both 0-15 and 15-30 cm soil layer over the sole aonla plantation (Table 5.59). This clearly implied to improvement in soil physical conditions under different cropping systems over sole aonla plantation. However, data on $CaCO_3$ did not depict any definite trend. Among various cropping systems, maximum favorableness in organic carbon, pH and bulk density was recorded under dhaincha at both 0-15 and 15-30 cm soil depth. However, all the cropping systems recorded lower tree height, GBH and mean spread of aonla than trees in sole aonla plantation which depicts a competitive effect of cropping systems on performance of woody perennial component. Maximum (1352 kg $ha^{-1}$) yield of mustard was obtained in sun-hemp green manure plots (Nitant and Om Prakash, 2003).

**Table 5.55: Biomass of intercrops and nutrients added to soil**

| Treatment | Biomass added to soil (t $ha^{-1}$) | | | | Nutrients added to soil (kg $ha^{-1}$) | |
|---|---|---|---|---|---|---|
| | 2006-07 | | 2007-08 | | | |
| | Green | Dry | Green | Dry | N | P |
| $T_1$: Cowpea | 9.2 | 2.3 | 9.16 | 2.29 | 45.3 | 8.7 |
| $T_2$: Black gram | 4.3 | 1.08 | 4.28 | 1.07 | 18.0 | 3.4 |
| $T_3$: Green gram | 4.2 | 1.05 | 4.18 | 1.05 | 19.7 | 3.8 |
| $T_4$: Dhaincha | 12.0 | 3.0 | 11.98 | 2.99 | 74.2 | 12.6 |
| $T_5$: Aonla (sole crop) | - | - | - | - | - | - |

**Table 5.56: Effect of association of intercrops with aonla on availability of micro-nutrients at different soil depths (2007)**

| Treatment | Available NPK (kg $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | N | | $P_2O_5$ | | $K_2O$ | |
| | 0-15 | 15-30 | 0-15 | 15-30 | 0-15 | 15-30 |
| $T_1$: Cowpea-mustard | 232 | 172 | 10.99 | 6.41 | 280.7 | 256.2 |
| $T_2$: Black gram-mustard | 222 | 166 | 10.17 | 5.95 | 266.2 | 229.9 |
| $T_3$: Green gram-mustard | 226 | 168 | 10.53 | 5.95 | 268.6 | 229.9 |
| $T_4$: Dhaincha-mustard | 246 | 180 | 10.82 | 6.41 | 300.08 | 268.6 |
| $T_5$: Aonla (sole crop) | 198 | 140 | 10.31 | 5.50 | 275.88 | 242.0 |
| Initial (soil) | 105 | 86 | 5.99 | 3.66 | 268.6 | 217.8 |

**Table 5.57: Effect of different crops in agri-horti association with aonla on availability of micronutrients at different soil depths**

| Treatment | Zn (ppm) | | Fe (ppm) | |
|---|---|---|---|---|
| | 0-15 cm | 15-30 cm | 0-15 cm | 15-30 cm |
| $T_1$ : Cowpea | 0.44 | 0.26 | 3.6 | 4.0 |
| $T_2$ : Black gram | 0.40 | 0.22 | 3.2 | 3.8 |
| $T_3$ : Green gram | 0.36 | 0.20 | 2.8 | 3.0 |
| $T_4$ : Dhaincha | 0.46 | 0.28 | 4.8 | 5.6 |

**Table 5.58: Effect of intercrops on profile moisture status (cm) in different soil layers during 2005**

| Treatment | 0-25 cm | | 25-50 cm | | 50-75 cm | | 75-100 cm | | Total (cm/100cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 9/8 | 7/9 | 9/8 | 7/9 | 9/8 | 7/9 | 9/8 | 7/9 | 9/8 | 7/9 |
| $T_1$: Cowpea | 3.62 (9.6) | 3.72 (10.2) | 4.13 (10.6) | 3.15 (8.1) | 4.03 (10.0) | 3.06 (7.6) | 3.86 (9.6) | 2.5 (6.2) | 15.64 | 12.43 |
| $T_2$: Black gram | 3.47 (9.2) | 2.49 (6.6) | 3.98 (10.2) | 3.12 (8.0) | 4.19 (10.4) | 2.82 (7.0) | 3.62 (9.0) | 2.42 (6.0) | 15.26 | 10.85 |
| $T_3$:Green gram | 3.62 (9.6) | 2.69 (6.8) | 4.13 (10.6) | 3.20 (8.2) | 4.27 (10.6) | 3.06 (7.6) | 3.86 (9.6) | 2.58 (6.4) | 15.88 | 11.52 |
| $T_4$: Dhaincha | 3.70 (9.8) | 3.79 (10.4) | 4.21 (10.8) | 3.2 (8.2) | 4.35 (10.8) | 3.14 (7.8) | 3.86 (9.6) | 2.62 (6.3) | 16.12 | 12.75 |
| $T_5$: Aonla (sole crop) | 3.32 (9.6) | 2.64 (7.0) | 3.74 (9.6) | 3.04 (7.8) | 3.22 (8.0) | 2.42 (6.0) | 3.14 (7.8) | 2.42 (6.0) | 13.42 | 10.52 |

**Table 5.59: Long term effect of association of different cropping systems on soil physical properties (2007)**

| Treatment | OC (%) | | Soil (pH) 1:2 | | $CaCO_3$ (%) | | Bulk density (Mg $m^{-3}$) | |
|---|---|---|---|---|---|---|---|---|
| | 0-15 cm | 15-30 cm | 0-15 cm | 15-30 cm | 0-15 cm | 15-30 cm | 0-15 cm | 15-30 cm |
| $T_1$:Cowpea-mustard | 0.42 | 0.18 | 8.2 | 8.4 | 3.2 | 6.0 | 1.52 | 1.66 |
| $T_2$: Black gram-mustard | 0.36 | 0.20 | 8.4 | 8.6 | 3.2 | 6.2 | 1.54 | 1.66 |
| $T_3$: Green gram-mustard | 0.38 | 0.20 | 8.4 | 8.6 | 3.6 | 6.2 | 1.56 | 1.66 |
| $T_4$:Dhaincha-mustard | 0.48 | 0.22 | 8.0 | 8.4 | 3.0 | 6.0 | 1.48 | 1.64 |
| $T_5$:Aonla (sole crop) | 0.30 | 0.14 | 8.6 | 8.8 | 3.8 | 6.2 | 1.58 | 1.68 |
| Initial (soil) | 0.18 | 0.14 | 8.6 | 8.8 | 4.6 | 6.0 | 1.62 | 1.72 |

**Table 5.60: Performance of aonla on reclaimed ravine land in association with different field crops**

| Treatment | Height (m) | GBH (cm) | Mean spread (m) |
|---|---|---|---|
| $T_1$: Cowpea-mustard | 1.40 | 15.08 | 1.08 |
| $T_2$: Black gram-mustard | 1.07 | 5.92 | 0.63 |
| $T_3$: Green gram-mustard | 2.03 | 18.18 | 1.74 |
| $T_4$: Dhaincha-mustard | 1.95 | 16.15 | 1.91 |
| $T_5$: Aonla (sole crop) | 2.63 | 27.33 | 2.33 |

### 5.5.3 Profile modification for aonla

The degraded Yamuna ravines characterized by highly calcareous and light textured soils are beset with low infiltration rate and poor organic carbon/phosphorus contents but they are rich in potassium. The content of calcium carbonate nodules usually vary from 15 to 20% in plow sole and increases with increase in soil depth, thus posing the infiltration problem. These edaphic conditions lead to poor establishment of aonla seedlings on these soils. Therefore, a two year experiment involving five treatments ($T_1$: control, $T_2$ : $CaCO_3$ nodules removed, $T_3$:$T_2$ + 15% finer fraction i.e. 30% silt + 14% clay, $T_4$:$T_2$ + 30% finer fraction and $T_5$:$T_2$ + 45% finer fraction/FF) was conducted in randomized block design replicated four times during 2000-01 to quantify the effect of $CaCO_3$ granules on establishment of aonla on Yamuna ravines (Table 5.61). Data revealed that there was very slight variation in pH, EC, $CaCO_3$ and organic carbon but $T_5$ or removal of $CaCO_3$ granules and use of 45% finer fraction resulted in maximum survival (92%) and plant height (93 cm) of aonla seedlings (Table 5.62). The profile modification done by addition of 15, 30 and 45% finer fraction pH varied from 7.8 to 8.4, EC 0.36 to 0.46 $dSm^{-1}$, organic carbon 0.25 to 0.30 % and $CaCO_3$ 9.6 to 13.5 per cent, respectively. Data clearly showed that removal of $CaCO_3$ granules and addition of finer fraction to an extent of 45% in $T_5$ led to maximum reduction in the pH and EC, registered maximum organic carbon and brought the $CaCO_3$ fraction to minimum level. Thus, removal of $CaCO_3$ granules + addition of 45% FF recorded maximum improvement in soil properties critical from growth and survival of aonla on degraded Yamuna ravines.

**Table 5.61: Growth and survival of aonla seedlings after two years of profile modification**

| Treatment | Survival (%) | Plant height (cm) |
|---|---|---|
| $T_1$ : Control | 67 | 75 |
| $T_2$ : $CaCO_3$ removed | 75 | 84 |
| $T_3$ : $T_2$+15% FF | 75 | 78 |
| $T_4$ : $T_2$+30% FF | 83 | 93 |
| $T_5$ : $T_2$+45% FF | 92 | 109 |

FF = Finer fraction

**Table 5.62: Soil properties at experimental site after two years**

| Treatment | Soil depth (cm) | pH | EC (dS $m^{-1}$) | OC (%) | $CaCO_3$ (%) |
|---|---|---|---|---|---|
| $T_1$: Control | 0-15 | 8.6 | 0.26 | 0.18 | 15.5 |
| | 15-30 | 8.3 | 0.25 | 0.13 | 15.4 |
| | 30-60 | 8.7 | 0.60 | 0.09 | 16.9 |
| $T_2$: $CaCO_3$ removed | 0-15 | 8.4 | 0.41 | 0.25 | 13.5 |
| $T_3$: $T_2$+15% FF | 0-15 | 8.1 | 0.46 | 0.28 | 12.0 |
| $T_4$: $T_2$+30% FF | 0-15 | 8.0 | 0.41 | 0.28 | 11.0 |
| $T_5$: T2+45% FF | 0-15 | 7.8 | 0.36 | 0.30 | 9.6 |

### 5.5.4 Alley cropping

Soils of ravines are usually poor in nutrient/moisture holding capacity and structural aggregates. Crop residue incorporation can help in improving soil organic matter, fertility and physical, chemical and biological soil properties. Therefore, subabul, a leguminous and hardy fodder tree well adopted in semi-arid region, was alley cropped with pearl millet-wheat rotation to harness the benefits of N fixation, litter fall/recycling of leaves/roots, improve soil fertility/organic carbon status and productivity of wheat and pearl millet system. Two rows of subabul were planted between 4, 6, 8 and 10 rows of pearl millet (Cv.BJ104) or 8, 12, 16 and 20 rows of wheat (Cv.RR21). Subabul leaves were incorporated into the soil 15 days before sowing of wheat crop which was fertilized with 120, 80 and 60 kg N, P and K $ha^{-1}$, respectively. Results showed that grain yield of wheat significantly increased on incorporation of subabul leaves over control (Table 5.63). The higher grain yield of 2635 kg $ha^{-1}$ was recorded when 20 rows of wheat were sown in between two rows of subabul managed at 75 cm height and subabul leaves @ 5 t $ha^{-1}$was incorporated in the soil. However, subabul can compete with agricultural crops for nutrients and moisture and can cast shade on crop but it provides green fodder and fire wood which stands the scares resource in semi-arid tropics. Therefore, adjusting different number of rows of crops in between two rows/alley of subabul (Cv. Poruvion) with and without the incorporation of green subabul leaves (5 t $ha^{-1}$) was undertaken in a six year study (1984-89). The study was conducted in randomized block design replicated six times and involved four treatments ($T_1$ : Two rows of subabul alternated with 4 rows of pearl millet/8 rows of wheat, $T_2$ : Two rows of subabul alternated with 8 rows of pearl millet/12 rows of wheat, $T_3$ : Two rows of subabul alternated with 8 rows of pearl millet /16 rows of wheat and $T_4$ : Two rows of subabul alternated with 10 rows of pearl millet/ 20 rows of wheat). Pure pearl millet-wheat crops were also maintained for comparison of yields under alley cropping. Data further revealed (Table 5.64) that alley cropping invariably reduced the grain yield of pearl millet (6.29% in $T_3$ and $T_4$ to 12.13% in $T_1$) and wheat (8.12% in $T_1$ to 14.26% in $T_4$) in comparison to pure stand of pearl millet and wheat. However, $T_3$ or raising of two rows of pearl millet/16 rows of wheat, registered the highest total grain yield of 3402 kg $ha^{-1}$ from pearl millet-wheat system (Om Prakash and Bhushan, 1991).

**Table 5.63: Yield of wheat (kg $ha^{-1}$) with and without incorporations of subabul leaves before sowing of wheat (average 1984-89)**

| Treatment | With incorporation | Without incorporation | Increase in grain yield (kg $ha^{-1}$) | % increase |
|---|---|---|---|---|
| $T_1$: Two rows of subabul with 8 rows of wheat | 2634 | 2217 | 417 | 18.8 |
| $T_2$: Two rows of subabul with 12rows of wheat | 2575 | 2083 | 492 | 23.9 |
| $T_3$: Two rows of subabul with 16 rows of wheat | 2603 | 2166 | 437 | 20.2 |
| $T_4$: Two rows of subabul with 20 rows of wheat | 2635 | 2069 | 566 | 27.4 |

**Table 5.64: Grain yield of pearl millet and wheat (kg $ha^{-1}$) as influenced by different alley cropping treatments (Average 1983-89)**

| Treatment | Grain yield (kg $ha^{-1}$) | | Total grain yield from pearl millet-wheat system (kg $ha^{-1}$) |
|---|---|---|---|
| | Pearl millet | Wheat | |
| $T_1$: Two rows of subabul alternated with 4rows of pearl millet / 8 rows of wheat | 1159 (12.13%) | 2217 (8.12%) | 3376 |
| $T_2$: Two rows of subabul alternated with 6rows of pearl millet /12rows of wheat. | 1224 (7.20%) | 2083 (13.68%) | 3307 |
| $T_3$: Two rows of subabul alternated with 8rows of pearl millet/16rows of wheat | 1236 (6.29%) | 2166 (10.24%) | 3402 |
| $T_4$: Two rows of subabul alternate with 10 rows of pearl millet/20 rows of wheat | 1236 (6.29%) | 2069 (14.26%) | 3305 |
| $T_5$: Pure crop of pearl millet and wheat | 1319 | 2413 | |

*Figures in the parenthesis indicate per cent reduction in grain yield than pure crop.

However, $T_1$ outperformed all other alley treatments in green fodder and fuel wood yield and average gross annual income (Table 5.65). Nevertheless, all alley cropping treatments outperformed the pure cropping of peal millet-wheat on the basis of average gross annual income (Table 5.66).

**Soil fertility:** Data on soil fertility showed that incorporation of subabul leaves (5 t $ha^{-1}$) generally improved soil OC, available N and P than their respective counter treatments involving no recycling of subabul leaves at both the soil depths *i.e.* 0-15 cm and 15-30 cm. However, available N at 0-15 cm depth in $T_2$, OC at 0-15 cm in $T_3$ and OC at 15-30 cm depth in $T_4$ registered lower values under subabul leaf incorporation under no subabul leaf recycling control.

**Table 5.65: Average grain yield of pearl millet and wheat (kg $ha^{-1}$), green fodder and fuel wood (t $ha^{-1}$) under subabul alleys cropped with pearl millet-wheat on net area basis (Average 1986-90)**

| Treatment | Yield | | | |
|---|---|---|---|---|
| | Wheat (kg $ha^{-1}$) | Pearl millet (kg $ha^{-1}$) | Green fodder (t $ha^{-1}$) | Fuel wood (t $ha^{-1}$) |
| $T_1$: Two rows of subabul alternated with 4rows of pearl millet/8 rows of wheat | 1556 | 721 | 19.9 | 4.7 |
| $T_2$: Two rows of subabul alternated with 6rows of pearl millet/12 rows of wheat. | 1609 | 871 | 15.6 | 3.5 |
| $T_3$: Two rows of subabul alternated with 8rows of pearl millet/16 rows of wheat | 1783 | 917 | 11.4 | 2.5 |
| $T_4$: Two rows of subabul alternated with 10 rows of pearl millet/20 rows of wheat | 1822 | 1008 | 9.2 | 2.1 |
| $T_5$: Pure crop of pearl millet and wheat | 2150 | - | - | - |

**Table 5.66: Average gross annual income (Rs. $ha^{-1}$) from grain yield of pearl millet and wheat, green fodder and fuelwood under alley cropping of pearl millet-wheat with subabul on net area basis (Average 1983-89)**

| Treatment | Gross income (Rs. $ha^{-1}$) | | | | |
|---|---|---|---|---|---|
| | Wheat | Pearl millet | Green fodder | Fuel wood | Total |
| $T_1$: Two rows of subabul alternated with 4rows of pearl millet/8 rows of wheat | 3657 | 1442 | 4975 | 1410 | 11484 |
| $T_2$: Two rows of subabul alternated with 6rows of pearl millet/12rows of wheat. | 3781 | 1742 | 3900 | 1050 | 10473 |
| $T_3$: Two rows of subabul alternated with 8rows of pearl millet/16rows of wheat | 4120 | 1834 | 2850 | 750 | 9624 |
| $T_4$: Two rows of subabul alternated with 10 rows of pearl millet/20 rows of wheat | 4282 | 2016 | 2300 | 630 | 9228 |
| $T_5$: Pure crop of pearl millet and wheat | 5203 | 2825 | - | - | 8030 |

### 5.5.5 Agro-forestry in mosambi/kinnow mandarine plantations

To identify a suitable intercrop in mosambi and kinnow mandarine, a trial was initiated during 1991-92. The fruit trees were planted at a spacing of 5 m X 5 m. Spinach, fenugreek, mustard and potato in *rabi*, water melon, bhindi, brinjal and cowpea in *zaid* and green gram in *kharif* season were incorporated in intercrop spaces of fruit trees. Results revealed that maximum fruit yield of mosambi was recorded where fenugreek was grown as intercrop. Although much research has not been carried out there was some indication that two rows of *Cenchrus ciliaris* grass at 30 cm apart reduced soil loss. Maximum vegetative growth (volume of trees) was recorded in kinnow mandarine as compared to mosambi irrespective of intercrops grown. Maximum vegetative growth was observed in both fruit trees when potato was grown as an intercrop and the minimum growth was recorded under control. Maximum fruit yield (3828 kg $ha^{-1}$) in mosambi was obtained with fenugreek as an intercrop followed by spinach and control. The yield of intercrops grown with both the fruit crops was the highest for spinach (16000 and 8400 kg $ha^{-1}$) and minimum with potato (10400 and 5600 kg $ha^{-1}$) (Kumar and Srivastava, 1998).

### 5.5.6 Effect of bund plantations of trees

A study to assess effect of different tree species on field bund on production of field crops was conducted during 1983-84 with crops like wheat, mustard and *taramira* and tree species like semal and kanji. Trees growing on the northern side field bunds and crops raised in 4 m strips perpendicular to the tree rows indicated that there was no crop production up to 4 m distance from the trees. Both tree species adversely affected the wheat crop up to 2 m distance. Mustard was affected to a distance of 15 m from tree line. Taramira production was adversely affected up to a distance of 20 m by semal tree but due to kanji the adverse effect was noticed to a distance of 10 m only.

### 5.5.7 Agro-forestry of medicinal plants with established ber and neem plantation

Effective utilization of the land resources is essential to enhance overall farm productivity and net returns, therefore, an experiment was started in 2005 to utilize interspaces of mature ber and Neem trees for raising medicinal plants (Indian Senna/*Cassia angustifolia*, Ghritkumari /*Aloevera* and Ashwagandha/*Withania somnifera*). Control plots (without any tree) were also maintained in each land use for assessment of effect of tree species on productivity of medicinal crops. Results (average of 4 years) revealed that yield of Ghritkumari corresponded to wheat equivalent yield (WEY) of 4 t $ha^{-1}$ followed by Indian Senna (1 t $ha^{-1}$ of WEY) under berplantation which provided a net additional economic returns of Rs. 40,000 $ha^{-1}$ and Rs. 10,000 $ha^{-1}$, respectively (Table 5.68). In case of neem, yield of Ghritkumari and Indian Senna corresponded to 2.4 t $ha^{-1}$ and 0.80 t $ha^{-1}$ WEY with a net additional economic return of Rs. 24,000 $ha^{-1}$ and Rs. 7800 $ha^{-1}$, respectively. During experimentation period of 4 years Ashwgandha could survive only in two years and failed in rest two.

**Table 5.67: Variation in physio-chemical soil properties and available N and $K_2O$ under wheat with and without the incorporations of subabul leaves (Average 1984-89)**

| Treatment | Soil depth (cm) | With incorporation | | | | Without incorporation | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | pH | OC % | Avl. N (kg $ha^{-1}$) | Avl. $K_2O$ (kg $ha^{-1}$) | pH | OC % | Avl. N (kg $ha^{-1}$) | Avl. $K_2O$ (kg $ha^{-1}$) |
| $T_1$: Two rows of subabul with 8 rows of wheat | 0-15 | 9.0 | 0.28 | 251 | 398 | 9.0 | 0.27 | 220 | 322 |
| | 15-30 | 8.9 | 0.16 | 199 | 368 | 8.6 | 0.13 | 165 | 255 |
| $T_2$: Two rows of subabul with 12 rows of wheat | 0-15 | 9.1 | 0.28 | 246 | 460 | 8.9 | 0.26 | 286 | 336 |
| | 15-30 | 8.6 | 0.18 | 199 | 324 | 8.6 | 0.17 | 196 | 288 |
| $T_3$: Two rows of subabul with 16 rows of wheat | 0-15 | 8.8 | 0.26 | 335 | 409 | 8.8 | 0.27 | 250 | 347 |
| | 15-30 | 8.5 | 0.14 | 225 | 315 | 8.6 | 0.13 | 235 | 266 |
| $T_4$: Two rows of subabul with 20 rows of wheat | 0-15 | 8.8 | 0.30 | 303 | 305 | 8.7 | 0.23 | 295 | 277 |
| | 15-30 | 8.8 | 0.17 | 225 | 308 | 8.5 | 0.20 | 227 | 223 |

**Table 5.68: Performance of medicinal crops (average of 4 years) under different tree based land use systems**

| Tree crop | Under storey crop | Yield ($t\ ha^{-1}$) | Gross return ($Rs.\ ha^{-1}$) | Net return ($Rs.\ ha^{-1}$) | WEY* ($t\ ha^{-1}$) |
|---|---|---|---|---|---|
| Ber | Indian Senna | 0.53 | 15900 | 10000 | 1.0 |
| | Ghritkumari | 30 | 60000 | 40000 | 4.0 |
| Control (Ber orchard) | Indian Senna | 0.84 | 25000 | 19000 | 1.9 |
| | Ghritkumari | 50 | 100000 | 72000 | 7.2 |
| Neem | Indian Senna | 0.46 | 13800 | 7800 | 0.8 |
| | Ghritkumari | 20.0 | 40000 | 24000 | 2.4 |
| Control (Neem field) | Indian Senna | 0.96 | 28800 | 22800 | 2.3 |
| | Ghritkumari | 42.0 | 84000 | 56000 | 5.6 |

* Minimum support price of wheat was Rs. 10,000 per ton

## 5.6 Package of Practices of Crops in Sheetalpur (Hamirpur) Watershed

### 5.6.1 Effect of agro-techniques on productivity of chickpea and wheat

Results appended in Table 5.69 show the impact of different agro-techniques on productivity of chickpea and wheat. Chickpea Cv. L550 enhanced the grain yield over local/ farmer's variety by 75% (470 kg $ha^{-1}$). Similarly changing the date of sowing of chickpea crop from first week of November to third week of October resulted in 29% higher grain yield which corresponded to 240 kg $ha^{-1}$. In case of wheat, high yielding Cv. WH 147 enhanced the grain yield by 217% or 2280 kg $ha^{-1}$ over the local/ farmer's variety. Changing the date of sowing of wheat from after December to first fortnight of November also enhanced grain yield by 217% or 2610 kg $ha^{-1}$. Similarly, changing the seed rate of improved variety from 125 to 100 kg $ha^{-1}$ resulted in 71% increase in grain yield which corresponded to 1350 kg $ha^{-1}$. Criss cross sowing of wheat also improved the grain yield by 17% or 250 kg $ha^{-1}$ over the farmer's practice of broadcasting seeds.

**Table 5.69: Influence of agro-techniques on increasing crop yield in Sheetalpur watershed**

| Agronomical practice | Practice | | Grain yield (kg $ha^{-1}$) | | Factor A |
|---|---|---|---|---|---|
| | | Chickpea | | | |
| | Local | Improved* | Local | Improved* | |
| Variety | Local | L 550 | 630 | 1100 | 1.75 |
| Date of sowing | I[st] week of Nov. | III[rd] week of Oct. | 830 | 1070 | 1.29 |
| Overall component factor | | | | | 2.26 |
| | | Wheat | | | |
| Variety | Local | WH 147 | 1050 | 3330 | 3.17 |
| Date of sowing | After Dec. | 1-15 Nov. | 1890 | 4500 | 3.17 |
| Seed rate (kg $ha^{-1}$) | 125 | | 1900 | 3250 | 1.71 |
| Sowing method | Broadcasting | Criss-cross | 1500 | 1750 | 1.17 |
| Overall component factor | | | | | 15.10 |

*Both the crops were raised with adequate fertilizer under demonstration.

These results were quite encouraging for predominantly resource poor farmers in Sheetalpur (Hamirpur) watershed.

### 5.6.2 High yielding varieties of crops

In another study on high yielding crop varieties, marked enhancement in productivity of different crops was recorded (Table 5.70). Results revealed that pigeonpea Cv. T 21 registered 99.66% or 5.5q $ha^{-1}$ over the local/farmer's variety. Sorghum Cv. CSH5 registered 26.01% or 3.2 q $ha^{-1}$ higher grain yield over the local/farmer's variety. Sesame Cv. T 4 also registered higher grain yield over local/farmer's variety which corresponded to 116.66% or 1.4 q $ha^{-1}$. In case of wheat Cv. WH 147, HD 2204 and RR 21 registered 100.6, 100.0 and 75.63% or 16.1, 16 and 12.1 q $ha^{-1}$ higher grain yield over the local/farmer's variety, respectively. Results further reveal that gram Cv. JG 315, K 850 and L 550 registered 132.76, 68.97 and 29.31% or 7.7, 4.0 and 1.7 q $ha^{-1}$ over the local/farmer's variety, respectively.

**Table 5.70: Performance of high yielding varieties of different crops in Sheetalpur (Hamirpur) watershed**

| Crops | Varieties | Yield (q $ha^{-1}$) |
|---|---|---|
| Pigeonpea | T-21 | 11.5 (91.66) |
| | Local | 6.0 |
| Sorghum | CSH5 | 15.5 (26.01) |
| | Local | 12.3 |
| Sesame | T4 | 2.6 (116.66) |
| | Local | 1.2 |
| Wheat | WH 147 | 32.1 (100.6) |
| | HD2204 | 32.0 (100.0) |
| | RR21 | 28.1 (70.63) |
| | Local | 16.0 |
| Gram | JG315 | 13.5 (132.76) |
| | K850 | 9.8 (68.97) |
| | L550 | 7.5 (29.31) |
| | Local | 5.8 |

*Figures in parenthesis indicate % increase over local/farmers varieties.

### 5.6.3 Sowing time of gram and wheat

Results appended in Table 5.71 reveal that best time of sowing of gram and wheat was upto 10th October and in between 1st and 15th November, respectively. Sowing beyond these dates illustrated a drastic reduction in grain yield of both gram and wheat which corresponded to 5.65 and 16.2 q $ha^{-1}$, respectively.

**Table 5.71: Effect of different dates of sowing on grain yield of gram and wheat in Sheetalpur (Hamirpur) watershed**

| Gram | | Wheat | |
|---|---|---|---|
| Date of sowing | Yield (q $ha^{-1}$) | Date of sowing | Yield (q $ha^{-1}$) |
| Up to 10th Nov. | 14.10 | 1-15th Nov. | 45.0 |
| 11-20th Nov. | 8.65 | 16-30th Nov. | 28.8 |
| 21-30th Nov. | 8.64 | 1-15th Dec. | 29.5 |
| After 30th Nov. | 6.00 | After15th Dec. | 18.9 |

### 5.6.4 Sowing method of wheat

Results on effect of different sowing methods on yield of wheat (Table 5.72) showed that out of various methods of sowing, criss cross sowing resulted in the highest grain yield of wheat (17.5 q $ha^{-1}$) which was 16.7% higher than the most popular method of sowing *i.e.* broadcasting of seeds/control.

**Table 5.72: Effect of sowing method on grain yield of wheat**

| Sowing method | Yield (q $ha^{-1}$) | % increase over control |
|---|---|---|
| Broadcasting of seed | 15.0 | – |
| Sowing behind plough | 16.0 | 6.7 |
| Sowing with bullock drawn seeddrill | 15.8 | 5.3 |
| Sowing by criss-cross method | 17.5 | 16.7 |

### 5.6.5 Effect of seed rate on grain yield of wheat

Results (Table 5.73) showed that the highest grain yield of wheat (32.5 q $ha^{-1}$) was recorded at the seed rate of 125 kg $ha^{-1}$ but further increase in the seed rate as practiced by farmers of Sheetalpur watershed beyond 125 kg $ha^{-1}$ resulted in considerable loss of wheat grain yield.

**Table 5.73: Seed rate affecting yield of wheat**

| Seed rate (kg ha$^{-1}$) | Grain yield (q ha$^{-1}$) | % of maximum yield |
|---|---|---|
| 100 | 28.3 | 87 |
| 125 | 32.5 | – |
| 150 | 25.5 | 78 |
| 175 | 22.0 | 67 |
| 200 | 19.0 | 58 |

**Table 5.74: Grain yield of gram as affected by fertilizer application**

| Fertilizer added (kg ha$^{-1}$) | Gram yield (q ha$^{-1}$) | % increase over control |
|---|---|---|
| N:P | | |
| 15:40 | 12.5 | 108 |
| 8:20 | 9.0 | 50 |
| 7:18 | 8.4 | 40 |
| Control | 6.0 | --- |

### 5.6.6 Fertilizer use in gram

It is an established fact that limited use of fertilizers in pulses often result in yield enhancement under rain fed conditions. However farmers were not applying fertilizers in rain fed pulse crops in Sheetalpur watershed.

Therefore, an on farm study involving three fertilizer doses (15:40, 8:20 and 7:18 N:P kg ha$^{-1}$) was conducted. Results show that use of 15:40 kg N:P ha$^{-1}$ resulted in the highest seed yield of gram (12.5 q ha$^{-1}$) which was 108% or 6.5 q ha$^{-1}$ higher than the control.

**5.6.7 Intercropping studies with gram and wheat:** Data appended in table 5.75 reveal that under rain fed conditions although gram + mustard recorded the highest main crop yield equivalent of 1233 kg ha$^{-1}$ but it was just higher by only 17 kg ha$^{-1}$ than the sole mustard crop. However gram + mustard registered 286, 812 and 299 kg ha$^{-1}$ higher main crop yield equivalent than sole gram, sole linseed and gram + linseed, respectively. Under irrigated conditions, wheat + mustard recorded the highest main crop yield equivalent (3081 kg ha$^{-1}$) which was 1041, 1592, 1486 and 1429 kg ha$^{-1}$ higher than sole wheat, sole mustard, sole gram and gram + mustard, respectively.

**Table 5.75: Crop yield (q ha$^{-1}$) under in intercropping and pure cropping system (average of 4 years)**

| Crop/cropping system | Main crop yield | Intercrop yield | Main crop equivalent |
|---|---|---|---|
| | **Rainfed condition** | | |
| Mustard | 1216 | -- | 1216 |
| Gram | 947 | – | 947 |
| Linseed | 421 | -- | 421 |
| Gram + mustard | 689 | 372 | 1233 |
| Gram + linseed | 729 | 142 | 934 |
| | **Irrigated condition** | | |
| Wheat | 2040 | -- | 2040 |
| Mustard | 1489 | -- | 1489 |
| Gram | 1235 | -- | 1235 |
| Gram + mustard | 924 | 490 | 1652 |
| Wheat + mustard | 1760 | 407 | 3081 |

Main crop equivalent yield was calculated on the basis of prevailing market rate.

**Photo 5.3: Terraced and bunded shallow Yamuna ravines**

## 5.7 Soil Erodibility under Different Land Uses

Out of different factors influencing the soil erosion, soil itself is the most important since certain soils get eroded readily whereas others under similar sets of rainfall, vegetation, topography and other factors erode very little. This difference caused by the soil properties in erosion rates themselves is referred to as soil erodibility. The erosion indices worked out for Agra watershed *viz.,* dispersion ratio (D.R.), erosion ratio (E.R.) and erosion index (E.I) registered much higher values than the prescribed threshold limits (Table 5.76), therefore, these soils can be rated as highly erodible. The erosion ratio was significantly and positively correlated with dispersion ratio and erosion index while it portrayed a negative correlation with total silt + clay. Clay ratio as well as silt/clay ratio also exhibited positive correlation with erosion ratio. Conversely, clay/M.E ratio, clay /1/2 W.H.C ratio and water stable aggregates showed a negative correlation with erosion ratio. Water stable aggregates were negatively correlated with D.R., E.R. and E.I. while it exhibited a positive correlation with clay/M.E ratio and clay/1/2 W.H.C. ratio. Water stable aggregates portrayed a negative correlation with clay ratio as well as silt/clay ratio in these soils. Thus, erosion indices were observed to be interrelated. A study was initiated to find out the erodibility characteristics of different land uses in Yamuna ravines of Agra watershed. Soil samples were collected from three depths (0-15, 15-30 and 30-60 cm) from seven land uses *viz.,* ravine proper, cultivated land (farmers' practice), terraced land and plantations of *Acacia nilotica, Prosopis juliflora, Dalbergia sissoo* and *Cenchrus ciliaris*. The mechanical fractions and organic matter were observed to vary considerably under different land uses. The erodibility indices indicate that the soils of Yamuna ravines in general are erosive in nature (ER 17.2 to 70.0) under all the land uses. However, the erodibility of different land uses was highest in case of ravine proper and lowest in case of *Cenchrus ciliaris*. Erosion ratio was significantly and positively correlated with dispersion ratio and erosion index (+ 0.976 and + 0.998, respectively). The ER was negatively correlated with silt and clay (-0.580 and -0.928), respectively. The ER was also correlated with various erosion indices. Therefore, the present study concluded that physico-chemical soil properties of Yamuna ravines are mainly responsible for high water erosion in the Agra watershed as well since these properties are well correlated with different erosion indices.

**Table 5.76: Correlation of erosion ratio (Y) with soil properties ($X_1$) and erosion indices ($X_2$)**

| Soil properties/ erosion indices | Correlation coefficient | Regression equation |
|---|---|---|
| Silt % | -0.859 *** | $Y = 87.52 - 1.99 X_1$ |
| Clay % | -0.928 *** | $Y = 133.17 - 550 X_1$ |
| Organic carbon % | -0.474 * | $Y = 75.20 - 69.59 X_1$ |
| Water stable aggregates (>0.25 mm) | -0.738 *** | $Y = 136.36-3.20 X_1$ |
| Clay/moisture equivalent ratio | -0.597 *** | $Y = 199.91-175.01 X_1$ |
| Clay/1/2 water holding capacity ratio | -0.597 ** | $Y = 195.42-162.69 X_1$ |
| Dispersion ratio | +0.976 *** | $Y = 3.15+1.30 X_1$ |
| Erosion index | +0.998 *** | $Y = 0.82+0.99 X_1$ |

*significant at 5% error, ** significant at 1% error and *** significant at 0.5% error

**Table 5.77: Average grain yield of castor and mustard as influenced by supplemental irrigation (1993-96)**

| Year | Grain yield (kg $ha^{-1}$) | | % increase |
|---|---|---|---|
| **Castor** | | | |
| | **No irrigation** | **Irrigation at kennel stage** | |
| 1993-94 | 1240 | 1580 | 27 |
| 1994-95 | 1250 | 1625 | 30 |
| 1995-96 | 1160 | 1537 | 33 |
| 1996-97 | 596 | 988 | 66 |
| **Average** | **1062** | **1433** | **35** |
| **Mustard** | | | |
| | **No irrigation** | **Irrigation at grain formation stage** | |
| 1993-94 | 997 | 1375 | 38 |
| 1994-95 | 1000 | 1450 | 45 |
| 1995-96 | 750 | 1531 | 104 |
| 1996-97 | 469 | 1050 | 124 |
| **Average** | **804** | **1352** | **68** |

# 6.0 CONSERVATION MEASURES FOR NON-ARABLE LANDS

The land feature of ravines is rugged and characterized by three distinct parts *viz.,* ravine top or hump (irregular in size and shape), slope and bottom/bed (Photo 6.1). In general, the depth of ravines ranges from 1 to 20 m but may reach up to >50 m. These lands are prone to accelerated erosion if proper conservation measures and landuses are not adopted. As a typical example of prevailing land use in the Chambal ravine system, 72% area of shallow gullies (<1 m deep), 39.6% area of the medium gullies (1-3 m deep) and 4.5% of deep gullies (>3 m deep) have been placed under cultivation (Anonymuos, 1972). Almost similar land uses prevail in the ravine regions in other parts of country as well and these are not always in agreement with scientifically advisable land uses and soil and water conservation practices. While the marginal and shallow gullied lands can be reclaimed economically and can be utilized for agriculture, the medium and deep ravinous lands, which constitute about 2/3 of total ravine area, are not fit for tillage and cultivation of agricultural crops due to high vulnerability to degradation and are classified as nonarable lands. These lands should be placed under permanent vegetation. The best scientific land use for these lands is to place them under tree and grass based production systems involving horticulture, hortipasture, silvipasture, energy plantation and plantation for timber or other forest produce. Thus these lands can augment supplies of fruits, fuel wood, fodder, industrial timber, bamboo and other minor forest produce if utilized judiciously. In this situation, tree-based farming offers excellent opportunities because of several advantages.

**Photo 6.1: The land feature of ravines is rugged**

## 6.1 Potential of Horticulture/Hortipasture for Productive Utilization of Ravines

Usually the ravine lands are associated with some river system and if provision for irrigation can be made with some capital investment, these lands can be utilized for economic utilization through introduction of hardy or underutilized fruits which can withstand the harsh resource poor conditions of ravines. Studies conduct at ICAR- IISWC, Research Centre, Agra for evaluation of suitability of fruit trees for use in ravines have found that hardy fruits like aonla (*Emblica officinalis*), ber (*Zizyphus mauritiana*), karonda (*Carissa carandus*), kinnow mandarine, pomegranate (*Punica granatum*) and bel (*Aegle marmelos*) can suitably grown in Yamuna ravines under rainfed conditions with provision of life saving irrigation in the initial establishment period. In case regular irrigation facilities can be developed planting of papaya can suitably be practiced. As these lands are not suitable for cultivation of food crops, the interspaces of the fruit plantation can be utilized for production of grasses under hortipastoral system at least till the time canopy of the trees closes. In order to study suitability and economic viability of different fruit crops in the Yamuna ravines, various fruit types were planted on top, bottom and terraces of the ravines (Photo 6.2). Maximum survival (90%) was recorded in aonla followed by ber (88%), pomegranate (83%) and kinnow mandarine (76.47%). Survival of bael was the minimum (17.06%) (Dubey, 1996). Ber exhibited better spread (N-S and E-W) followed by aonla, custard apple and pomegranate. On an average, 21.5 kg tree$^{-1}$ fruit yield was recorded in aonla followed by ber (18.50 kg tree$^{-1}$), kinnow mandarine (8.40 kg tree$^{-1}$) and it was minimum in bael (3.00 kg tree$^{-1}$). In lands where assured irrigation facilities were available, performance of papaya was economically remunerative. The cultivars Ranchi, Cylone and Coorg honey dew were found suitable which produced about 40 t ha$^{-1}$ fruits and generated a net profit of about Rs. 25000 ha$^{-1}$ at 1997 prices.

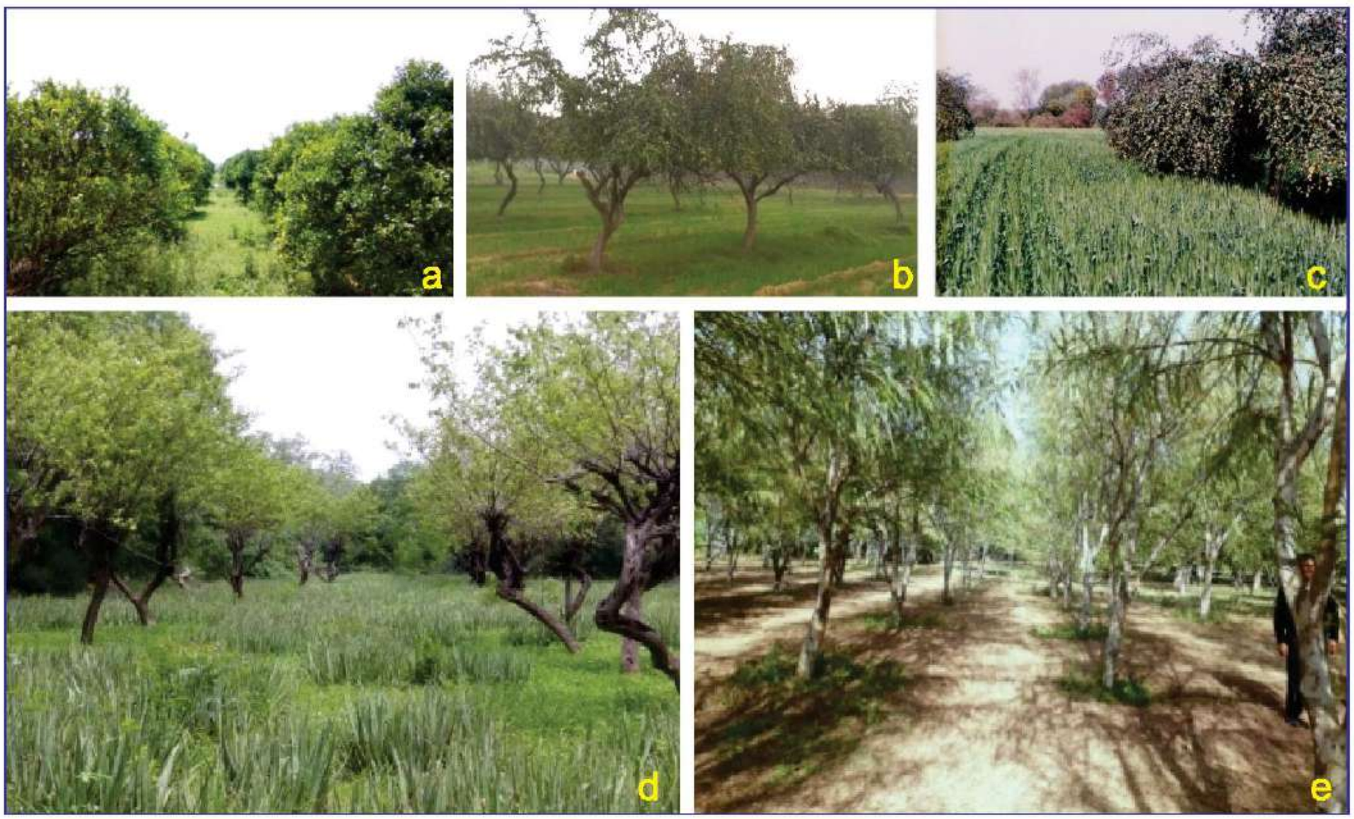



**Photo 6.2: Kinnow mandarine (a), Ber (b), Ber + Wheat intercropping (c), Ber + *Aloe vera* intercropping (d) and Aonla (e) in ravines**

In selection of suitable fruit trees varietal variations are important as performance of different varieties of fruits varies with the variation in edaphic, topographic and climatic parameters. Keeping this view a comparative study on the performance of 12 ber cultivars was conducted at Agra centre. A total of 12 ber cultivars Aliganj, Banarasi, Gola, Jogia, Kanker Kalan, Karaka, Muria Mehrara, Narma, Ponda Safeada, Ponda, Suamundi and Umran were investigated for their suitability on Yamuna ravines at Agra centre. Ber plants were planted in 60 cm × 60 cm × 60 cm pits at a spacing of 4 m × 4 m. Subsequently, alternate rows were removed and a spacing of 8 m X 4 m was maintained. These budded plants started producing fruits from third year. Data recorded from 1998 to 2000 revealed that Ponda safeda and Banarasi are the most promising cultivars for the reclaimed class III ravines land (Table 6.1, Fig. 6.1). Highest yield was obtained from Ponda Safeda (33 kg $tree^{-1}$ or 10 t $ha^{-1}$) followed by Banarasi (22 kg $tree^{-1}$ or 7 t $ha^{-1}$) and Gola (15 kg $tree^{-1}$ or 4.5 t $ha^{-1}$) (Kumar and Bhushan, 2001).

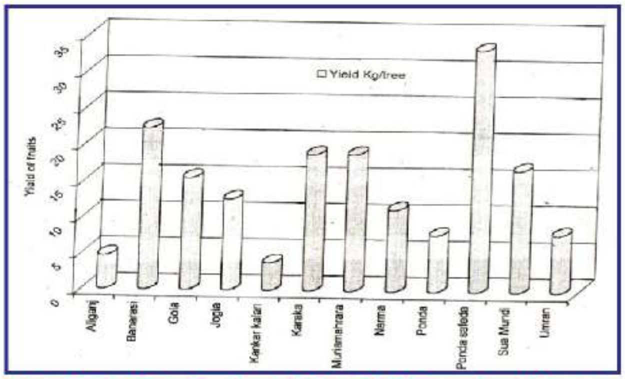



Fig. 6.1: Ber fruit yield of different cultivars

**Table 6.1: Fuelwood and fodder yield of ber cultivars**

| Cativars | Fuelwood (kg/tree) | Leaf fodder yield (kg/tree) |
|---|---|---|
| Aliganj | 43.420** | 11.57 |
| Banarasi | 32.472 | 9.97 |
| Gola | 27.695 | 8.94 |
| Jogia | 26.330 | 7.50 |
| Kankar kalan | 13.335 | 6.30 |
| Karaka | 27.500 | 8.75 |
| Ponda | 20.500 | 7.50 |
| Ponda safeda | 15.400 | 6.85 |
| Sua-Mundi | 23.500 | 8.24 |
| Umran | 46.350** | 10.30 |

** Including dry and dead wood

Karonda (*Carissa carandus*) is an under utilized fruit crop which is widely found in the arid to semi-arid regions of India. The fruits of karonda are rich source of iron and vitamin C. The fruits have use in preparation of pickles, jelly, candy and coloured wine. Because of presence of thorns on the stems, the plant is used in live fencing of field boundaries. In order to evaluate its production potential, plantations at 1 m distance were made on the field boundaries. Total fruit yield of 800 kg $ha^{-1}$ and 1000 kg $ha^{-1}$ were harvested along the field boundaries in the $3^{rd}$ and $4^{th}$ year after planting, respectively.

No regular planting distance was observed in the farmers field, which varied from 0.5 m to 1 m. The fruit yield varied from 1 to 3 kg $tree^{-1}$ depending on the size and vigour of the trees. Therefore, Karonda was found to be an effective live fencing material which also generated an additional income of Rs. 4000 to 5000 $ha^{-1}$ (Kumar and Yadav, 2001).

## 6.2 Economic Utilization of Ravines by Silvipasture

The medium and deep ravines are potential areas for augmenting supplies of fuel and fodder as more fertile lands can not be diverted for energy plantation/fodder production at the cost of reduced food grain production.

Studies conducted at ICAR-IISWC, Research Centre, Agra suggest that multipurpose tree species such as *Acacia nilotica, Acacia leucophloea, Ailanthus excelsa, Bauhinia variegate, Eucalyptus tereticornis, Leucaena leucocephala, Azadirachta indica, Albizia lebbeck, Soymida febrifuga, Salvadora oleoides, Tecomella undulata, Pongamia pinnata, Melia azedarach, Erythrina indica, Holoptelea integrifolia* and *Dalbergia sissoo* are suitable for use on medium and deep ravines (Table 6.2).

**Table 6.2: Growth performance of various tree species in ravines (Age 11years)**

| Tree species | Height (m) | D.B.H. (cm) |
|---|---|---|
| *Albizia amara* | 7.00 | 13.6 |
| *Azadirachta indica* | 5.4 | 11.8 |
| *Cassia siamea* | 7.84 | 9.6 |
| *Dalbergia sissooo* | 7.55 | 10.4 |
| *Gliricidia maculate* | 3.66 | 2.7 |
| *Parkinsonia aculeate* | 5.47 | 10.1 |
| *Pongamia pinnata* | 5.23 | 8.0 |
| *Prosopis chilensis* | 11.35 | 19.9 |

**Source:** Prajapati *et. al.*, 1987

**Table 6.3: Distribution of trees (%) in different diameter classes of 4 and 5 years old plantation of *E. tereticornis***

| Age of plantation | DBH class | | | |
|---|---|---|---|---|
| | 5 – 10 cm | 10 – 15 cm | 15 – 20 cm | 20 – 25 cm |
| 5 years | 28.7 | 38.1 | 28.7 | 3.1 |
| 4 years | 40.7 | 48.3 | 10.0 | 1.0 |

Perusal of Table (6.3) revealed that after 4 years plantation more than 60% trees and after 5 years of plantation more than 70% of the trees attain more than 10 cm dbh. This implies that *E. tereticornis* with a rotation of 4 to 5 years could be taken up as a farm forestry or commercial forestry activity in the Yamuna ravines (Prajapati and Singh, 1986).

(a) (b)

**Photo 6.3: Natural vegetation (a) and *Acacia nilotica* (b) in ravines**

### 6.2.1 Species compatibility and optimization of spacing in silvipastoral system

Two fuel wood species *viz., Acacia nilotica* and *Acacia tortilis* were evaluated from 1977-92 to optimize fuel and fodder productivity of uncultivable deep ravines under varying planting densities (Photo 6.3). These trees were planted at spacing of 3 m x 3 m, 4 m x 4 m and 5 m x 5 m while the inter spaces were planted with fodder grass *C. ciliaris*. The study was conducted at the ravine top, side slope and the bottoms.

At the end of the rotation year (15 years), it was found that higher planting density did not have any negative effect on the growth of both the tree species. The highest fuel wood yield was recorded in case of 3 m x 3 m spacing as it accommodated maximum number of trees (1111 trees ha$^{-1}$) in a unit area. Distribution of trees in different height and diameter classes revealed that 10.5% of *Acacia nilotica* and 23.9% *Acacia tortilis* were wiry and lanky and were having less than 5 cm dbh and 4 m height after 15 years of plantation.

This phenomenon should be given due consideration while selecting a tree species in a silvipastoral system for the ravines. Trees maximum fuel wood yield was recorded at the ravine bottom while the ravine top, which faced maximum moisture stress recorded lowest fuel yield per unit area in both species.

The yield of *C. ciliaris* was higher in the interspaces of *Acacia tortalis* in comparison to interspaces of *Acacia nilotica* in all planting spacing (Table 6.4).

**Table 6.4: Productivity of silvipastoral systems in the uncultivable deep ravines**

| Tree species | Spacing | Fuel wood (t $ha^{-1}$ $yr^{-1}$) | Grass yield (t $ha^{-1}$ $yr^{-1}$) | Total biomass (t $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|---|
| *Acacia nilotica* | 3 m x 3 m | 1.8 | 1.5 | 3.3 |
| | 4 m x 4 m | 1.3 | 1.5 | 2.8 |
| | 5 m x 5 m | 0.9 | 1.8 | 2.7 |
| *Acacia tortilis* | 3 m x 3 m | 1.9 | 1.8 | 3.7 |
| | 4 m x 4 m | 0.7 | 1.8 | 2.5 |
| | 5 m x 5 m | 0.7 | 2.1 | 2.8 |

**Table 6.5: Fuel yields by *Acacia* species at different physiographic locations in ravines (3 m x 3 m spacing)**

| Tree species | Physiographic location | Fuel wood (t $ha^{-1}$ in 15 year rotation) |
|---|---|---|
| *Acacia nilotica* | Ravine top | 19.7 |
| | Ravine side | 27.4 |
| | Ravine bottom | 34.4 |
| *Acacia tortilis* | Ravine top | 27.3 |
| | Ravine side | 28.6 |
| | Ravine bottom | 30.2 |

Both the tree species did not reveal any marked difference in fuel wood and grass productivity in a rotation of 15 years (Table 6.5). It was evident that these species have the potential to yield 1.8 to 1.9 t $ha^{-1}$ $yr^{-1}$ of fuel wood and 3.3 to 3.7 t $ha^{-1}$ $yr^{-1}$ of fodder in the uncultivable ravine lands (Prajapati *et. al.*, 1993). Some destructive sampling was also carried out in this study to develop an equation to predict fuel wood yield (kg $tree^{-1}$) for both the species.

*Acacia nilotica*: $Y = 18.73695 + 15.851X_1 - 20.432X_2$

*Acacia tortilis*: $Y = -42.4148 + 11.4981X_1 - 0.6179X_2$

Where,

Y = Fuel wood yield (kg $tree^{-1}$)

$X_1$ = Tree height (m)

$X_2$ = dbh (cm)

### 6.2.2 Evaluation of various fodder grasses for Yamuna ravines

With a view to assess the suitability of various grasses for fodder production in the ravines adoption potential of *Cenchrus ciliaris, Cenchrus setigerus, Dicanthium annulatum and Panicum antidotable* was studied under Agra conditions. Five strains each of *Cenchrus ciliaris* (strains no- 214, 262, 303, 357 and 358), *C. setigerus* (strains no- 175, 296, 412, 416 and 418), *Dicanthium annulatum* (strains no- 488, 490, 491, 495 and 499) and *Panicum antidotale* (strains no- 29, 333, 335, 340 and 341) received from Central Arid Zone Research Institute, Jodhpur were grown to evaluate their productivity in the Yamuna ravines at Agra (Photo 6.4). Among all the four grass species, *C. ciliaris* recorded highest yield. Based on four years average yield data (1972 to 1975), it was observed that strain no 303 of *C. ciliaris* produced highest average air dry biomass (7.4 t $ha^{-1}$) followed by stain no 217 (6.3 t $ha^{-1}$) (Singh and Puri, 1975). The forage yield in all grasses was highest during second year and it reduced significantly in fourth year of planting (Table 6.6).

**Photo 6.4: *Dicanthium annulatum* in ravines**

**Table 6.6: Average dry forage (kg $ha^{-1}$) production**

| *C. ciliaris* | | *C. setigerus* | | *D. annulatum* | | *P. antidotaie* | |
|---|---|---|---|---|---|---|---|
| Strain | Forage | Strain | Forage | Strain | Forage | Strain | Forage |
| 214 | 5312 | 175 | 2409 | 488 | 1253 | 29 | 3595 |
| 262 | 3976 | 296 | 4071 | 490 | 1426 | 333 | 4493 |
| 303 | 4707 | 412 | 3875 | 491 | 1518 | 335 | 3433 |
| 357 | 3063 | 416 | 3779 | 495 | 1143 | 340 | 5063 |
| 358 | 5238 | 418 | 3381 | 499 | 1720 | 341 | 4420 |
| Avr. | 4459 | - | 3503 | - | 1412 | - | 4201 |

### 6.2.3 Potential of *Cenchrus ciliaris* and legumes intercropping

The natural grass lands in India in general and central India in particular are low in soil nutrients which leads to low productivity of grasses. Legumes have proven effects on improving soil nutrient status. Keeping this in view four combinations of Cenchrus ciliaris + legume intercropping were studied for suitability in ravines. *Cenchrus ciliaris* grass was planted in 1m row to row and 50cm plant to plant spacing. Seeds of four legumes namely *Stylosanthes humitis*, *S. gracilis*, *Macropitilum atropurpurium* and *Atylosia scarabibediosis* were drilled between the rows of grass. 50 kg. A uniform dose of $P_2O_5$ @ 50 kg $ha^{-1}$ and $K_2O$ @ 30 kg $ha^{-1}$ was applied to all the plots. Grasses were cut twice a year and legumes were harvested when second cutting of grass was undertaken. The legumes did not have any adverse effect on the productivity of the grass species. In the inter row spaces of *C. ciliaris*, *Atylosa scarabeedis* produced highest air dry biomass (1.73 t $ha^{-1}$). *C. ciliaris* and *Atylosa scarabeedis* combination produced highest air dry biomass (8.17 t $ha^{-1}$) as compared to the yield produced by the other grass legume combinations (Bhushan and Singh, 1983). *Atylosia* produced 17.5 $qha^{1}$ additional protein rich fodder. Apart of N transfer of fixed N from legume to grass was determined by the difference between N yield of grass fraction in grass + legumes and N yield of grass alone treatment. Due to intercropping of legumes 15-37 kg $ha^{-1}$ N was fixed in the soil. The apparent nitrogen transfer appears to be 8-16 kg $ha^{-1}$.

### 6.2.4 Effect of nitrogen application on *Cenchrus ciliaris* yield

In a corresponding study to assess the impact of nitrogen doses on yield of *Cenchrus ciliaris* five doses of nitrogen *i.e.* 0 (control), 25, 50, 100 and 200 kg $ha^{-1}$ were applied to the *Cenchrus ciliaris* stands with three replications. A highly significant effect of N application was observed on yield of grass. The grass yield of 5.95 t $ha^{-1}$ in control plot was progressively increased to 13.64 t $ha^{-1}$ at 200 kg N $ha^{-1}$ (Fig. 6.2).

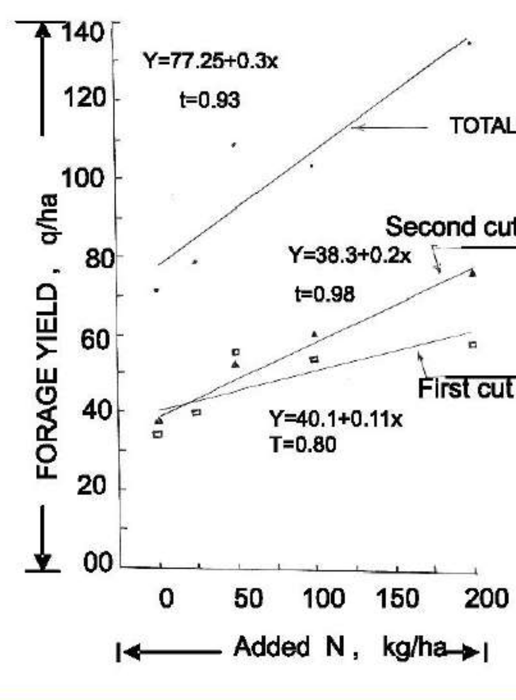



**Fig. 6.2: Impact of added Nitrogen on yield of *Cenchrus ciliaris* grass in Yamuna ravines**

### 6.2.5 Root characteristics and soil binding ability of grasses and shrubs

*Saccharum munja, Desmostachis bipinnata,* and *Ipomea fistulosa* are commonly used to protect earthen bunds, diversion channel and stream bank. Root characteristics namely depth, diameter, number, lateral spread and angular position were studied by trench wash method and soil binding capacity was studied by box cut method (Dhingra and Bhushan, 1993). Root characteristics *viz*. number, length and lateral spread of root system were highest in *Saccharum munja*.

Average diameter of root was greater in *Ipomea fistulosa* as compared to *Saccharum munja*. *Ipomea fistulosa* was observed to have average root penetration upto 89 cm depth followed by *Saccharum munja* (74 cm). Eighty per cent (80%) of the roots were confined to 1 m depth and only 5% of roots were observed below 1.5 m depth of soils. On the other hand, 18% of roots of *Ipomea fistulosa* penetrated more than 1.5 m soil depth.

Minimum standard deviation in angular position of roots (3.2) in case of *Saccharum munja* indicated more homogeneous spread of its root. Estimated suitability index based on merit of roots and shoot characteristics indicated that *Saccharum munja* was the most efficient grass among the three plant species studied to protect and improve soil under semi-arid conditions of Agra (Table 6.7 to 6.9).

**Table 6.7: Root characteristics of three plant species in Yamuna ravines**

| Name of species | No. of root/plant | Av. Length (cm) | Av. Dia (mm) | Std. Deviation angular position |
|---|---|---|---|---|
| *Saccharum munja* | 867 | 184 | 1.54 | 3.22 |
| *Desmostachya bipinnata* | 558 | 171 | 1.05 | 4.98 |
| *Ipomea fistulosa* | 112 | 163 | 6.30 | 6.43 |

**Table 6.8: Root characteristics of three plant species in Yamuna ravines**

| Name of species | Size of unit volume of soil taken | Av. radius of roots & stolons (r) | Weight of roots and stolons in grams (W) | Soil binding value ($Wr^2$) | Root matter added in 30 cm soil depth (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| *Saccharum munja* | 1'x1'x1 | 0.63 | 184.35 | 464.47 | 6137.19 |
| *Desmostachy abipinnata* | 1'x1'x1 | 0.46 | 70.56 | 326.36 | 2347.65 |
| *Ipomea fistulosa* | 1'x1'x1 | 1.36 | 75.00 | 40.25 | 2497.50 |

**Table 6.9: Comparative shoot characteristics and soil protecting ability of three plant species in Yamuna ravines**

| Name species | Cover of basal area at collar ($cm^2$) | Herbage spread (cm) | Soil protecting index with reference to | |
|---|---|---|---|---|
| | | 112 | Root characteristics | Shoot characteristics |
| *Saccharum munja* | 526.82 | 34 | ++++++++ | ++ |
| *Desmostachy abipinnata* | 38.54 | 281 | ++++++ | + |
| *Ipomea fistulosa* | 325.28 | - | +++++ | ++ |

### 6.2.6 Evaluation of suitability *Eucalyptus species* in Yamuna raivnes

A study to evaluate the suitability of twelve species of *Eucalyptus* for Yamuna ravines was initiated in 1964. One year old seedlings procured from the Central Arid Zone Research Institute, Jodhpur were planted on a bunded flat terrace (ravine bottom) in 60 $cm^3$ pits at 2.75 m x 2.75 m spacing in randomized block design with 8 replications. Only six species *viz. Eucalyptus tereticornis, E. sargentii, E. crebra, E. citriodora, E. melanophloia and E. leucoxylon* survived till the final harvest at the age of 15 year. The remaining six species *viz. E. camaldulensis, E. occidentalis, E. setosa, E.oleosa, E. cladocalyx* and *E. gracilis* died before the final harvest. Among all species evaluated, *E. tereticornis* produced highest air dry wood biomass (484 kg $tree^{-1}$). It was more than double the amount of air dry wood biomass produced by *E. sargentii* which ranked second for wood biomass yield. *E. tereticornis* with highest survival, growth and yield parameters exhibited the best adaptability to the edaphic and climatic conditions of Yamuna ravines at Agra. In view of its proven adaptability in Yamuna ravines, large-scale plantation of *E. tereticornis* was raised along the bank of river Yamuna during 1979 at 2 m X 2 m spacing. Maximum height growth of 7.5 m was attained within three growing seasons. The crop was harvested after 6 years, *i.e.* in 1985. Average height and DBH were 11.85 m and 12.45 cm, respectively. It produced 50 to 60 kg of fuel wood per tree or one pole (*Ballhi*) of at least 6 m length (Table 6.10).

**Table 6.10: Survival, growth parameters and air dry yield of *Eucalyptus* species on bunded flat a terrace in ravine bed (15 year rotation)**

| Name | Survival (%) | Height (cm) | D.B.H. (cm) | Air dry wood yield (kg $tree^{-1}$) |
|---|---|---|---|---|
| *Eucalyptus tereticornis* | 75 | 17.7 | 25.7 | 484 |
| *E. sargentii* | 50 | 14.9 | 20.0 | 199 |
| *E. crebra* | 62 | 14.6 | 16.2 | 160 |
| *E. citrodora* | 62 | 14.5 | 16.1 | 143 |
| *E. melanophloea* | 62 | 13.3 | 15.4 | 118 |
| *E. leucoxylon* | 12 | 15.3 | 14.0 | 95 |

From the data on height, DBH and fuel wood yield, the following regression equation was developed for prediction of wood yield:

Regression relationship is as under

i) $Y = -166.27 + 22.19 X_1$ (r=0.9)

ii) $Y = -87.77 + 12.7 X_2$ (r=0.9)

Where, Y is the yield (kg $tree^{-1}$) and $X_1$ and $X_2$ are the height (m) and dbh (cm), respectively.

However, the second equation is more useful because of simplicity with which the independent variable (DBH) can be measured.

There is a great demand for poles of about 6 m length and 8 to 12 cm mid diameter (corresponding dbh is 10-15 cm), in the urban areas located in the vicinity of ravines, which are suitable for building construction works, hut making and other such propping works in the construction industry. The natural forests around the Yamuna ravines do not have any species which can provide poles of such dimension in large quantities. Therefore, it was tried to find a suitable rotation at which *E. tereticornis* would produce poles of desirable dimensions. Therefore, growth and development data of *E. tereticornis* was tabulated and the tree diameters (DBH) were distributed in different diameter classes for 4 and 5 years rotation.

## 6.3 Status of Plant Nutrients under Different Land Uses

The ravine lands at the research farm of centre were reclaimed by terracing for agriculture purpose. Very deep and narrow ravine was stabilized by plantation in early sixties. After 20 years of reclamation, soils under different land uses/land cover were analyzed for physical and chemical properties. The study revealed that pH varied in the range 7.6 to 9.4. $CaCO_3$ was present in large amount (4 to 14%) in reclaimed ravines.

It was observed that organic carbon was higher under forestry plantation as compared to agriculture, horticulture and grassland especially up to 60 cm soil depth. Similarly, available nitrogen, Zn, Fe, Mn were also higher under forestry land use. Infiltration rate was also higher under plantation as compared to terraced field used for agricultural crops (Nitant and Bhushan, 1987).

## 6.4 Soil and Water Conservation Practices for Range Lands

### 6.4.1 Contour trenching for gully stabilization and productivity enhancement

The marginal lands located between the table lands and gullies are major contributors of runoff to the gullies. These lands are also prone to accelerated erosion if left unprotected. Contour trenching is an important measure for conservation of runoff and arrest soil loss in the ravines as it retains greater part of incident rain falling in the catchment, thus, reducing the runoff from these lands significantly.

Effect of staggered contour trenching on runoff, soil loss and productivity of grass and tree in ravines was studied in a 0.21 ha watershed at the research farm, Agra. This watershed was planted with *Cenchrus ciliaris* grass during 1965 and runoff and soil loss were measured (Table 6.11). During 1965-70, 25% of rainfall was going as runoff causing gully head extension and moisture stress to the grasses. After imposition of contour trenching in 1971, there was no runoff from the watershed. As a result, not only the gully head could be stabilized but also production of grasses increased manifold.

It also helped in natural regeneration of 441 trees of mixed species producing 3.5 tons of firewood from the watershed (Table 6.12). Later the contour trenches were removed which again generated runoff. This runoff was about 12 % of the rainfall (Bhushan *et. al.*, 1992).

**Table 6.11: Runoff and sediment yield as influenced by staggered trenches in Yamuna ravines**

| Year | Average rainfall (mm) | Runoff as % of rainfall | Soil loss (tons $ha^{-1}$) |
|---|---|---|---|
| 1965-70 | 662 | 25 | 3.53 |
| 1971 | Imposition of contour trenches | | |
| 1972-82 | 670 | Nil | Nil |
| 1983 | Removal of contour trenches | | |
| 1984-85 | 611 | 12 | 3.51 |

**Table 6.12: Yield of grasses trees as influenced by staggered trenches in Yamuna ravines**

| Phytomass (tons/ha) | Year | | | |
|---|---|---|---|---|
| | 1970 | 1971 | 1978 | 1981 |
| Green grass | 3.3 | 7 | 13.9 | 15.6 |
| Fuelwood from natural regeneration | - | - | - | 3.5 |

### 6.4.2 Checkdams in deep gullies

The deep gullies in ravines are not amenable to cultivation of agricultural crops due to susceptibility to accelerated erosion if placed under tillage. These lands also face high biotic pressure and low soil moisture regime. Thus, the deep gullies remain devoid of vegetation. In a study carried out in a unit source deep gully watershed at the research farm, it was observed that checkdams (height 0.5-2.0 m) should be located at 25 m from the toe of gully in the upper catchment and narrow catchment and at an interval of 45 m and riverine catchments. This pattern of location of earthen check dams would help uniform regeneration of natural vegetation in the deep gullied lands (Anonymous, 2003). In another study initiated in 1960, small earthen checkdams (0.5 m to 2.0 m height) were constructed in a watershed of 7.2 ha. The watershed was evaluated afresh in 1987 to study the utility of small earhen check dams in reducing gradient of ravine bed and functioning and effectiveness of the constructed earthen structures. During 27 years, the structures could withstand the discharge generated from 22 events having more than 80 mm rains. Out of 17 structures constructed, 76% remained intact and 23% breached due to animal tramps, pathways, rodent burrows and some flaws in site selection and construction works.

The sub-catchments enclosed by each check dam were categorized on the basis of contour in the catchment (Table 6.13).

**Table 6.13: Change in mean gully bed slope due to earthen check dams**

| Type of catchment | No. of sub-catchments | Mean area of sub-catchment (ha) | Channel bed slope (%) | | Reduction in channel gradient (%) |
|---|---|---|---|---|---|
| | | | Original | After 27 yrs | |
| Upstream catchment with broken topography | 4 | 0.41 | 9.1 | 3.9 | 57 |
| Narrow catchment with steep side slope | 9 | 0.31 | 4.1 | 1.4 | 66 |
| Ravine catchment | 1 | 0.24 | 4.0 | 1.23 | 69 |

The original mean valley slope of the catchments varied from 4.0 to 9.1%. The earthen check dams were most effective in reducing channel gradient or bed slope in the ravine catchment followed by narrow catchment with steep side slopes (Yadav *et. al.*, 1987). These ravine lands were thus developed in to terraced lands and could be used for planting of forest species.

## 6.5 Demand and Supply of Fuel for Cooking in Ravine Watershed

Ravine lands are invariably owned by resource poor people. These communities largely depend on the plant biomass as source of energy for cooking. A detailed survey was conducted in a gullied watershed along river Uttangan in Bah Teshil of Agra district (UP) to find out the energy source, its consumption, deficit and dependency on agroforestry systems to meet fuel wood requirement of the village population. It was observed that farmers were growing trees on the field boundaries but not in the field with agriculture crops.

The dominant tree species grown on field boundaries were Babul (*Acacia nilotica*), Sisham (*Dalbergisa sissoo*), Neem (*Azadirachta indica*) and Ber (*Zizyphus mauritiana*). The village population was a representative of a typical ravine region society having 4% landless families, 57% marginal farmers possessing less than 1 ha land, 37% small farmers having land holding 1-2 ha and only 2 % families having more than 2 ha land holding. About 70% of the farm families had 5 to 10 children which was indicative of the average family size in the ravines. Estimates based on the standard household energy consumption behavior, about 24% energy deficit was observed at house hold level. Out the total energy used by the standard individual household, 75% was met from fuel wood, 13% from crop residues and rest 12% from the cow dung available from the domestic cattle. In the fuel wood segment, about 31% of the total fuel wood was met out from the trees grown on the farmers own agricultural field (mostly on the boundaries) and 63% from the trees on the nearby wastelands.

When the results were extrapolated to the watershed level, it was inferred that, an area of 9.3% of the total watershed area should be kept under quick growing energy plantation like *Acacia nilotica* with a density of 600 trees $ha^{-1}$ in a 25 years rotation to meet energy needs of villagers in a ravenous watershed (Om Prakash *et. al.*, 2000).

**Table 6.14: Cooking energy requirement, consumption and deficit in ravine watershed in ravine region (year 2000)**

| Land holding class | No. of families | Energy required | Energy consumed | Energy deficit |
|---|---|---|---|---|
| | | Kilo calories | | |
| Landless | 95 | 8460 | 6661 | 1799 |
| Marginal | 1359 | 201207 | 142726 | 58481 |
| Small | 882 | 128498 | 99682 | 28816 |
| Large | 48 | 9823 | 7593 | 2230 |
| Total | 2384 | 317988 | 256662 | 91326 |

An average family member of six needed 4-10 kg of fuelwood or 1.33 kg $capita^{-1}$ $day^{-1}$ or 6261 kg calories $capita^{-1}$ $day^{-1}$ (Table 6.14).

## 6.6 Bamboo in Ravines

Ravine beds in medium and deep ravines have higher soil moisture than ravine slopes and ravine humps and can sustain mesophytic vegetation. Bamboo which is known as poor man's timber is important vegetation which provides excellent protection from soil erosion due to extensive net-like root systems and rhizomes, which bind soil together and thus helps in prevention of land degradation. When planted in ravine beds bamboo provides good vegetative cover and helps in arresting ravine extension. It also provides good production of bamboo sticks which are much in demand for multiple uses. *Dendrocalamus strictus* is the only species of bamboo that grows fairly well in the ravinous region where the climatic conditions are stressful with soil moisture as one of the primary limiting factors. The common solid type *Dendrocalamus strictus* was planted at 3 m x 3 m spacing on the protected gully beds that were treated with 2 to 3 gully plugs per hectare. The experiment was conducted to study the effect of number of old culms on the new culm recruits, size and vigour of mature bamboo culms and development and mortality of bamboo clumps on the protected gully beds. Four treatments *viz.* $N_0$- retaining no old culm per clump, $N_2$ - retaining 2 old culms in a clump, $N_4$ 4 old culms per clump and $N_6$ - 6 old culms in a clump were imposed in mature bamboo clumps.

Harvesting of mature culms was undertaken in annual felling cycle. Rainfall influenced the number of new recruits that increased with increase in rainfall. There was not much difference in number of new recruits per clump among the treatments. Highest number of recruits per clump (5 culms $clump^{-1}$ $year^{-1}$) was observed for $N_4$ although it was not significantly higher than the other treatments. However, treatments had marked effect on the size of the harvestable bamboos (culms more than 2 years age). The clumps under $N_0$ and $N_2$ had only 425 culms above 5 m height as compared to 62% and 55% under treatments $N_4$ and $N_6$, respectively. Occurrence of 3, 9, 15 and 21% culms of more than 7 m height under treatments $N_0$, $N_2$, $N_4$ and $N_6$, respectively further emphasized the need to keep higher number of old culms in a clump to boost productivity of bamboo in the ravines. Results of the study indicated that *Dendrocalamus strictus* plantation on the gully beds could be maintained under annual felling cycle with six old culms per clump. This could produce an annual yield of 4000 culms $ha^{-1}$ $yr^{-1}$ that includes 2900 culms of more than 5 m length size (Prajapati *et. al.*, 1993) Photo 6.5.

**Photo 6.5: *Dendrocalamus strictus* plantation on the gully beds in ravines**

In another study conducted during 2009 to 2014, plantation of bamboo (*Dendrocalamus strictus)* was raised in the research farm as well as in Manikpura village. In Manikpura village the ravine beds of a 9.8 ha ravine watershed was planted with two rows of bamboos in staggered manner. One year old seedlings of bamboo were planted at a spacing of 2 m x 2 m in the ravine bed having a slope of 0.5 to 1.5%. Hydrological results showed that runoff reduced from 9.6% to 1.8% and soil loss from 4.2 to 0.6 t $ha^{-1}$ $year^{-1}$ after 4 years of planting of bamboo. Based on bamboo growth performance, average value of culm height and culm collar diameter were recorded as 3.80 m and 22.50 mm, the average crown size and number of culms per clump was 3.93 m and 18, respectively (Table 6.15). Further, the soil under bamboo plants improved in terms of decreased pH and enhanced soil organic carbon. It was projected that there will be a cash outflow of Rs. 48,000 $ha^{-1}$ from 7th year onwards to the stakeholders, in addition to the benefits accrued to society at large in terms of value of nutrient (Rs. 2125–5555 $ha^{-1}$) saved through soil conservation (Singh *et. al.,* 2015 & 2017).

**Table 6.15: Runoff and soil loss under bamboo plantation**

| Year | Seasonal rainfall (mm) | Runoff (mm) | Runoff (%) | Soil loss (t $ha^{-1}$ $year^{-1}$) |
|---|---|---|---|---|
| 2010 | 456 | 44 | 9.65 | 4.27 |
| 2011 | 226 | 6.04 | 2.67 | 0.66 |
| 2012 | 531 | 14.5 | 2.73 | 0.78 |
| 2013 | 494 | 8.96 | 1.81 | 0.60 |

## 6.7 Plant Succession in the Ravines

The ravines are most fragile ecosystem subjected to various kinds of natural resource losses and threat to biodiversity. These lands face various abiotic and biotic disturbances which lead to depletion of flora and fauna and loss of productivity resulting in slow recovery during natural succession of vegetation on these lands. Study of plant succession helps in proper selection of various species of vegetation and planning of rehabilitation efforts in these degraded lands. A study was taken up in 1962 to assess the effect of protection from biotic interference on plant community development in Yamuna ravines of

Indo-gangetic plains. An area of 625 $m^2$ (25 m x 25 m) each on ravine top, side slope and bottom was protected with barbed wire fence in 1962. For comparison, same sized plots in above said locations were taken up in unprotected sites. One denuded quadrat of 1 m x 1 m size in each protected site (enclosures) was randomly located and permanently fixed. To simulate a disclimax condition and provide an edaphic environment for the primary succession to initiate, soil in the quadrat was dug upto 1 m depth, all the roots, seed nuclei and vegetative materials were removed, and cleaned soil was refilled into the pit. Vegetation within the denuded quadrat was recorded annually to find out the pioneering species and subsequent seral vegetations. Simultaneously all the woody plants in all the plots were completely enumerated to record the chronosequence of occurrence of woody perennials. Prominent natural woody species around the plots were taken into account to help establish realistic chronosequence. In the open and unprotected conditions, the biotic climax comprised of *Caparis deciduas* and *Prosopis cineraria* community. In the protected but denuded quadrates (disclimaxed), the pioneering communities were herbaceous species like *Aristida cyanantha*, *Apluda mutica* on the ravine top, *Apluda mutica*, *Cymbopogon jwarancusa* on side slopes and *Cymbopogon fulvus*, *Cenchrus ciliaris* on the bottom. These communities after eleven years of protection against biotic interference were succeeded by woody tree species of *Prosopis cineraria*, *Dalbergia sissoo* and *Balenites aegyptica* on ravine top, side slope and bottom, respectively. By the ninetinth year, the dynamism of chronosequences in protected plots ended up in physiognomically dominant sets of tree communities *viz. Prosopis cineraria-Azadirachta indica* (xero-mesic) on top, *Acacia catechu-Dalbergia sissoo* (xero-mesic) on side slopes and *Dalbergia sissoo-Salmalia malabaricum* (mesic) on the bottom of the ravines. These seral vegetations continued to exhibit signs of maturity, stability and self reproduction which indicated that the plant communities had reached climax stage. It could be inferred that allogenic chronosequences of vegetation in subtropical Yamuna ravines acquired climax stage within twenty years of protection (Prajapati *et. al.*, 1999; Samra *et. al.*, 1999; Balaji and Nitant, 2002).

**Grasses**

*Alpnda mutica* and *Cenchrus ciliaris* were recorded in all the three location. The density and frequency were the highest for *C. ciliaris* in top and bottom *i.e.* 13.1 and 65.5 $m^{-2}$ and 1.0 and 5.0 $m^{-2}$, respectively during 2002 (after 40 years) (Fig. 6.2 to 6.4).

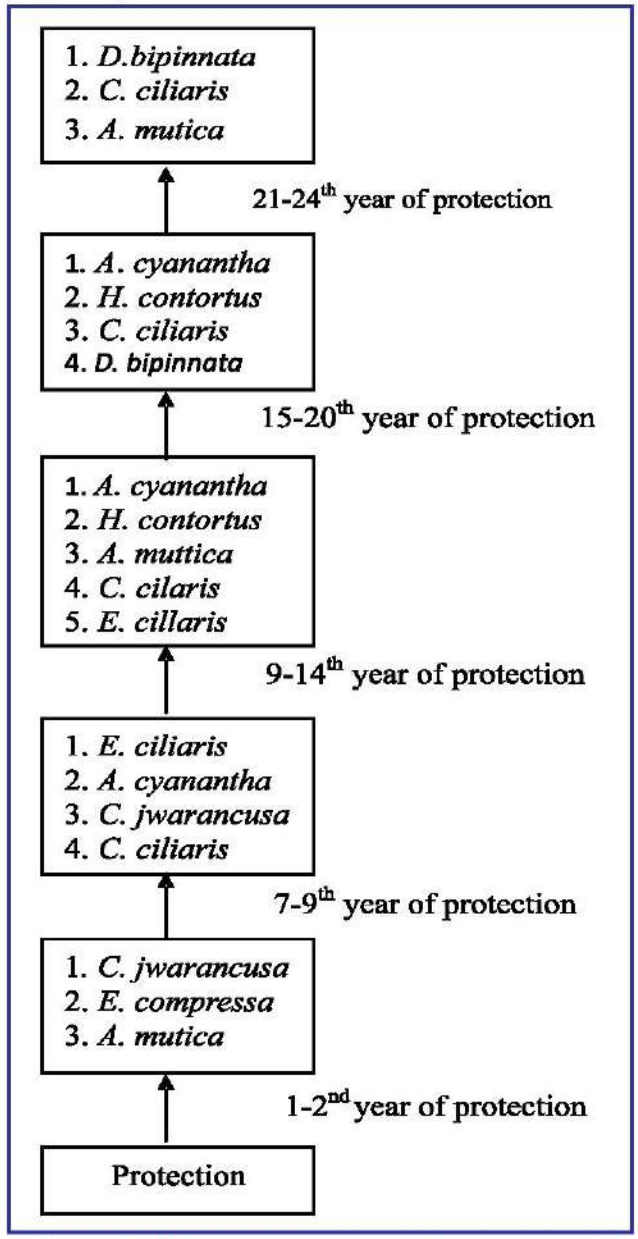



**Fig. 6.2: Chronosequence of grass species occurrence in ravine top after protection (within a box species are arranged in a decreasing order of densities).**

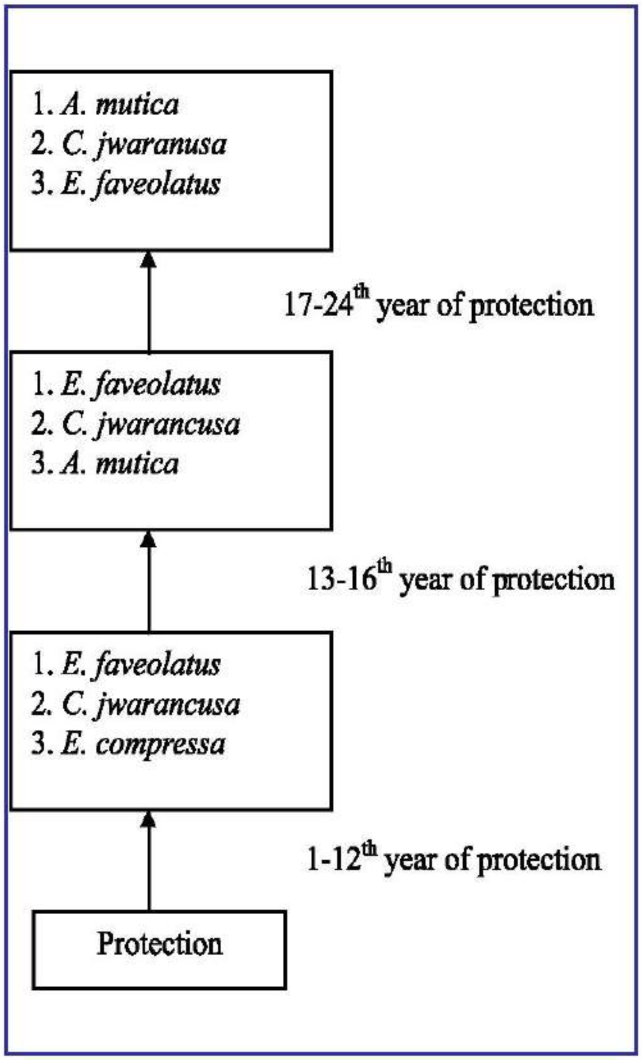



**Fig. 6.3: Chronosequence of grass species occurrences on ravine slopes after protection (Within a box species are arranged in a decreasing order of densities).**

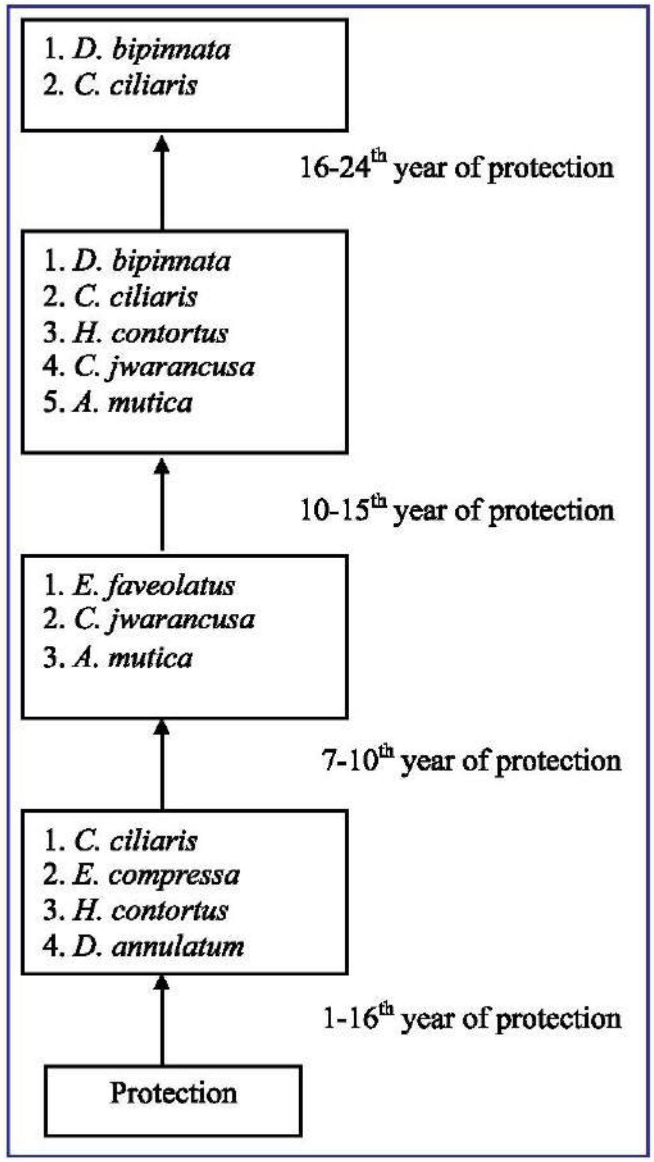



**Fig. 6.4: Chronosequence of grass species occurrences on ravine bottom after protection (Within a box species are arranged in a decreasing order of densities).**

## 6.8 Planting Techniques

Quality of planting material, soil working techniques and planting techniques are important for ensuring optimum survival of planted vegetation in degraded ravine lands as these lands pose severe climatic and edaphic constraints for survival and growth of vegetation. Studies to evaluate nursery and afforestation techniques to suit the specific conditions of soil and climate of ravines were conducted at the centre. As hardening off is an important nursery technique for developing stblack gramy planting material for use in harsh conditions, studies to determine optimum quantity and interval of watering of seedlings in nursery bed were conducted. Eight tree species, 3 watering quantities (1, 2 and 3 litres per plant) and 3 watering intervals (5, 8 and 11th day) were studied. Optimum quantity and frequency of watering for different species are given below in Table 6.16.

**Table 6.16: Quantity (liters plant$^{-1}$) and interval of watering for seedlings in nursery bed that produced maximum growth**

| Species | Quantity (litres) | Interval (days) |
|---|---|---|
| *Pongamia glabra* | 3 | 5 |
| *Albizzia lebbek* | 2 | 5 |
| *Dalbergia sissoo* | 2 | 5 |
| *Dendrocalamus strictus* | 3 | 11 |
| *Salmalia malabarica* | 2 | 5 |
| *Heterophragma adenophyllum* | 2 | 5 |
| *Ailanthus excelsa* | 2 | 8 |
| *Thespera pipulnea* | 3 | 5 |

### 6.8.1 Manuring of nursery beds

To determine optimum doses of manure for nursery of various tree species three doses *viz.* 30, 40, 50 t ha$^{-1}$ of farm yard manure were given to the nursery beds to study the performance of seedlings of *Albizzia lebbek, Dalbergia sissoo, Dendrocalamus strictus* and *Salmalia malabarica*. The recommended doses of manure for these species are as under:

| | |
|---|---|
| *Albizzia lebbek* | 30 t ha$^{-1}$ |
| *Dalbergia sissoo* | 40 t ha$^{-1}$ |
| *Dendrocalamus strictus* | 50 t ha$^{-1}$ |
| *Salmalia malabarica* | 50 t ha$^{-1}$ |

### 6.8.2 Soil working techniques

Soil working technique plays an important role on the establishment, growth and developments of seedlings in afforestation works. Studies were therefore conducted to find out the most suitable soil working technique for afforestion of Yamuna ravines.

Staggered contour trenches of 180 cm length, 61 cm width and of different depths (45.7, 61 and 76.2 cm) were dug at 3 m X 3 m spacing on the humps having slopes upto 6 %.

The dug out soil was refilled into the trenches in different types of refilling such as ridge-ditch ($F_1$), raised mound ($F_2$), sunken mound ($F_3$) and berm or double trench ($F_4$) types of refilling. Seeds of *Acacia nilotica* were sown on the refilled trenches.

Depth of trench did not affect the seedling mortality, height and collar diameter at the initial stage, but it significantly affected these parameters from the fourth year onwards. The trenches of 61.0 cm in depth ($D_2$) proved superior to 45.7 cm ($D_1$) and 76.2 cm ($D_3$) deep trenches (Table 5.94).

The seedling mortality decreased while the growth in height and collar diameter increased with the increase in the water storage capacity of the trench which depends on the type and depth of refilling of trenches Table 6.17).

Refilling in the form of ridge-ditch ($F_1$) and raised-mound ($F_2$) were not effective soil working techniques for the Yamuna ravines as compared to sunken-mound ($F_3$) and double-trench ($F_4$) system. The Double-Trench ($F_4$) system impounded maximum quantity of water, retained it for 3 to 4 days and increased availability of the soil moisture to the seedlings during dry spell which resulted in minimum seedling mortality, and maximum seedling height and collar diameter growth.

At the end of fourth year, the treatment $D_2$ x $F_4$ was found better which was closely followed by '$D_2$ x $F_1$'. The cost for '$F_4$' is not very high as compared to '$F_1$' '$F_2$' and '$F_3$'. Further, this technique is simple to practice and does not require subsequent maintenance.

It is suggested to dig trench of about 180 cm lengths, 60 cm width and 60 cm depth with double trench/berm refilling for successful afforestation programs in the Yamuna ravines (Prajapati *et. al.*, 1968).

Table 6.17: Effect of trench depths and type of refilling on seedling mortality and growth parameters of *Acacia nilotica*

| Depth and refilling | Seedling mortality (%) | Growth in height (cm) | Growth in collar diameter (cm) |
|---|---|---|---|
| **Depth of trench** | | | |
| 45 cm | 36.5 | 429.8 | 7.5 |
| 60 cm | 34.1 | 495.5 | 9.2 |
| 75 cm | 31.6 | 425.2 | 7.7 |
| C.D. | Not Significant | 21.5 | 1.1 |
| **Type of trench refilling** | | | |
| Ridge-ditch | 46.9 | 383.3 | 6.9 |
| Raised mound | 48.9 | 426.1 | 7.6 |
| Sunken mound | 28.4 | 464.9 | 8.2 |
| Berm or double trench | 12.0 | 526.8 | 10.0 |
| C.D. | 9.57 | 24.8 | 1.6 |

## 6.9 Effect of Goat Grazing on Hydrological Behaviour, Vegetation and Soil Characteristics of Ravine Watershed

It is widely believed that grazing by goats lead to increase in soil loss and runoff. Therefore, an experiment was conducted to study the effect of various grazing intensities on runoff and soil loss and to find out the effect of goat grazing on watershed vegetation. A small watershed of 7.3 ha was planted with trees and grasses and the channels (gully beds) were treated with 2-3 gully plugs per ha. The small watershed was equipped with a triangular weir and an automatic water stage level recorder for monitoring soil and water losses. At the time of initiating grazing, the watershed contained 289 trees $ha^{-1}$; 14.8 % on top, 62.0 per cent on sides and 23.2 % at the bottom of the ravines. Direct continuous range grazing with yearlings of Jamunapari goats was allowed at the rate of 2 goats $ha^{-1}$ for two years and thereafter intensity of grazing was increased to 4 goats $ha^{-1}$. Goats short in height (64.0 to 71 cm in height) mostly browsed on ground vegetation while the taller ones (80 cm) preferred to feed on the crown foliage of shrubs and trees. The intensity of grazing @ 2 or 4 goats $ha^{-1}$ had no adverse effect on runoff and soil loss. Despite grazing, the runoff ranged between 2.02 to 8.24 % of the rainfall and the soil loss between 0.07 to 2.66 t $ha^{-1}$. These values were well within (8.50 % runoff and 2.40 t $ha^{-1}$ soil loss) the range of runoff and soil loss values obtained during the calibration or non-grazing period (about 9 years data).

The reason might be that grazing by goats caused no injury to the protective characters of vegetation. Mostly, they browsed the shrubs and tree foliage up to 2 m height above the ground. In this process, all the grasses on ground and the entire tree crown above 2 m height remained unaffected by goat grazing. Therefore, it was inferred that grazing of 4 goats $ha^{-1}$ in a ravine watershed protected by 20 years old forest and 2-3 gully plugs per ha has no adverse effects on protective characters of vegetation as well as on runoff and soil loss characteristics of watershed. In addition to the conservation effect, the goats produced about 1.65 kg $goat^{-1}$ $month^{-1}$ of live body weight and generated an income of Rs. 1600 $ha^{-1}$ $yr^{-1}$ (value based on prevalent prices during 1988-89) (Prajapati *et. al.*, 1989).

# 7.0 SOCIO-ECONOMIC ANALYSIS AND POLICY DEVELOPMENT FOR WATERSHED MANAGEMENT

Integrated watershed development is the strategy adopted for sustainable development of country's dry land area. In most of the developed watersheds with intensive intervention to manage rainwater, the livelihood improved in not only the watershed but the downstream area also benefited with increased ground water recharge.

Alongwith increased surface and groundwater availability, associated activities also significantly increased in the watershed resulting in the increased income as well as improved livelihoods. Increased water availability also had a positive impact in improving socio-economic and environmental impact in addition to increased productivity in watershed.

The results from the watershed case study are discussed here to find some conclusions.

## 7.1 Socio-Economic Implications on Agricultural Productivity in Bilauni Watershed

Bilauni watershed is located 48 km away from Agra on Agra-Fatehabad road near Uttangan river, tributary of Yamuna river and comprising of severely gullied lands under Semi-Arid climate with annual average rainfall of 730 mm. Soil and water conservation work was carried out in the year 1990-91 by the state department of soil and water conservation under EEC project.

The study was conducted by the Centre during 1997-98 to assess the socio-economic implications on agricultural productivity in watershed. The participatory rural appraisal (PRA) was carried out by transact walk and interview with the people in different seasons to assess the problems and the agricultural situation in the watershed.

The upland and shallow gullies in the watershed were being used for agriculture and the medium and deep gullies remained under forest as scrub land. The productivity of land in the watershed area had improved because of soil conservation work.

**Table 7.1: Average yield and net return of crops in treated and untreated area during 1999-2000**

| Crop | Yield (q $ha^{-1}$) | | % increase over untreated | Net return (Rs.) | | Additional return over untreated (Rs.) |
|---|---|---|---|---|---|---|
| | Treated | Untreated | | Treated | Untreated | |
| ***Kharif* crop** | | | | | | |
| Pearl millet | 18.5 | 8.75 | 211 | 3385 | 1488 | 1897 |
| Black gram | 6.0 | 3.0 | 200 | 3260 | 1380 | 1880 |
| Green gram | 6.25 | 3.50 | 179 | 3563 | 1825 | 1738 |
| ***Rabi* crop** | | | | | | |
| Wheat | 34.25 | 12.50 | 274 | 11893 | 4025 | 7868 |
| Barley | 27.50 | 10.75 | 256 | 5850 | 2313 | 3537 |
| Mustard | 20.0 | 7.0 | 286 | 12275 | 4005 | 8270 |

The productivity of crops in treated area were found higher as compare to untreated area mainly due to soil and water conservation measures *i.e.* land leveling, bunding, chekdam, terracing *etc.* and improved agro-techniques, and increased number of tubewells and pump sets in ravine land area. In the ravine fields the economic returns from crops were almost two third of the returns from upland fields. In addition to agriculture crops, the people were also depended on livestock for their livelihood. Results revealed that due to soil and water conservation work and improved irrigation facilities, farmers started growing green fodder for their animals which resulted in higher production of milk. However, there were increased incidences of social conflict, as the land could not provide the required need, demand and employment. The study also revealed that when socio-economic condition of people deteriorates beyond a certain minimum level, there is need of strong security and industrial support so that the people are able to earn their livelihood (Table 7.1).

## 7.2 Impact of Soil and Water Conservation Measures on Productivity and Socio-Economic Condition of Kuber Pur Ravine Watershed

The study was carried out with objectives to assess the impact of soil and water conservation practices on productivity of crops and socio-economic status in Kuberpur watershed. The total area of watershed is 424 ha that comprises of cultivated area 270 ha (64%), afforestation 12 ha, waste land with thorny forest 81.5 ha and deep ravine 57 ha. The major crops pearl millet, wheat, barley and mustard were grown in watershed. The terracing and leveling were the main soil and water conservation followed in agricultural land and 271 ha area was brought under agriculture.

In Kuberpur watershed, soil conservation work had produced remarkable impact on improvement of productivity, forage yield, system adoptability, reduction in erosion level and tolerance of social and environmental change. There is vast scope for improvement on food self-sufficiency, diversity of species, technical innovation, participation and independence from external inputs. The impact of soil and water conservation practices in Kuberpur watershed was evaluated in terms of following factors (Singh *et. al.*, 2003).

### i. Increase in grain yield

The results revealed that productivity of major crops were increased in watershed mainly due to terracing and leveling, improved agronomic practices and timely irrigation (Table 7.2).

**Table 7.2: Average productivity of major crops in Kuberpur watershed on leveling and terracing during 2002-05**

| Crop | Terraced field production (q ha$^{-1}$) | Un-terraced field production (q ha$^{-1}$) | Difference in grain yield (q ha$^{-1}$) | % Increase to terraces |
|---|---|---|---|---|
| Pearl millet | 20.16 | 16.80 | 3.36 | 18.9 |
| Wheat | 32.96 | 21.75 | 11.21 | 51.5 |
| Barley | 29.60 | 20.92 | 8.68 | 41.5 |
| Mustard | 10.54 | 6.15 | 4.39 | 71.4 |

### ii. Forage availability

People had been started cultivation of the green fodder such as sorghum and pearl millet even in the month of May and June with the tubewell irrigation water. Thus, it is evident that soil and water conservation measures in the Kuberpur watershed had increased forage availability.

### iii. B:C Ratio

B: C ratios of major crops were found higher on terraced fields as compared to un-terraced fields in the watershed.

Thus, implemented soil and water conservations were found appropriate and economical in the watershed (Table 7.3).

**Table 7.3: Average crop production, net return and B:C ratio of terraced and un-terraced fields**

| Crop | Yield q ha$^{-1}$ | Cost of cultivation Rs. ha$^{-1}$ | Gross return Rs. ha$^{-1}$ | Net return Rs. ha$^{-1}$ | B:C ratio |
|---|---|---|---|---|---|
| **Terraced fields** | | | | | |
| Pearl millet | 20.16 | 6416 | 11581 | 5165 | 1.8:1 |
| Wheat | 32.96 | 16500 | 24143 | 7463 | 1.5:1 |
| Barley | 29.60 | 9600 | 17908 | 8308 | 1.9:1 |
| Mustard | 10.54 | 8600 | 18972 | 10322 | 2.2:1 |
| **Un-terraced fields** | | | | | |
| Pearl millet | 16.80 | 5750 | 9766 | 4521 | 1.7:1 |
| Wheat | 21.75 | 12325 | 15834 | 3509 | 1.3:1 |
| Barley | 20.92 | 7800 | 12657 | 4857 | 1.6:1 |
| Mustard | 6.15 | 7250 | 12870 | 5620 | 1.8:1 |

**iv. Food self-sufficiency**

Results of analysis of the requirement and production of food for the entire population revealed that sufficiency was only 40% and remaining 60% was earned from other means such as animal husbandry and off-farm income. The animal husbandry had played important role in improvement of socio-economic condition of farmers and it was reported that buffalos were more economical than cows and goats.

**Erosion level**

Erosion level had considerably reduced in the watershed due to terracing and leveling.

**v. Diversity of species**

Survey of the watershed revealed that farmers were adopting diversified agriculture including cereals, pulses, oilseed, cotton, vegetable, floriculture, fodder during *kharif* and *rabi* season and cucumber, vegetables *etc.* during summer season.

**vi. Technical innovation**

After improvement in the land condition in the watershed, farmers had started cultivation of potato in larger areas. Integrated nutrient and pest management had also been adopted in watershed.

## 7.3 Agra Watershed

Agra watershed was implemented to improve the productivity of degraded ravine habitat under the auspices of National Watershed Development Project (NWDP). Agra watershed, a joint effort and achievement of the Uttar Pradesh State Soil Conservation Department (funding and work execution) and Central Soil and Water Conservation Research and Training Institute, Research Centre, Chhalesar, Agra (technical guidance).

Agra watershed, situated at the north bank of river Yamuna (21 km East from Agra district headquarters) at 27.10 N latitude and 78.10 E longitudes, is a typical ravine watershed (total area: 851 ha) in a fan shaped topography. The watershed comprises of five villages (Burhia Ka Tal, Dharera, Surera, Satta and Kharani) and their seven hamlets mainly the Nagla Garapur and Nagla Gangaram. Climate of Agra watershed is semi-arid sub-tropical (annual rainfall: 480 to 1377 mm with coefficient of variation of 29.5) (Table 7.4-7.9).

The impact assessment study of watershed development activities was mainly concentrated on treatment of shallow ravines particularly spread in Garapur hamlet because of inaccessibility to remaining watershed area and paucity of funds. Garapur has a total area 155.4 ha (irrigated: 40.4 ha and rainfed: 15.0 ha), total 141 families having farmers categories of landless: 34, marginal (0-1 ha): 48, small (1-2 ha): 29, medium (2-5 ha): 27 and large (5-10 ha): 03 and human population of 913 (male: 264, female: 219 and children: 430) in 1986.

**Table 7.4: Details of land development in Agra watershed**

| Item | Target (ha) | Area developed (ha) | Cost (Rs. $ha^{-1}$) | Total cost (Rs.) |
|---|---|---|---|---|
| Bench terracing | 327 | 215 | 2253 | 484395 |
| Contour bunding | 252 | 171 | 956 | 163476 |
| Gully plugging | 122 | 104 | 2216 | 230464 |
| Afforestation | 23 | 23 | 665 | 15295 |
| **Total** | | | | **893630** |

**Table 7.5: Different indices of socio-economic changes in ORP village, Garapur in Agra watershed**

| Indices | 1986 | 1992 | 2011 |
|---|---|---|---|
| **Land holding (ha)** | | | |
| Landless | 34 | 22 | 96 |
| 0-1 | 48 | 67 | 150 |
| 1-2 | 29 | 22 | 17 |
| 2-5 | 27 | 29 | 10 |
| 5-10 | 03 | 03 | 03 |
| Total families | 141 | 143 | 276 |
| **Population** | | | |
| Male | 264 | 234 | 365 |
| Female | 219 | 202 | 344 |
| Children | 430 | 411 | 723 |
| Total population | 913 | 847 | 1432 |
| **Agricultural facilities** | | | |
| Tractors | 0 | 01 | 04 |
| Drought cattle | 91 | 59 | 0 |
| Drought buffaloes | 10 | 10 | 0 |
| Bullock drawn implements | 140 | 250 | 0 |
| Bullock cart | 01 | 01 | 08 |
| Tube well | 0 | 0 | 09 |
| Thresher | 0 | 0 | 01 |
| Trolley | 0 | 0 | 04 |
| Tractor cultivator | 0 | 0 | 04 |
| Tractor harrow | 0 | 0 | 04 |
| Seed drill | 0 | 0 | 02 |
| **Cattle/live stock** | | | |
| Cow | 54 | 63 | 61 |
| Buffaloes | 182 | 148 | 309 |
| Male buffaloes | 10 | 10 | 0 |
| Bullocks | 74 | 59 | 03 |
| Goat | 200 | 254 | 228 |
| Male goat | 0 | 0 | 03 |
| Sheep | 65 | 74 | 21 |
| Camel | 3 | 4 | 0 |
| Total | 598 | 612 | 625 |
| **Milk production** | | | |
| Milk animals | 236 | 211 | 326 |
| Average milk production (litre $animal^{-1}$ $year^{-1}$) | 1003.5 | 1232.7 | 1651 |
| Total milk production (litre $year^{-1}$) | 236826 | 236009 | 604266 |

**Table 7.6: Changes in farming features due to bench terracing in Garapur hamlet of Agra watershed**

| Particular | Before bench terracing | After bench terracing | | | | |
|---|---|---|---|---|---|---|
| | 1986 | 1991 | 1992 | 1993 | 1994 | Average |
| Total area (ha) | 7.04 | 7.04 | 7.04 | 7.04 | 7.04 | 7.04 |
| Area under bund (ha) | 0.18 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 |
| Net cultivated area (ha) | 6.86 | 6.33 | 6.33 | 6.33 | 6.33 | 6.33 |
| Cropped area, rainy season (ha) | 3.14 | 1.95 | 2.47 | 3.05 | 3.05 | 2.63 |
| Cropped area, winter season (ha) | 3.70 | 6.33 | 6.21 | 6.50 | 6.50 | 6.39 |
| Area under fallow (ha) in rainy season | 3.60 | 4.38 | 3.86 | 2.63 | 3.28 | 3.54 |
| Area under fallow (ha) in winter season | 3.34 | 0 | 0.12 | 0 | 0 | 0.03 |
| Cropping intensity | 104 | 131 | 137 | 161 | 151 | 1.45 |
| Irrigated area (ha) | 1.53 | 6.33 | 6.33 | 6.33 | 6.33 | 6.33 |
| Nitrogen use (kg) during rainy season | 10 | 135 | 49 | 51 | 74 | 77.25 |
| Nitrogen use (kg) during winter season | 79 | 434 | 355 | 554 | 623 | 491.50 |
| Annual phosphorus use (kg) | 39 | 285 | 169 | 320 | 303 | 269.25 |
| Annual use of farm yard manure (tons) | 12 | 52 | 10 | 12 | 6 | 566.67 |

**Table 7.7: Effect of gully plugs on cropped and fallow area (ha), cropping intensity (%), irrigated area (ha), fertilizer consumption (kg ha$^{-1}$), FYM use (t ha$^{-1}$) and other farming indicators during winter season in Garapur hamlet**

| Farming indicators | Winter season | | Rainy season | |
|---|---|---|---|---|
| | 1986 | Mean (1987-94) | 1986 | Mean (1987-1991) |
| Total area (ha) | 6.0 | 6.0 | 6.0 | 6.0 |
| Area under gully plugs (ha) | - | 0.5 | - | 0.5 |
| Net cultivated area | 6.0 | 5.5 | 6.0 | 5.5 |
| Cropped area | 4.18 | 4.74 (13.40) | 4.10 | 2.36 |
| Area under fallow | 1.82 | 0.76 (-58.24) | 1.90 | 3.14 |
| Cropping intensity | 138 | 117 (-15.22) | 138 | 133 |
| Irrigated area | 2.02 | 4.43 (119.31) | 0 | 0.5 |
| Nitrogen fertilizer consumption | 242 | 349 (44.21) | 9 | 113 |
| Phosphoric fertilizer consumption | 101 | 187 (85.15) | - | - |
| Potassium fertilizer consumption | 09 | 14 (55.56) | - | - |
| FYM use | 16 | 6 (-62.5) | 0 | 9 |

Figures in the parenthesis indicate percent increase or decrease in mean value over 1986

Results reveal that the mean cultivated area and cropping intensity were found less than 1986 after gully plug construction due to invariable water impounding in up and downstream sides of the structure during rainy season.

**Table 7.8: Change in productivity of major crops (kg ha$^{-1}$) during rainy and winter seasons after development of bench terraces and gully plugs in Agra watershed (Average of 1991 to 1997)**

| Crop | Bench terracing | | Gully plugging | |
|---|---|---|---|---|
| | Before | After | Before | After |
| Pearl millet | 926 | 1463 (57.99) | 927 | 60 (-1545.0) |
| Wheat | 1950 | 3616 (85.44) | 2064 | 2618 (26.84) |
| Barley | 2290 | 3461 (51.14) | 2000 | 2478 (23.90) |
| Mustard | 710 | 1508 (112.39) | 800 | 575 (-139.13) |

Figures in the parenthesis indicate % increase in crop yield

Bench terracing enhanced the productivity of crops mainly due to higher *in-situ* rainwater conservation in soil that enabled rainy season crops to tolerate short and medium spell droughts in Semi-arid tropics. While productivity of pearl millets decreased under gully plugging because of water logging in agricultural fields near gully plugs and productivity of mustard also retarded due to prolonged stay of rainwater on surface and excessive wetting of soil that delayed the sowing of mustard and declined the productivity.

**Table 7.9: Growth of tree species on deep ravines under different soil and water conservation interventions in Agra watershed**

| Soil and water conservation intervention | Gully site | Desi babool (*Acacia niloticaL*) | | Vilayti babool (*Prosopis juliflora*) | |
|---|---|---|---|---|---|
| | | Height (m) | Basal diameter (cm) | Height (m) | Basal diameter (cm) |
| Staggered contour trences | Top | 1.32 | 1.89 | 0.53 | 1.03 |
| | Bottom | 1.32 | 2.09 | - | - |
| Marginal trenches | Top | 0.36 | 0.87 | 1.09 | 1.28 |
| | Bottom | 0.94 | 1.20 | 2.50 | 3.70 |
| Gully plugs | - | 3.25 | 4.86 | 4.70 | 7.86 |

### 7.3.1 Economics of bench terracing and gully plugging

The B: C ratio was 1.93:1 in 1983 at the price level of 1983. The B:C ratio was calculated for the individual year during 1991-94 *i.e* for four year after completion of resource conservation work (Table 7.10-7.15).

**Table 7.10: Benefit and cost for different resource conservation work in Agra watershed**

| Year | Bench terrace | Contour bund | Gully plug | Total | Net return | B:C ratio |
|---|---|---|---|---|---|---|
| 1991 | 2449066 | 1629722 | 873912 | 4952700 | 1913777 | 2.2 |
| 1992 | 1578326 | 1255319 | 732766 | 3566411 | 2846265 | 3.2 |
| 1993 | 2235206 | 1777768 | 977340 | 4990314 | 5192656 | 5.9 |
| 1994 | 2744518 | 2182849 | 855746 | 5783113 | 8336846 | 9.5 |
| Total | 8607116 | 6845658 | 3439764 | 19292538 | 18289544 | 5.2 |

All calculations are based on price level of 1991-92

**Table 7.11: Gross additional return (Rs. $ha^{-1}$) under bench terracing and gully plugging in Agra watershed**

| Year | Bench terracing | Gully plugging |
|---|---|---|
| 1991 | 4645 | 1162 |
| 1992 | 2456 | (-)196 |
| 1993 | 5511 | 2156 |
| 1994 | 7880 | 987 |
| 1995 | 7112 | 2928 |
| 1996 | 8028 | 2927 |
| 1997 | 6142 | 3218 |
| Mean | 5968 | 1883 |
| Pre-project productivity Price level: 1991-92 | 4886 | 7242 |

Results revealed that in case of gully plugs the mean additional return (Rs. 1883 $ha^{-1}$) was lower than the unit cost of gully plugs (Rs. 2263 $ha^{-1}$). Thus, considering the economic viability the gully plugs can not be recommended as a reclamation measure in shallow gullies of Yamuna ravines. However, results further revealed that additional gross return registered from area under hydrological influence of gully plugs was higher than the unit cost during 1995-97. This advises for suitable financial assistance from government sources, if gully plug is to be recommended as a reclamation measure on shallow gullies in backdrop of fact that this structure also links with recharge of underground water and favourably influencing other ecological benefits.

To achieve the overall objective of the ORP project in Agra watershed, farmers were also motivated to harness the full benefit of land resource development and a series of field demonstrations on improved agro-techniques of different crops were carried out on bench terraced fields in three villages of watershed during 1988-91.

**Table 7.12: Details of institutional aid and crop demonstrations in Agra watershed (1988-1991)**

| Crop | Variety | Input (N:P, kg $ha^{-1}$) | | Number of demonstrations conducted | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Demonstration | Non demonstration | 1988 | 1989 | 1990 | 1991 | Total |
| Pearl millet | WCC 75, PSCL | 80:40 | 40:20 | 0 | 14 | 8 | 8 | 30 |
| Green gram | PS 16, T 44 | 18:46 | 0 | 0 | 6 | 7 | 0 | 13 |
| Cluster bean | - | 18:46 | 0 | 0 | 4 | 06 | 0 | 4 |
| Sorghum | MFSH 3 | 90:60 | 0 | 27 | 15 | 8 | 0 | 50 |
| Wheat | Lok 1, HD 2009, HD 2285, Sonalika, HD 2329, Kalyansona | 100:50 | 60:20 | 10 | 13 | 35 | 33 | 91 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mustard | T 59, Pusabold | 80:50 | 40:25 | 24 | 35 | 22 | 10 | 91 |
| Lentil | L 59, L 639 | 25:60 | 30:10 | 2 | 0 | 0 | 0 | 2 |
| Lentil + mustard | L-9-12 + Rohini | 25:60 | 30:10 | 1 | 0 | 6 | 0 | 7 |
| Gram | C 235 | 25:60 | 0 | 0 | 0 | 3 | 0 | 3 |
| Pea | Azad pea-1 | - | - | - | - | - | - | - |
| Total | | | | 64 | 87 | 95 | 51 | 297 |

**Table 7.13: Grain yield (kg $ha^{-1}$) and financial returns (Rs. $ha^{-1}$) from different rainy season crops on demonstrations in Agra watershed (1989-91)**

| Crop | Year | Grain yield | Gross return | Net return |
|---|---|---|---|---|
| Pearl millet | 1989 | 1718 (858) | 4829 (2329) | 2569 (749) |
| | 1990 | 1539 (879) | 4058 (2318) | 1858 (718) |
| | 1990 | 1500 (750) | 4400 (2100) | 2200 (500) |
| Average | - | 1586 (829) | 4429 (2249) | 2209 (656) |
| Green gram | 1989 | 808 (300) | 5454 (2025) | 3564 (955) |
| | 1990 | 847 (300) | 5929 (2100) | 4129 (1000) |
| Average | - | 828 (300) | 5692 (2063) | 3847 (978) |
| Cluster bean | 1989 | 850 (360) | 3560 (1520) | 1590 (320) |
| Sorghum (green fodder) | 1989 | 46000 (25000) | 6900 (3750) | 4350 (2220) |

Figures in parenthesis represent the non-demonstration field (local practices). Demonstration package consisted of improved agro-techniques viz use of seed of high yielding crop varieties, recommended doses of fertilizers and pesticide etc.

**Table 7.14: Grain yield (kg $ha^{-1}$), gross & net return (Rs. $ha^{-1}$) and additional yield (kg $ha^{-1}$) under demonstration and non-demonstration fields in Agra watershed**

| Year | Grain yield | Gross return under improved agro-technique | Net return over local practice | Additional grain yield |
|---|---|---|---|---|
| **Wheat** | | | | |
| 1988 | 3323 (2099) | 8528 (5346) | 3698 | 1224 |
| 1989 | 3500 (2178) | 10125 (6333) | 5295 (2552) | 1322 |
| 1990 | 3723 (2049) | 10770 (5958) | 5770 (1958) | 1674 |
| 1991 | 3645 (2520) | 14740 (10190) | 9740 (5990) | 1125 |

| | | | | |
|---|---|---|---|---|
| Mean | 3548 | 11041 | 6126 | 1336 |
| | | Mustard | | |
| 1988 | 1722<br>(963) | 10332<br>(5778) | 7757<br>(3653) | 759 |
| 1989 | 1565<br>(750) | 10173<br>(4875) | 7598<br>(2750) | 815 |
| 1990 | 1840<br>(1209) | 11960<br>(7858) | 9360<br>(5658) | 613 |
| 1991 | 1400<br>(900) | 11200<br>(7200) | 8600<br>(4900) | 500 |
| Mean | 1632<br>(956) | 10916<br>(6428) | 8329<br>(4240) | 676 |
| | | Lentil + mustard | | |
| 1988 | 1355<br>(494) | 11217<br>(2475) | 8017<br>(750) | 861 |
| | | Lentil | | |
| 1988 | 1100<br>(625) | 7470<br>(4222) | 4250<br>(1737) | 475 |

Figures in the parenthesis indicate yield from non-demonstration fields

**Table 7.15: Total area (ha), average grain yield (q ha$^{-1}$) and total production (q) of different crops in Garapur hamlet of Agra watershed**

| Crop | Area | | | Average grain yield | | | Total production | | | Additional production | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1986 | 1991 | 2011 | 1986 | 1991 | 2011 | 1986 | 1991 | 2011 | 1991 | 2011 |
| Pearl millet | 47.4 | 46.5 | 83.6<br>(76.4) | 9.8 | 12.5 | 19.9<br>(103.1) | 464.5 | 581.3 | 1661.9 | 116.7 | 1197 |
| Sorghum | 16.6 | 17.0 | 1.1<br>(-93.4) | 24.3 | 25.5 | 29.1<br>(19.8) | 403.4 | 433.5 | 32.0 | 30.1 | -371 |
| Cluster bean | 2.0 | 3.5 | - | 5.0 | 5.5 | - | 10.0 | 19.3 | - | 9.3 | -10.0 |
| Green gram | 1.0 | 0 | - | 0.2 | 0 | - | 0.2 | 0 | - | -0.2 | -0.2 |
| *Dhaincha* | 2.0 | 2.0 | - | 4.0 | 4.0 | - | 8.0 | 8.0 | - | 0 | -8.0 |
| Wheat | 63.3 | 66.0 | 93.2<br>(47.2) | 23.2 | 30.0 | 31.0<br>(33.6) | 1168.6 | 1980 | 2892.1 | 811.4 | 1724 |
| Barley | 28.0 | 23.0 | 15.5<br>(-44.6) | 19.8 | 28.0 | 30.7<br>(55.1) | 554.4 | 644 | 475.5 | 89.6 | -78.9 |
| Mustard | 51.8 | 60.0 | 13.8<br>(-73.4) | 11.5 | 6.0 | 18.2<br>(58.3) | 595.7 | 360 | 250.5 | 235.7 | -345 |
| Gram + mustard | 2.5 | 1.5 | - | 5.0 | 25.0 | - | 12.5 | 37.5 | - | 25.0 | -12.5 |
| Potato | - | - | 11.8 | - | - | 240 | - | - | 2833 | - | 2833 |
| Paddy | - | - | 2.0 | - | - | 23.5 | - | - | 47.0 | | |
| Berseem | - | - | 0.64 | - | - | 1602 | - | - | 1025 | | |
| **Total** | **214.0** | **219.5** | **221.0** | **11.42** | **17.06** | **25.40** | **3717.3** | **4063.6** | **9217.0** | **1317.8** | **4941.1** |

**Note:** Figures in the parenthesis indicate the per cent mean increase or decrease over 1986

The area, productivity and total production of different crops clearly enhanced in 1991 and 2011 over 1986 which corresponded to 2.57, 3.27; 49.39, 122.42 and 9.32, 147.95%, respectively. The results further indicate that the net impact of different soil and water conservation interventions and agro-techniques on agriculture corresponded to an additional production of 1317.8 and 4941.1 q on about 155 ha net cultivated area in the Garapur hamlet during 1991 and 2011, respectively. Thus, soil and water conservation as well as agronomical interventions highly improved the livelihood/food security and income of farmers apart from setting in a favourable change in food habits from coarse food grain (pearl millet and sorghum) to fine grain (wheat and barley) and substantially increased per capita availability of milk. The decrease in the sorghum fodder production during 2011 than 1986 were well compensated and even largely enhanced due to a quantum increase in the production of wheat and pearl millet and consequently the higher availability of straw/stover as dry fodder. The change in area under different crops during 1991 and 2011 in comparison to 1986 was to a large extent governed by the relative productivity/ profitability of crops as well as domestic needs and was delicately driven by the changing irrigation facilities, mechanization *etc.* As such, soil and water conservation and improved agro-technique interventions benefitted the farmers of Agra watershed in a gradual but stable manner and enabled them to harvest bumper crop yields by 2011.

**7.3.2 Critical appraisal**

The executing agency (State Soil Conservation Department, Uttar Pradesh) had their own norms for selection and implementation of soil and water conservation interventions & they were far different from the ideally/really required treatment plan so far as development of an area on watershed basis that holistically considers the land/site/ natural resources/ socio-economic conditions is concerned but it was rather governed by a preconceived selected/imposed criteria. Thus, land treatment was not carried strictly in accordance with the technical plan given by the scientists of Research Centre, Agra following different surveys, interactions with people etc. Out of several soil and water conservation interventions, bench terracing proved the most economical and nucleus practice. Nevertheless, there occurred some yield reduction in the cut portion as against the yield from the fill part. The key conclusion was that soil moisture is a more profound factor than available nutrients in soil governing the productivity of different crops. The gully plugs induced water logging during continuous/heavy rains causing crop failures/productivity losses but it had a counter productive effect on winter season crops. Since money spent on land treatment with gully plugs was nearly same as development of bench terraces, the later practice was more beneficial but in ecological terms the former practice was useful in ground water recharge and restoration of perennial vegetation by promoting the growth of trees through more *in-situ* conservation of rain water in soil profile, however over grazing and cutting trees for fire wood were major hblack gramles in restoration of desired vegetation level and to provide adequate ground cover on degraded gullied lands of Yamuna ravines. Since, the ground water source is limited/brackish, cultivation of low water demanding crops, treatment of sodium rich water with gypsum and use of irrigation water saving drip and sprinkler systems are suggested. Results further confirm that cost of entire land development using bench terraces, gully plugs, contour bunds *etc*, can be recovered within a time span of about 2-3 years In Agra watershed, cultivation on degraded lands was practiced and there was no way to restrain the farmers from cultivating these lands. It is clearly evident from the results that there was no improvement/ rehabilitation of ravine due to afforestation works mainly owing to overgrazing and cutting trees for fire wood. Therefore, more concentration on treatment of agriculture land can be a right approach in these areas. Nevertheless, interventions of soil and water conservation and improved agro-techniques ensured food/livelihood security by maintaining a sustained higher agricultural productivity and to a little extent by promotion of agro-forestry in the watershed. The program clearly enhanced the eagerness of farmers to participate in Government led ravine reclamation programs. The work on ORP has generated enough experience on the suitability of different mechanical measures in Yamuna ravines. In case of gully plugs, there can be water impounding for longer periods but there is also a high and parallel seepage loss useful in maintenance of higher soil moisture storage in profile/ground water recharge and these dispositions can favour the stabilization of gully channel/side slopes in Yamuna ravines through natural regeneration of vegetation.

### 7.4 Jalapur Watershed

The Jalalpur watershed is located in Jagner block of Agra district in Uttar Pradesh and implemented under NWDPRA during 2009 to 2012. The total area of watershed is 697.5 ha with undulating to slopping (upto 10%) topography. The geographical location is 26°49' to 26°51' N and 77°32'30" to 77°35'30" E (Code No. 2C5A5g1b & 2C5A512e) with an elevation ranging from 184 to 217 m amsl.

The watershed has arid to semi-arid climate with average annual rainfall <500 mm in about 35 rainy days. Temperature ranges 1°C during December-January to 48°C during May-June. The trend of rainfall is highly erratic and maximum water goes as runoff. The ground water supply is very poor as most of the runoff flows down the slopes in very short duration thereby limiting ground water recharge.

Majority of the farmers are in the category of marginal (<1 ha) and small (1-2 ha) with average land holding of about 2.4 ha. The watershed has diversified land uses *viz.*, agriculture (394.65 ha), waste land/open scrub (180.95 ha), seasonal water bodies (104.50 ha) and village roads *etc.* (17.4 ha). Watershed management plan was prepared with specific objectives to ensure food sufficiency, income, employment and environment security holistically considering production components like topographic, land suitability, irrigation potentially, prevailing farming systems, farmers preferences and priorities. Crop and tree selection and area distribution was done as per farmers priorities revealed through PRA exercise. The proposed land use plan of the watershed is presented in Table 7.16.

**Table 7.16: Existing and proposed land use of the Jalalpur watershed**

| Land use | Present ( ha) | Proposed area (ha) |
|---|---|---|
| Agriculture | | |
| Rainfed | 380.77 | 346.77 |
| I Crops | 380.77 | 338.52 |
| II Agro-forestry | Nil | 8.25 |
| Irrigated | 118.38 | 152.38 |
| I Assured | 39.46 | 73.46 |
| II Partial | 78.92 | 78.92 |
| Waste land | 180.95 | 180.95 |
| Aforestation | Nil | 24 |
| Pasture | Nil | 116.35 |
| Untreatable | 40.6 | 40.6 |
| Village land | 17.4 | 17.4 |
| **Total** | **697.5** | **697.5** |

#### 7.4.1 Activities/achievements in watershed

- As entry Point Activities, three bathrooms and water tank of 2000 liter for drinking purpose were constructed as per community demand.
- Three gauging stations to monitor runoff and soil loss from wasteland, agricultural land and mix land uses (wasteland + agriculture) were constructed at outlet of the Jalalpur watershed.
- Village pond was desilted (approx. 2000 $m^3$) to enhance capacity of pond and increase ground water recharge.
- Four animal health camps were organized during watershed development period. More than 1023 animals were vaccinatedand treated, resulting in improvement in general health of animals and milk production by 39%.
- Kisan goshthis and trainings were organized in Jalalpur watershed at the beginning of both *kharif* and *rabi* seasons in order to provide detailed information on package of practices of different crops, agronomical demonstrations and on farm trials and all other interventions to be taken up in the watershed.

- Sivi-pastoral systems were developed on an area of about 3.08 ha by planting about 1119 seedlings of *Prosopis julifera* (168 on 0.17 ha), *Acacia nilotica* (168 on 0.41 ha), *Acacia arabica* (162 on 0.42 ha), *Azadirachta indica* (379 on 1.11 ha), papdi (142 on 0.61 ha) and karang (100 on 0.36 ha) with grasses like napier, para, guinea and anjan.
- Dryland horticulture was developed by plantation of 2238 fruit trees on an area of 14.32 ha that comprised of aonla, bael and ber seedlings of 788, 615 and 835 in number on an area of 5.04, 3.94 and 5.34 ha, respectively.
- Old bunds having existing cross sectional area 0.38 with dimensions top width: 0.45 m, bottom width: 1.45 m and height: 0.5 m were renovated with cross sectional area of 0.9 $m^2$ with top width: 0.45 m, bottom width: 1.95 m and height: 0.75 m in 20 h area that constituted 3500 m running length.
- Staggered trenches (dimension; 30 cm: bottom width; 120 cm: top width and 45 cm: depth) were dug out in 7.0 ha area (2000 rm) to harvest runoff and increase moisture availability to plants as well as to allow water infiltration in to soil.
- Five recharge filters were constructed in submergence areas of watershed to promote artificial ground water recharge. Irrigated area was increased by 27 % due to recharge filters.
- Gully plug structures (masonry retaining wall type) were constructed to harvest rainwater as well as to retain soil behind the structures.

### 7.4.2 Demonstrations in Jalalpur watershed

The following on farm trials were conducted in backdrop of PRA carried out to improve the pulse productivity (Table 7.17 to 7.20).

## (a) Development of nutrient schedule in lentil (*Lens esculenta* L.)

**Table 7.17: Effect of different nutrient management options on grain, straw and biological yield (kg $ha^{-1}$) and harvest index of lentil in semi-arid Aravalli soils**

| Treatment | Grain yield | Straw yield | Biological yield | Harvest index |
|---|---|---|---|---|
| $T_1$: Farmer's practice | 887.17 | 1064.33 | 1951.50 | 45.46 |
| $T_2$: No fertilizer | 896.83 | 1053.33 | 1950.16 | 45.99 |
| $T_3$: Phosphorus Solubilising Bacteria (PSB) | 981.00 | 1135.08 | 2116.08 | 46.36 |
| $T_4$: *Rhizobium* | 1073.58 | 1227.00 | 2300.58 | 46.67 |
| $T_5$: PSB + *Rhizobium* | 1115.58 | 1268.33 | 2383.92 | 46.80 |
| $T_6$: Recommended dose of fertilizers (RDF) | 1185.58 | 1323.00 | 2508.58 | 47.26 |
| $T_7$: PSB + *Rhizobium* + RDF | 1302.83 | 1450.83 | 2753.67 | 47.31 |

**Table 7.18: Mean performance of four gram varieties under different nutrient management options in respect of grain, straw and biological yield ( kg $ha^{-1}$) and harvest index of gram in semi-arid Aravalli hills**

| Treatment | Grain yield | Straw yield | Biological yield | Harvest index |
|---|---|---|---|---|
| $T_1$: Farmer's practice | 561.22 | 691.33 | 1252.56 | 44.83 |
| $T_2$: No fertilizer | 579.78 | 711.11 | 1290.84 | 44.94 |
| $T_3$: Phosphorus Solubilising Bacteria (PSB) | 640.33 | 779.44 | 1419.78 | 45.18 |
| $T_4$: *Rhizobium* | 706.11 | 845.33 | 1551.44 | 45.60 |
| $T_5$: PSB + *Rhizobium* | 826.22 | 975.00 | 1801.22 | 45.92 |
| $T_6$: Recommended dose of fertilizers (RDF) | 876.00 | 1026.89 | 1902.89 | 46.09 |
| $T_7$: PSB + *Rhizobium* + RDF | 960.78 | 1116.67 | 2077.44 | 46.29 |

### (b) Nutrient management in green gram (*Vigna radiata*), black gram (*Vigna mungo*) and arhar (*Cajanus cajan* L.)

**Table 7.19: Grain yield (kg $ha^{-1}$) of green gram, black gram and arhar under different nutrient management options in semi-arid soils of Aravalli hills**

| Treatment | Green gram | Black gram | Arhar |
|---|---|---|---|
| No fertilizer | 466.7 | 387.5 | 1096.7 |
| Farmers practice | 443.3 | 361.9 | 1018.0 |
| PSB only | 483.3 | 395.6 | 1223.3 |
| *RDF | 512.2 | 416.3 | 1257.8 |
| *Rhizobium* only | 533.3 | 441.2 | 1268.9 |
| *Rhizobium* + PSB | 564.4 | 466.9 | 1312.2 |
| *Rhizobium* + PSB + RDF | 607.8 | 498.6 | 1372.2 |

*RDF is recommended fertilizer dose

### (c) Nutrient management in jowar (*Sorghum biclor* L.) and pearl millet (*Pennesetum typhoides* L.)

**Table 7.20: Grain and straw yield of pearl millet and jowar (kg $ha^{-1}$) under different nutrient management options on semi-arid soils of Aravalli hills**

| Treatment | Pearl millet | Jowar |
|---|---|---|
| Farmer's practice | 1388 | 838.9 |
| HYV seed | 1390 | 823.9 |
| 75% RDF* | 1497 | 880.0 |
| 100% RDF | 1552 | 918.9 |
| 75% RDF + PSB | 1644 | 856.1 |
| 100% RDF + PSB | 1714 | 949.6 |
| 75% RDF + weed mulch | 1723 | 1040.0 |
| 100% RDF + weed mulch | 1861 | 1086.1 |
| 75% RDF + PSB + weed mulch | 1816 | 1129.6 |
| 100% RDF + PSB + weed mulch | 2086 | 1171.1 |

### 7.4.3 Impact assessment of Jalalpur watershed

The survey was conducted for studying the impact of watershed development programme on land use, cropping pattern and crop productivity, horticulture plants and livestock; ground water and water table. For collection of primary data, 120 households were selected from watershed area. The data of pre and post-development of watershed pertaining to various aspects were collected on developed structured schedule by interviewing the respondents personally and collected data were analyzed and compared.

Out of total cultivated area 647 ha during base year 2009-10, the irrigated area was 381 ha and rainfed area was 266 ha. While in 2013-2104 year, the irrigated area was increased by 35.17 percent (515 ha) and rainfed area has decreased by 50.37 percent (132 ha).

It was observed that average water table rose from 3.1 m to 6.3 m after watershed implemented. Similarly, the duration of water availability in wells went up from 3-7 months to 8-12 months.

**Table 7.21: Impacts of implemented SWC measures in watershed**

| Impact | Pre-development (2009-10) | Post-development (2013-14) |
|---|---|---|
| Irrigated area (ha) | 381 | 515 |
| Rainfed area (ha) | 266 | 132 |
| Horticulture plants (No.) | 28 | 359 |
| Livestock (No.) | 782 | 1172 |

The livestock survey in the area indicated increasing trend in livestock over pre-development period (2013-14). The increased number of buffalo, cow, goat and sheep (58.96, 36.30, 43.89 and 28 %, respectively) over pre-development watershed period could be due to increase in availability of feed and fodder. After the availability of fodder, farmers were encouraged to have more number of livestock to achieve higher level of income (Table 7.21).

In watershed area, main *rabi* crops grown by the farmers are wheat, mustard, lentil, barley and gram whereas in *kharif* season pearl millet is main crop and scanty area is under sesame, redgram, greengram and black gram. In post-development period farmers also started to cultivate the sugarcane crop as well as vegetable crops. The area under major crops and their productivity in *Rabi* and *Kharif* seasons in pre-development and post-development period of watershed is presented in table 7.22.

**Table 7.22: Impacts of SWC measures on area under major crops and their productivity in watershed**

| Crop | Pre-development (2009-10) | | Post-development (2013-14) | | % Change | |
|---|---|---|---|---|---|---|
| | Area (ha) | Productivity (q $ha^{-1}$) | Area (ha) | Productivity (q $ha^{-1}$) | Area (ha) | Productivity |
| Wheat | 176.78 | 33.00 | 199.24 | 37.06 | 12.70 | 12.31 |
| Mustard | 267.38 | 12.75 | 315.97 | 14.88 | 18.17 | 16.66 |
| Lentil | 112.70 | 7.50 | 96.60 | 8.80 | 14.28 | 14.88 |
| Pearl millet | 223.75 | 17.15 | 176.36 | 18.45 | 21.17 | 7.55 |

The increased area under wheat and mustard crop was attributed to the availability of irrigation water as well as increased in water table depth. The better management practices, land improvement and intervention of high yielding variety as well as availability of irrigation facilities increased the productivity of all crops. The Increase in crop productivity and livestock population resulted in better economic condition of farmers, which led to improvement in living standard of watershed community.

# 8.0 HUMAN RESOURCE DEVELOPMENT AND TECHNOLOGY TRANSFER

The knowledge and skills are essential component required for the execution and implementation of resource conservation based measures in the country. The different level of stakeholders are involved in the process of recourse conservation and transfer of technologies *i.e.* starting from field functionaries to executive level who involved in the top of the programme. At each level the kind of human resource development is required are different and also based on the training/human resource need assessment. The huge amount of public exchequer is involved in the project and to have deliverable outcomes necessary knowledge and skill enhancement is must to the stakeholders for the effective and efficient way of handling the project at field level.

## 8.1 Human Resource Development

The institute and its research centres are organizing training and skill development programmes regularly of varying duration for different stakeholders *viz.* policy makers, state departmental officers, NGOs, field functionaries and farmers for soil and water conservation and watershed management. Table 8.1 revealed the details of human development programmes at the Centre.

**Table 8.1: Year-wise training programme conducted at the research centre**

| Year | Training | | | | No. of stakeholders in exposure visit |
|---|---|---|---|---|---|
| | Farmers | Students | Officers | Total | |
| 2006-07 | - | 20 | - | 20 | - |
| 2007-08 | 30 | 6 | - | 36 | 60 |
| 2008-09 | 67 | 3 | - | 70 | 576 |
| 2009-10 | 461 | - | 6 | 467 | 461 |
| 2010-11 | - | 5 | 107 | 112 | 523 |
| 2011-12 | 150 | - | 60 | 210 | 278 |
| 2012-13 | - | 30 | - | 30 | 144 |
| 2013-14 | 50 | 11 | - | 61 | 215 |
| 2014-15 | 200 | 20 | - | 220 | 482 |
| 2015-16 | 275 | 7 | - | 282 | 453 |
| 2016-17 | 483 | 47 | - | 530 | 345 |
| 2017-18 | 529 | 43 | - | 572 | 229 |
| 2018-19 | 150 | 8 | - | 158 | 279 |
| **Total** | **2395** | **200** | **173** | **2768** | **4045** |

## 8.2 Participatory Transfer of Technology

Participatory technology development and transfer has been advocated as a way of increasing the likelihood of the farmers in the region. The transfer of technology from research into farming practice is a constant requirement for the agriculture to develop new way of working and thinking. It is crucial to realizing the value of innovative research. The ultimate goal of research is to have it put to meaningful use in real world. The four different technologies transferred successfully in the fields by this center have been shown in the photographs given below (Photo 8.1 through 8.4).




Photo 8.1: Bamboo plantation in ravine land



**Photo 8.2: *In-situ* moisture conservation and biomass incorporation through green manuring (Dhaincha) for yield enhancement in mustard/wheat**


**Photo 8.3: Deep ploughing once in three years and use of pearl millet – wheat cropping sequence**


**Photo 8.4: Follow up of green gram – mustard crop in place of fallow-mustard sequence**

# 9.0 TECHNOLOGIES DEVELOPED AND REFINED BY OTHER RESEARCH AND DEVELOPMENT ORGANIZATION

## 9.1 Appraisal of Erosion Problems

Huda *et. al.* (1989) analyzed the agro-climatic data to develop moisture index to assess water accessibility to crops. Annual rainfall (P) and estimated potential evapotranspiration (PE) were used to calculate the moisture index [(P/PE)-1] x 100. Areas with a moisture index value between 0 and 20 % were classified as moist sub-humid, and those with a value between 0 and 33 % as dry sub-humid. According to this classification, parts of West Bengal, Bihar, Orissa, Madhya Pradesh and Uttar Pradesh are in the sub-humid zone. The mean annual temperature of these regions ranges between 23 to 29$^{0}$ C. Major soils of these regions are alfisols, entisols, inceptisols and vertisols and rice is the principal crop. It is suggested that in the dry subhumid zones, particularly in locations where the probability of receiving below-normal rainfall exceeds 20 %, adoption of crops/cropping systems as an alternative to rice, with efficient soil and water management practices should be examined.

Singh and Phadke (2006) conducted an experiment to predict soil erosion from a watershed. The land cover/land use data at village level is collected from the Revenue Department, and detailed soil data from the All India Soil and Landuse Survey, New Delhi that were used in USLE for determining soil erosion rate. Map Info Professional Version 5.5 GIS Software was used as a platform for spatial data analysis required in the USLE. The potential soil loss has been estimated and mapped. Maps covering each parameter were integrated to generate a composite map of erosion intensity based on advanced GIS functionality. The map is expected to assist in the identification of priority areas of the basin and would thus help in future planning of a watershed and its sustainable development (Singh and Phadke, 2006).

A Geographical Information System (GIS) based method is proposed and demonstrated for the identification of sediment source areas and the prediction of storm sediment yield from catchments by Jain and Kothyari (2000). Data from the Nagwa and Karso catchments in Bihar (India) were used. The Integrated Land and Water Information System GIS package has been used for carrying out geographic analyses. An Earth Resources Data Analysis System Imagine image processor was used for the digital analysis of satellite data for deriving the land cover and soil characteristics of the catchments. The catchments were discretized into hydrologically homogeneous grid cells to capture the catchment heterogeneity. The cells thus formed were then differentiated into cells of overland flow regions and cells of channel flow regions based on the magnitude of their flow accumulation areas. The gross soil erosion in each cell was calculated using the Universal Soil Loss Equation by carefully determining its various parameters. The concept of sediment delivery ratio was used for determination of the total sediment yield of each catchment during isolated storm events.

A drought management strategy was described mathematically in terms of short and long-term profiles by Agrawal and Mehrotra (1991). The factors considered include groundwater availability storage of storm run-off, artificial groundwater recharge, improved water-lifting technology and better education.

Verma *et. al.* (1992) analyzed soil samples taken from low, medium and high topographic positions of three sites of fluvial deposition (Chaurs); Chanman, Deopar and Nemopur, in northern Bihar, (25°30' N, 85°40' E), India, and their water transmission characteristics was measured. Clay content decreased from low to high positions.

Bulk density and penetration resistance increased with depth. At the Nemopur site infiltration was greatest at the lowest point in topography, due to biotically produced macropores.

Tejpura watershed in the southern tip of Uttar Pradesh, India covers an area of 775.7 ha. Appropriate soil and water conservation measures were adopted in the watershed area for controlling soil and water loss, *in situ* conservation of rain water and groundwater recharge. Approximately 23 ha m of rain water was stored in 5 check dams. This raised the groundwater table by 3-7 m and led to a subsequent increase in digging of wells from 5 to 380 wells. This change in water supply was reflected in increased land area under irrigation (3.8% to 100%) and an increase in the cropping intensity (82% to 218%). This increased productivity raised incomes by 12 times over the base year. A substantial amount (128 ha) of degraded land was brought back to cultivation. Forage and fuelwood resources greatly increased and milk production doubled. Soil and water conservation reduced runoff by 66% and soil loss by 99%. Silvipasture helped in increased biomass production and rehabilitation of degraded lands. Employment opportunity for villagers was increased by more than threefold and the benefit-cost ratio of the watershed programme was 2.7 (Hazra, 1997).

A few areas of the watershed are critical and responsible for high amount of soil and nutrient losses. Implementation of best management practices is required in those critical erosion prone areas of the watershed for controlling the soil and nutrient losses. Identification of these critical areas is essential for the effective and efficient implementation of watershed management programmes. In this study, a calibrated Soil and Water Assessment Tool (SWAT) model was verified for a small watershed (Nagwan) and used for identification and prioritisation of critical sub-watersheds to develop an effective management plan. Daily rainfall, runoff and sediment yield data of 7 years (1992-1998) were used in this study. Data related to nutrient losses for few storm events of 1997 were also used. Besides these data, the topographical map, soil map, land resources data and satellite imageries of the study watershed were used in this study.

A geographical information system was used for generating the watershed and sub-watershed boundaries, drainage networks, slope, soil series and texture maps. Supervised classification method was used for land use/cover classification from satellite imageries. The weighted average values of parameters such as runoff curve number, surface slope, channel length, average slope length, channel width, channel depth, soil erodibility factor and other soil layer data were taken for each sub-watershed to verify the model. The calibrated SWAT model was verified for the monsoon season on daily basis for the year 1997 and monthly basis for the years 1992-98 for both surface runoff and sediment yield. It was also tested for the available data on nutrient losses. Critical sub-watersheds were identified on the basis of average annual sediment yield and nutrient losses during the period of 3 years 1996-98. The erosion rates and their classes were used as a criterion for identifying the critical sub-watersheds. Out of the 12 sub-watersheds, one sub-watershed fell under moderate soil loss group and five sub-watersheds fell under high soil loss group of soil erosion classes whereas other sub-watersheds fell under slight erosion classes. The study revealed that the SWAT model could successfully be used for identifying and prioritising critical sub-watersheds for management purposes (Tripathi, *et. al.*, 2003).

## 9.2 Rainfall Characteristics in Central Uttar Pradesh

Rainfall data of 20 years was analyzed for soil conservation and crop planning at CSAU&T, Kanpur. The results showed that only 10 % rainfall was received during winter season. Weekly rainfall has more importance in crop planning than monthly and annual rainfall. It has also been worked out that one year out of every ten years was drought year. The annual average rainfall at Kanpur is about 800 mm.

## 9.3 Rainfall Distribution of Faizabad

The variation of yearly rainfall of Faizabad is from 800 mm to 1400 mm. Normal rainfall is 1041 mm. The corresponding years rainfall (1986) reveals that distribution pattern of rainfall concentrates in the months of July, August and September. The rainfall is skewed towards low rainfall after year 1992.

## 9.4 Climatic Features of Poorvanchal Semiarid Sub-humid

Climatology of the Varanasi region is characterized as semi-arid and sub-humid covering large areas belonging to different soil groups (alluvial, red and black soils). The average rainfall ranges between 1050-1100 mm (997 mm dependable) and evapotranspiration (1500-1545 mm). About 87% of total rainfall is received during the monsoon season. The CV of rainfall is 19.1%. The potential evapotranspiration during monsoon period is 574 mm. The area is characterized as potential region for enhancing and stabilizing crop production sequential/intercropping system based on climatic edaphic features. The mean relative humidity is 68% which vary upto 81%, during july to September and comes down to 39% from end of April to 1[st] week of June. An attempt has been made at IGAU, Raipur (Chhattisgarh) to assess a comprehensive decision support system for evapotranspiration (DSS_ET) for estimation of reference crop evapotranspiration ($ET_0$) representing Chhattisgarh plains, Bastar plateau and Northern Hills agro-climatic zones. All the imperical methods compared statistically well with the Penman-Monteith method for Jagdalrpur and Ambikapur research station. The estimated crop ET values were 470 mm, 307 mm, 385 mm, 175 mm and 232 mm for rice, maize, wheat, gram and mustard respectively for Raipur and Jagdalpur stations and almost alike values for Ambikapur station.

## 9.5 Clay Mineralogy of Major Soil Types-Study at CSAU Kanpur

The alluvium of the Western and central regions of Uttar Pradesh is predominantly composed of illite and chlorite minerals while those of Eastern region are richer in montmorillonite. The ratio of coarse (2-0.2 µ) to fine (<0-0.2 µ) clay in the western region was found to be 2:1, in the central region 3:1 but eastern region it was reversed to 1:3. On mechanical separates, illite and chlorite minerals got concentrated in the coarse clay and montmorillonite in the fine clay. Small amounts of vermiculite and significant amounts of quartz and feldspars have also been reported in the coarse clay fraction especially in the western and central regions. The mineralogical variations of the alluvium in the different regions were attributed to differences in soil forming materials arising out of the different flood plains from where the alluvium is derived.

In another study, on the clay mineralogy semi-arid soils of Western Uttar Pradesh and eastern Rajasthan the two groups of soils exhibited similarity in mineral composition. One group forming Mathura, North of Bharatpur and Jaipur soils, contained 25-35 % montmotrillonite, 19-34 % illite, 19-26 % chlorite, 9-16 % kaolinite, 9-11 % quartz and feldspar and traces of allophone and colloidal silica in their clay fraction. The other group consisting of Southern part of Bharatpur and Agra in trans Yamuna area and Etawah, Aligarh and Meerut in the Doab, contained 35-45 % montmorillonite, 26-31 % illite, 19-28 % chlorite minerals with 3-11 % quartz and feldspar, 4-6 % allophone and practically no kaolinite and colloidal silica.

## 9.6 Runoff, Soil Loss and Splash Erosion on 2% Slope under Varying Crop Canopy

Cover efficiency of different legumes, namely cowpea, guar, black gram, green gram and jowar for fodder etc. under unfertilized and fertilized conditions was determined at CSAU, Kanpur. It was found that green gram and black gram give early and dense (85%) ground cover which coincides with the peak rate of runoff. The splash loss of soil was highest (44.2 t $ha^{-1}$) in fallow plots followed by jowar and cowpea while it was lowest (26.3 t $ha^{-1}$) in plots having green gram and black gram crops. All the cover crops in general were found equally good in conserving moisture but all were better than plots kept fallow during *kharif* for raising a *rabi* crop on residual moisture. Fertilization of crops was found beneficial to reduce splash erosion as it enhanced crop growth providing a better cover on land surface.

## 9.7 Sedimentation in Canals and Fields

In the Northern part of Bihar where flood is a recurring problem, sedimentation is the main cause of flood. River courses are silted up and water flows covering wide area.

The rivers originating from Himalayan ranges of Nepal release sediment in Bihar. This problem is coming to the minds of academicians, but has yet to capture attention of state Soil Conservation programme implementing agency. The problem is of complex dimension as it involves international sphere.

## 9.8 Drought Analysis of Bihar

Study on occurrence of agricultural drought at Pusa Farm (Bihar) by utilizing 20 years of rainfall data (1969-89) revealed that normal, surplus rainfall year and drought year are 46%, 14% and 40%, respectively. Further, occurrence of drought during *rabi* season was at 90% probability level which requires ensured irrigation for cultivation of *rabi* crops.

Another study at Patna, a critical water deficit index (%), a numerical measure about the percent of paddy crop growth periods that experience water deficiency (non-submergence of paddy field for more than three days) was evaluated by Singh *et. al.* (2002). Paddy fields 6-26% have 66 to 24 critical days.

About 25 to 23% of the paddy fields have 48 to 24 days critical water deficit days. Because these paddy fields lie at different elevations, water from one field to another field will get collected, therefore, it will vitiate the status of critical condition of the paddy field.

Therefore, still better rational approach of analyzing the critical growth period for paddy will be necessary for undertaking research and development in the area.

## 9.9 Resource Conservation Measures for Sustainable Production System for Arable Lands

Experiments conducted by Rout *et. al.* (1989) during the *kharif* and *rabi* seasons of 1977-78 revealed that in contour basins under transplanted rice on a sandy loam, use of polythene sheets and bentonite clay can reduce seepage loss. Polythene lining up to a depth of 60 cm along the three outflow checks could reduce the paddy water requirement by 11.8% and 13.5% by incorporating bentonite at 500 kg $ha^{-1}$ in the soil surface. The corresponding water use efficiency values were 41.6 and 42.2 kg $ha^{-1}cm^{-1}$ compared to 36.1 by puddling with the country plough only. Polythene lining 60 cm down and along all four bands reduced the water requirement by 45% and increased water use efficiency to 63.2 kg $ha^{-1}cm^{-1}$. However, its high cost reduces its practicability. Puddling by tractor or application of 250 kg $ha^{-1}$ bentonite did not reduce the seepage loss appreciably.

Data on N, P, K, S and Mo in twenty four soil samples taken from shallow, medium, and deep ravines, and the surrounding flat land, on reclamation projects near the Yamuna River, Uttar Pradesh, India, were reported by Chaudhary and Das (1990). The contents of N, P, K, S and Mo in the soils varied widely in different categories of land, having maximum values at peripheral table-land followed by shallow ravines, medium ravines and lowest in deep ravines. Nutrient loss was shown to depend on intensity of erosion as well as on slope. The available nutrients were mostly lost by soil loss and runoff. Nutrient levels were minimum in ravine-side samples, followed by top samples and maximum in bottom samples. With the exception of potassium, the soils were deficient in all the nutrients studied.

An experiment on oat yield and evaporation loss of water was computed in a lysimetric study by Lal and Shukla (1988). In oats cv. Kent grown in lysimeters in the winter seasons of 1978-81 and irrigated at 0.45 atm tension in the active root zone depth of 15-30 cm, the total evapotranspiration (ET) losses were 361.9, 422.9

and 431.0 mm with mean ET rates of 3.80, 4.36 and 3.59 mm $day^{-1}$ during the growth period of 1978-79, 1979-80 and 1980-81, respectively. The ET rate increased with increase in crop age up to the boot stage and did not follow any definite trend thereafter in different years. The dry matter yields were 13.26, 11.79 and 14.00 t $ha^{-1}$ and the water use efficiency was 37.0, 28.5 and 32 kg dry matter $mm^{-1}$ $ha^{-1}$ in the 3 years, resp. The crop used only 20 to 33% of the total water requirement from sowing to the jointing (stem elongation) stage and the remaining water was used from jointing to milk/dough stages, suggesting a need for rationalization of irrigation water during later growing stages.

In an experiment in Uttar Pradesh, India, P, S and Mo application significantly increased the canopy, nodule count, yield of rainfed black gram (*Vigna mungo*), yield of succeeding safflower and reduced splash loss and conserved more soil water. Water stable aggregates, infiltration rate, organic carbon, total N, available P, K, S and Mo in soil increased considerably after the harvest of black gram but decreased after the harvest of succeeding safflower. Plant canopy showed significant positive relationship with nodule count, soil water conservation, water stable aggregates and infiltration rate but showed significant negative relationship with splash loss (Chaudhary and Das, 1996).

An experiment was carried out at Soil Conservation and Water Management Research Farm of C.S. Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India, during *Kharif* season of 1995-96 to study the effect of alley width and intra-row spacing of *Leucaena* on soil loss, growth and yield of sorghum (*Sorghum bicolor*). The treatments comprised of three intra-row spacing of *Leucaena leucocephala* (0.5, 1.0, and 1.5 m) and two alley width at 4.5 and 6.5 m. The results showed that initial and final plant populations of sorghum were unaffected due to alley width and intra-row spacing of *Leucaena*. Plant height of sorghum increased significantly with advancement of crop up to harvest due to alley width and also intra-row spacing of *Leucaena leucocephala* except at early stages of crop *i.e.* 30 to 60 DAS. Plant girth increased significantly with increasing days after sowing due to alley width of *Leucaena* where wider alley width produced healthier plants as compared to narrow alley width. Grain yield of sorghum significantly increased in wider alley width of 6.5 m while this was not affected significantly by intra-row spacing of *Leucaena*. Thus, alley width and intra-row spacing of *Leucaena* has an impact on plant growth and phenological parameter of sorghum as well as on grain yield. The soil loss was significantly higher under wider alley width of 6.5 m as compared to narrow alley width of 4.5 m apart. However, intra-row spacing of 1.5 m led to maximum soil loss (1.80 t $ha^{-1}$) while lowest (1.55 t $ha^{-1}$) was recorded at 0.5 m (Ekhlaq *et. al.*, 2005).

A study was conducted in Jhansi, Uttar Pradesh, India during 1998-01 to assess the productivity of fodder-based cropping sequences and the changes in soil properties in *Leucaena* (*Leucaena* leucocephala) alleys with foliage mulch and incorporation under rainfed conditions by Burman *et. al.* (2004). The treatments used in the study included combinations of 4 cropping sequences (maize-chickpea, maize fallow, cowpea-barley and cowpea fallow) and 3 *Leucaena* foliage treatments (control, foliage mulch and foliage incorporation). The green fodder yields of maize and cowpea were lower under *Leucaena* alleys at all the foliage treatments compared to those without alley as indicated by the relative yields of the crops. The relative yields of chickpea and barley during *rabi* were also affected due to *Leucaena* alleys wherein a considerable reduction of 11-12 and 21-23% in chickpea grain and straw yields and 9 and 18-20% in barley grain and straw yields were observed in the mulch and incorporation treatments, respectively. A decline in the value of pH, electrical conductivity and bulk density and an increase in porosity, water stable aggregates and infiltration were noticed under both foliage treatments. The average profile moisture content during *rabi* under both chickpea and barley was maximum in the mulch treatment. A reduction in the average soil temperature was also evident in the same treatment. Significantly higher values of organic C, available N, P and K were observed as a result of *Leucaena* foliage mulching and incorporation over the control and initial values. The results indicated that the application of *Leucaena* foliage increased the green and fodder yield of maize and cowpea during *kharif* and grain yield of chickpea and barley during *rabi*. The *Leucaena* foliage can be incorporated in the soil during kharif and applied as mulch during *rabi* for increasing the crop yields under alley cropping system. The foliage incorporation and/or mulching also improved the physical and chemical properties of the soil.

A field experiment was conducted during 1986-87 and 1987-88 with 5 cropping systems: (1) rice ( *Oryza sativa*)-wheat (*Triticum aestivum*)-green gram (*Vigna radiata*); (2) maize (Zea mays)-pea (*Pisum sativum*)-common millet (*Panicum miliaceum*); (3) pigeon pea (*Cajanus cajan*)-wheat-green gram; (4) maize-potato (*Solanum tuberosum*) + Indian mustard (*Brassica juncea*)-black gram (*V. mungo*), and (5) black gram-Indian mustard-maize + fodder cowpea (*V. unguiculata*), under irrigated conditions were conducted by Newaj and Yadav (1994). Physio-chemical analysis of soil after 2 years of experimentation showed that the bulk densitty was reduced and infiltration rate of the soil was increased from their initial values. The organic carbon, available nitrogen, phosphorus and potassium contents of the soil were increased from their initial content. The soil pH was decreased at the end of study under all the cropping systems. The most productive system (4) removed a greater amount of N, P and K (345.94, 78.43 and 387.86 kg $ha^{-1}year^{-1}$, respectively) from soil compared with the other systems. The balance for N and K was negative in all the systems but greater depletion of N and K (110.94 and 267.93 kg kg $ha^{-1}year^{-1}$, respectively) was recorded under system (4). The balance for P was positive in all the systems and a greater buildup of P (101.56 kg $ha^{-1}year^{-1}$) in the surface layer was found under system (4).

A field experiment was conducted in 1992-93 to study the relative productivity and profitability of different cropping systems under dryland conditions. Black gram (*Vigna mungo*) equivalent yield was the highest in maize + green gram (*Vigna radiate*) (1:2), maize + black gram (1:2) and maize + black gram (1:1) intercropping systems. Soil loss was the highest from maize grown alone and lowest from maize + urid (1:2). Yield of the following safflower crop was highest after maize + soyabeans (1:2) or a soyabean pure stand. The rotation maize + soyabeans (1:2) followed by safflower gave the maximum total water use, water use efficiency and net profit.

## 9.10 Effect of Surface Mulching and Conservation Irrigation on Yield of Mustard

At BHU, Varanasi application of 60 kg N $ha^{-1}$ and mulching inter-rows with straw mulch (2.5 t $ha^{-1}$) in Mirzapur district were found effective in terms of enhanced yield (34.0 per cent) and moisture use efficiency of barley crop during winter season. The performance was comparable to cultivating soil for creating dust mulch. Super imposing different mulch materials in plots treated during summer revealed that supplementing organic mulch (pearl millet stover/paddy straw) during winter season helped to boost chickpea yield significantly higher than that from control plot. Inter-row mulch application boosted chickpea yield by 25% over no mulch application.

## 9.11 Tillage Practices for Erosion Control and Crop Productivity

In the Vindhyan tract, summer ploughing in combination with compartmental bunding resulted in 71 per cent retention of rainfall compared to 32-51 per cent in conventional farming practices. This treatment also helped boosting yield of green gram significantly.

Study on effect of zero, minimum and conventional tillage with and without rice straw mulch on conservation of soil moisture, root growth and yield of chickpea and mustard grown under rainfed conditions was carried out for three years (1990 to 1992) in a deep clay soil (typical *chromusterts*) by Rathore *et. al.* (1998). Minimum tillage with and without starw mulch enhanced soil moisture conservation and moisture availability during the crop growth that resulted in increase in root mass, yield components (plant stand, number of parts per plant and plant height) and grain yield. Zero tillage was superior to the other tillage practices for mustard and zero tillage and minimum tillage produced similar yields. Soil mulching was found to be effective in redistributing soil moisture in the soil profile during later part of the crop growth. Yield of chickpea and mustard was higher under mulch than in no mulch plots. Yield of both the *rabi* crops were very poor.

Study carried out by Institute for Agricultural Sciences, BHU, Varanasi, revealed that deep tillage along with graded earthen bund and stover mulching (*rabi*) should be followed for efficient *in-situ* rain water management and sustained productivity of maize –chickpea cropping sequences on soil of Vindhyan Hills. Deep tillage was more remunerative than off season and conservation tillage with respect to maize and chick pea yields in maize-chickpea cropping sequence. Earthen bunds were superior to live bunds as well as live bunds + small sectional bunds. Stover mulch was superior to soil mulch and control.

## 9.12 Supplemental Irrigation

Use of harvested water as supplemental irrigation at two critical stages *i.e.* pre-flowering and pre-pod formation stages (*rabi* crop) showed that chickpea of maize based cropping system produced sustainable productivity in agro-eco region of Vindhyan Hills. Having the facility of rain water harvesting and recycling, introduction of high value cash crops *i.e.* maize (green cob) + cowpea (vegetables – garden pea) be adopted to increase and stabilize the productivity and raise the socio-economic status of resource poor farm community of agro-eco region of Vindhyan hills.

Farm pond water, collection bundhies in mild to flat topo-sequence of Gangetic plains and foot hills of Vindhyan range holds promise for increased and stabilized production through intensive runoff farming and resource conservation. Such a conservation practice can only be economically viable when community approach is adopted for structures and sharing conserved water resource. Water, thus, stored helps in negating the ill effect of weather fluctuations in the agro-eco Zone-11. With supplementary irrigation with harvested water double cropping is being practiced in major part where monocropping was a common practice earlier.

One irrigation of 5 cm helped to boost yield of barley and rajmah each by over 17 % in barley-rajmah intercropping system and as such system advantage is enhanced 18 %. Similarly, tomato (variety Pusa ruby) recorded 28 % higher yield to control when 5 cm depth of irrigation water was applied 30 days after planting.

## 9.13 Irrigation Borders for Reclaimed Ravine Lands

ICAR Research Complex for Eastern Regions Patna has carried out studies on border irrigation for wheat under DFID project. The recommended border size for Bihar for carrying out flood irrigation is given in relation to length of field, rate of flow and width of the border. The recommended width of border is 6 m and length of the border is 50 m with 12 l $s^{-1}$ discharge, 100 m with 18 l $s^{-1}$ and 150 m with 24 l $s^{-1}$. The border sizes are found to save the volume of irrigation water.

A new innovative method of low energy water application system is being developed at the ICAR Research Complex Patna which will enable applying irrigation water without causing flooding, thereby saving irrigation water. The application rate is 0.32 l $s^{-1}$ for *kharif* and 0.15 l $s^{-1}$ for *rabi* crops per two riser sets.

## 9.14 Resource Conservation Measures for Sustainable Production System for Non-Arable Lands

In the highly degraded wastelands of Gaharawa village near Jhansi, 83.75 ha of barren hills were planted with pasture grasses and legumes (including *Atylosia scarabaeoides*, *Clitoria ternatea*, *Pueraria tuberosa*, *Stylosanthes hamata* and *Cenchrus ciliaris*), shrubs (including *Carissa spinarum* and *Inga dulcis*) and trees (including *Azadirachta indica, Albizia lebbeck*, A. procera, Acacia nilotica, *Leucaena* leucocephala and Prosopis juliflora) and a range of soil and water conservation measures were carried out as appropriate in 1990. Total dry matter yields in 1991-92 were 6.18 t $ha^{-1}$ compared with 0.46 t in the untreated control area. Soil and water conservation methods increased dry matter yields, as did 40 kg N + 40 kg $P_2O_5$ $ha^{-1}$. Dry matter yields were in the order silvipasture (*Cenchrus ciliaris, Pennisetum pedicellatum, S. hamata, L. leucocephala*) and improved pasture (*C. ciliaris, P. pedicellatum, S. hamata*) > natural rangeland vegetation (*Heteropogon contortus, Themeda sp., Eremopogon foveolatus*). Soil losses were reduced from 41 to 9.5 t $ha^{-1}$ from barren hillocks and from 20.5 to 5.5 t $ha^{-1}$ from wastelands; silt deposition was reduced from 0.28-0.40 m to 0.05-0.1 m, and run-off from 70 to 30% with a rise in water table from 1 to 4 m. Crop (unspecified) yields increased from 0.36 to 2 t $ha^{-1}$ and cropping intensity from 80 to 156%. The cost:benefit ratio of the programme was 1:2.89 (Hazra and Singh, 1994).

An area of 665 ha of community land comprising mostly degraded hills belonging to a cluster of seven villages at Jhansi was treated with appropriate soil and water conservation measures. The area was planted with a number of tree species and shrubs and sown with grasses and legumes. A number of tree species regenerated naturally due to improvement in soil moisture status including protection. These activities restored 317 ha of wastelands into cultivation, increased irrigation water availability from 10 to 69%, cropping intensity from 81 to 172% and crop productivity from 0.7 to 2.8 t $ha^{-1}$. The soil and water conservation treatments reduced soil loss from 22.5 to 1.7 t $ha^{-1}$, runoff water loss from 49 to 20% of annual rainfall and sedimentation from 36 to 1 cm. Forage productivity was greatly increased from 0.7 to 5.3 t $ha^{-1}$. Higher fuelwood availability from the third year onwards resulted in substantial reduction of the use of cow dung for fuel purposes which could then be used as organic manure for crop production. Soil organic carbon value increased from 0.20 to 0.80% and the soil fertility status increased (Hazra, 1996).

The effects of tillage, inter-terracing and mulching on the performance of a maize-chickpea cropping system were studied in Barkaccha, Mirzapur, Uttar Pradesh, India, was studied by Singh *et. al.* (2002). Maize Cv. Ganga 5 and chickpea Cv. Avarodhi were cultivated during the rainy and winter seasons, respectively. Conventional tillage (criss-cross cultivation up to 15 cm depth after the onset of the southwest monsoon), off-season tillage after harvesting of the winter crop and deep tillage (25-30 cm depth) were evaluated in main plots, whereas inter-terracing with earthen bund, live bund or live bund + small bunds were evaluated in subplots. Deep tillage and inter-terracing with earthen bunds resulted in the highest maize green cob length (14.00 and 13.53 cm), number of kernel rows (15.43 and 13.97), number of grains per cob (289.53 and 290.37), green cob yield (6.21 and 6.38 t $ha^{-1}$), sustainable yield index (SYI; 0.84 and 0.86), stover yield (10.39 and 10.45 t $ha^{-1}$), and nitrogen (178.88 and 179.21 kg $ha^{-1}$), phosphorus (37.62 and 37.05 kg $ha^{-1}$) and potassium (167.44 and 165.86 kg $ha^{-1}$) uptake; chickpea grain (1.15 t $ha^{-1}$) and stalk (2.45 t $ha^{-1}$) yields, SYI (0.80) and cost benefit ratio (CBR; 1:1.53); and nitrogen (262.79 kg $ha^{-1}$), phosphorus (49.84 kg $ha^{-1}$) and potassium (219.37 kg $ha^{-1}$) uptake by MCCS. Inter-terracing with earthen bunds also gave the highest chickpea grain (1.06 t $ha^{-1}$) and stalk (2.45 t $ha^{-1}$) yields, SYI (0.74) and CBR (1:1.44), and nitrogen (257.49 kg $ha^{-1}$), phosphorus (48.73 kg $ha^{-1}$) and potassiuum (216.56 kg $ha^{-1}$) uptake by MCCS. Mulching with stover during winter resulted in higher chickpea grain (1.18 t $ha^{-1}$) and stalk (2.63 t $ha^{-1}$) yields, SYI (0.2) and CBR (1:1.56), as well as higher nitrogen (261.63 kg $ha^{-1}$), phosphorus (47.84 kg $ha^{-1}$) and potassium (216.64 kg $ha^{-1}$) uptake by MCCS than mulching with soil.

This study was conducted in the Eastern part of Jaunpur, Uttar Pradesh, India at Chachakpur (site I) and Vazidpur-North (site II) to evaluate soil losses, water and nutrients (N and P) under two repeated artificial showering of 100 litres during winter and rainy season. On each site, the plot surface vegetation was scraped or clipped (bare) and the other plot was retained with natural vegetation cover (vegetated). The vegetation of both sites was dominated by *Cynodon dactylon*, *Saccharum munja*, *Cyperus rotundus*, *Saccharum spontaneum*, *Digitaria adcedens* (*Digitaria ciliaris*), *Desmodium triflorum*, *Chloris barbata* and *Eragrostis unioloides*. The vegetated plots showed lower values of soil erosion, run-off water, nutrient loss and high infiltration rate as compared to bare plots at both sites. Loss of soil and water was high during rainy season, but loss of nutrients was higher during winter at both study sites. The annual soil loss in total rainfall was 3.52 (vegetated) and 25.22 t $ha^{-1}$ $year^{-1}$ (bare) at site I, however, it was 5.77 (vegetated) and 28.69 t $ha^{-1}$ $year^{-1}$ (bare) at site II (Kapoor and Singh, 2005).

## 9.15 Effect of Fire on Plant Available Nutrients

Three of 6 plots established in dry tropical savanna ecosystems on the Vindhyan Plateau, Uttar Pradesh were burned in January and November 1988. The effects of fire on plant available nutrients (nitrate-N, ammonium-N and phosphate-P), N-mineralization and nitrification rates, soil microbial biomass C, N and P, canopy biomass and root biomass were studied during selected phenological phases in 1988-89. Phenological phases studied were made at the vegetative (August), flowering and fruiting (October), fruitfall (November), early senescence (December-January) and late senescence (June). Results indicated significant differences due to month and treatment (burning vs no burning) but not due to year. Following fire, the increase in the build up of microbial biomass in the dry season and canopy growth and N-mineralization rate in the wet season are nutrient conserving mechanisms that prevent nutrient loss. Therefore fire can be a management tool for better productivity and nutritive quality in dry tropical environments.

# 10.0 THUMB RULES OR INDIGENOUS TECHNICAL KNOWLEDGE/ PRACTICES ADOPTED BY STATE AGENCIES

Some of the important and effective ITKs for soil and moisture conservation are given below:

**i. Soaking of sorghum seed in cow urine to ensure better germination**

In the central India indigenous practice is to soak sorghum seed in cow urine to ensure better germination. To induce tolerance to drought seed are treated with salt solution before sowing.

**ii. Putting of seeds inside the petiole of cucumber leaves for ensuring germination**

For testing the germination of crop, farmers put the seeds inside the petiole of cucumber leaves and close the cut portion of petiole. After 36-48 hrs, the seeds inside the petiole germinate (Gonda, Uttar Pradesh)

**iii. Sheep and goat sitting in the sugarcane paddy fields**

In the summer largely sheep and goat grazers take their herds from one place to another. These herds are made to sit in the fields thereby droppings and urine is directly reaches to the field. These urine and droppings come in reaction soon after the first shower and no nutrient loss occurs because of the summer. It is estimated that the herd of 700 sheep will produce around 14.93 quintal of manures. This manure increases water holding capacity and microbial activity in the field which are very essential for the nutrient extraction by the crops. Advantage of this practice is uniform application of the sheep droppings and urine etc. The extra advantage is that there is no extra expenditure of money and energy towards spreading of the manure. Urine is the very rich source of potash. Therefore, this practice is suitable for the crops which require high content of potash.

**iv. Gurr**

Gurr is an indigenous practice operated in the pearl millet field when crop grows upto height of knee to waist. Largely pearl millet is sown by broadcasting either singly or mixture of pearl millet, green gram and pigeonpea. At knee height, a country plough is drawn at regular interval with the help of bullocks. The plough furrow so created gives a tillage effect, furrow for moisture conservation, bring row effect in the field and control weeds. This practice is found very effective in the Agra region.

A feeler trial study under OFR (on farm research) was undertaken at Bilauni-Fatehabad tehsil in the year, 2001, to assess the efficacy of gurr in comparison to no gurr. Moisture conservation by gurr has resulted in more number of ear bearing plants per meter square that produced almost double yield of crop as compared to without gurr. Giving an allowance for other management factors, an increase by 22-30% in yield of pearl millet can be expected on account of gurr.

**v. Green manuring**

Green manuring is indigenous age old practice. In this practice, leguminous crops such as sunhemp, dhaincha, green gram, black gram, jute and to some extent pearl millet is grown in the rainy season. When the crop attains the height of about 1-1.5 m (within 45 days after sowing), the crop is ploughed down and incorporated into the soil. In that particular year when the green manuring is practiced, one crop (rainy season crop) is lost. In Agra region, the green manuring was found to increase the yield of mustard equivalent to 40 kg N $ha^{-1}$.

From the agricultural statistics of Uttar Pradesh, it is found that in the central Uttar Pradesh *viz.* Kanpur region green manuring with sunhemp is the highest in hectarage per Commissionery/mandal. Agra mandal is second in the state to have large area under green manuring.

Among the districts highest hectarage under green manuring is in the Etawah district (8500 ha) followed Aligarh district (6500 ha).

**vi. Ploughing and planking early morning**

In the central Uttar Pradesh ploughing in the early morning and planking had been the earlier practice of capitalizing the residual moisture already in the soil and accumulation of the dew in the month of October and November *i.e.* before sowing of the winter season crops.

**vii. Desi hal for land preparation**

Desi plough made of bamboo and sal wood can be operated by a pair of bullocks and one man for land preparation of paddy in Bihar. The average weight of yoke is 12-20 kg covering 0.6 acre per day with an average depth of 2-4 inch and width 4-5 inches depending on soil conditions.

**viii. Termite control by using kerosene with irrigation water**

Farmers use 2.5 litre kerosene per acre at the time of irrigation to control the termite problems in the field. Neem cake is also practiced as top dressing to control termites (Gonda, Uttar Pradesh).

**ix. Saving sugarcane crop from wild animals by mahua (*Madhuca latifolia*) trap**

Jackals and such other animals harm the sugarcane crop by biting cane at about one foot above the ground. For the control of jackals, farmers place mahua flowers in an earthen pot tied to a pole. A rope trap is attached to the earthen pot. These mahua flowers attract the animals in the night. Once animals gets attracted and put their mouth in the pot, they fail to take it out as the rope noose tightens around the neck of the animal.

**x. Submergence bundhi in the aravali and bundelkhand region**

Submergence bundhi is an age old practice in the Aravali region of Agra district and in the Bundelkhand region. In this practice on the long slopping land, a long moderate height dam is constructed to detain water and create water pondage before the dam in the upstream side. The objective of the water pondage is to increase moisture build up and ground water recharge so that *rabi* crop is cultivated on the conserved moisture. Supplementary irrigation can be given from the ground water lifted by pumping. After the rainy season the water under pondage is released in the month of October. The fields are cultivated and *rabi* crop is sown. In this practice, it is possible to take one crop. The submergence practice is known by different names in different parts of the country. Its name in the Rajasthan is Khadin, in UP it is submergence bundhi, in Madhya Pradesh it is Haveli and in Bihar it is known as Tal – a large area under submergence. As rainfall increases from western to eastern part of the country the size of the submergence bundhi goes on increasing. The emphasis and density of the submergence bundhi is more in Rajasthan particularly Bharatpur district than it is in Agra district of Uttar Pradesh.

**xi. Summer ploughing**

The summer ploughing is practiced to utilize pre-monsoon showers to facilitate timely sowing and weed control. This age old practice is followed by all categories of farmers on individual basis for receiving rain of South-West monsoon. This practice is cost effective, technically feasible besides socially acceptable. Reduced soil loss due to improved soil aggregate stability, reduced weed intensity, enhanced soil moisture status, facilitate timely seed bed preparation and seeding to boost up production.

**xii. Compartmental bunding**

This an age old practice, is carried over by all categories of farmers on individual basis for retention of rain water for runoff modulation. This is widely practiced by farmers with rice based cropping system. Compartmental bunding facilitates impounding rice culture at times facilitate control spilling of excess water from field to field and finally to diversion range.

**xiii. Ridge and furrow planting**

Medium and large farmers are practicing this ITK on about 25 to 30% problematic area for conservation of rain water, moderating excess water, controlling soil loss and boosting productivity. Farmers plant pigeonpea on ridges and rice in furrows for effective utilization of rainwater. The system can be adopted in pulse based cropping system being taken in the region.

**xiv. Farm pond**

This ITK is being followed by medium and big farmers on individual basis covering about 4-5% of the problematic areas for water harvesting and recycling. Due to this practice there is safe disposal of overland flow reducing soil erosion, water stagnation and likely crop damage and creating minor irrigation resources for supplemental/life saving irrigation. Additional revenue from water are generated by cultivating fish, coral and water nut.

**xv. Contour cultivation/cultivation across slopes**

This ITK is largely practiced by medium and large farmers covering about 30-50% of problematic area for eliminating slope length, creating barriers for water flow and enhancing soil moisture status.

# 11.0 PHYSICAL AND FINANCIAL ACHIEVEMENTS OF THE STATE AGENCIES INVOLVED IN SOIL AND WATER CONSERVATION

## 11.1 Soil and Water Conservation and Watershed Management in Uttar Pradesh and Bihar

### Progressive Action

Soil conservation work began in the first five year plan (1951-56). The intensive work was taken up in 1963 by way of legislation on soil and water conservation. About 2.90 lakh saline, 3.70 lakh ha ravine and 52 lakh ha eroded lands had been treated for agriculture productivity with an investment of Rs. 106824 lakhs.

In the participatory watershed management treatment of land, production of food, fodder, fruits, fuel and animal husbandry were taken up. In this programme formation of homogenous groups, such as user groups, self help groups, women and children welfare groups are fostered and promoted.

**Table 11.1: Five year plan wise works and budget expenditure in erstwhile Uttar Pradesh**

| Name of the Plan | Physical achievement (lakh ha) | | | | Expenditure (Rs. in lakhs) |
|---|---|---|---|---|---|
| | Treatment of eroded land | Treatment of alkaline land | Treatment of ravine land | Total treated land | |
| 1st Five Year Plan 1951-56 | Establishment of soil conservation division and alkaline farms | | | | 44.96 |
| 2nd Five Year Plan 1956-61 | 0.31 | - | - | 0.31 | 59.93 |
| 3rd Five Year Plan 1961-66 | 3.16 | - | - | 3.16 | 351.05 |
| Annual Plan 1966-69 | 3.44 | - | 0.17 | 3.61 | 609.49 |
| 4th Five Year Plan 1969-74 | 10.46 | - | 0.82 | 11.28 | 1919.39 |
| 5th Five year plan 1974-78 | 2.44 | 0.04 | 0.36 | 2.84 | 2309.70 |
| Rolling Plan 1978-80 | 1.93 | 0.30 | 0.05 | 2.28 | 2115.36 |
| 6th Five Year Plan 1980-85 | 4.35 | 0.72 | 0.23 | 5.30 | 7315.40 |
| 7th Five Year Plan 1985-90 | 5.73 | 0.36 | 0.51 | 6.60 | 14990.10 |
| Annual Plan 1990-92 | 2.59 | 0.36 | 0.32 | 3.27 | 11495.66 |
| 8th Five Year Plan 1992-97 | 10.33 | 0.93 | 0.10 | 11.36 | 38908.07 |
| 9th Five Year Plan 1997-2002 | 6.55 | 0.12 | 0.74 | 7.42 | 26709.70 |
| 10th Five Year Plan (2002-03 to 2006-07) | 1.50 | 0.10 | 0.43 | 2.03 | - |
| **Total** | **52.79** | **2.93** | **3.73** | **59.46** | **106823.81** |

Up to 6th five year plan (1980-86) soil conservation was not taken up in holistic watershed management approach. Watershed management approach was taken up in 7th five year plan (1985-90) at the advent of Operational Research sponsored by ICAR, New Delhi. In the 9th five year plan the watershed management was reoriented as peoples' participatory watershed management with bottom to top approach. All the soil conservation schemes operated in the State of Uttar Pradesh (erstwhile and present) are shown in Table 11.1 (Map 11.1).

After partition of the erstwhile Bihar state, most of the areas suffering from soil erosion problems are now in the state of Jharkhand. The districts adjacent to Jharkhand have problems of soil erosion. The problem is getting severe during the drought year creating a clear cut contrast in hydrologic regime. The northern part of Bihar is suffering from high flood because of sedimentation in the river coarse which causes overflow leading to occurrence of large area under inundation whereas southern Bihar faces drought problem because of drying of river. Therefore, erosion is a cause of flood in northern Bihar and drought in the southern Bihar. Soil conservation work in the high rainfall area (1150 mm) comprises of silt detention dams and water harvesting for supplementary irrigation. All the soil conservation schemes operated in the state of Bihar are shown in Table 11.2 (Map 11.2).

**Table 11.2: Five year plan wise works and budget expenditure in erstwhile Bihar**

| Period | State Sector | | Central Sector | | Total | |
|---|---|---|---|---|---|---|
| | Physical, (Lakh ha) (SCT+SDD+WHT) | Financial, (Rs in Lakhs) | Physical, (Lakh ha) (SCT+SDD+WHT) | Financial, (Rs in Lakhs) | Physical, (Lakh ha) (SCT+SDD+WHT) | Financial(Rs in Lakhs) |
| 1st five year plan 1951-56 | - | - | - | - | - | - |
| 2nd five year plan, 1956-61 | 30.99+0+0 | 34.48 | - | - | 30.995+0+0 | - |
| 3rd five year plan, 1961-66 | 75.695+127+0 | 98.53 | 12.468+17+0 | 15.90 | 88.163+214+0 | 34 |
| Annual Plan, 1966-69 | 42.187+209+0 | 37.13 | 14.044+88+0 | 28.14 | 56.231+297+0 | 114.43 |
| 4th five year plan, 1969-74 | 77.270+2072+0 | 242.79 | 98.616+1558+0 | 276.86 | 175.886+3630+0 | 65.27 |
| 5th five year plan, 1974-78 | 79.616+1725+0 | 420.11 | 31.692+983+0 | 282.66 | 111.308+2708+0 | 519.65 |
| Rolling Plan, 1978-80 | 39.527+771+0 | 333.25 | 25.102+857+14 | 336.89 | 64.719+1628+14 | 702.5 |
| 6th five year plan, 1980-85 | 95.065+1671+15 | 1169.86 | 72.779+2218+297 | 1688.48 | 167.844+3889+312 | 670.14 |
| 7th five year plan, 1995-90 | 73.072+992+1118 | 1929.61 | 77.462+1270+1442 | 3019.26 | 150.534+2271+2565 | 2853.34 |
| Annual Plan, 1990-1992 | 17.312+126+277 | 554.00 | 15.251+452+313 | 972.87 | 32.563+578+590 | 4948.87 |
| 8th five year plan, 1992-97 | 3.101+61+124 | 261.08 | 12981+693+824+1801 | 1445.98 | 15.282+754+948 | 1526.87 |
| 9th five year plan, 1997-02 | 533.840+7824+1534 | 5080.84 | 359.685+8145 | 8117.04 | 893525+15969+4429 | 13197.88 Lakh |

S.C.T.- Soil conservation treatments S.D.D.- Silt detention dams (Nos.) W.H.T.- Water harvesting tank (Nos.)

## 11.2 Operating Schemes

Following schemes operated for soil and water conservation in Uttar Pradesh:

1. National Watershed Development Programme for Rainfed Areas (NWDPRA)
2. Flood Prone Gomti and Sone River Project.
3. Centrally Sponsored Salinity Treatment Project.
4. NABARD Funded Integrated Watershed Management Project in Bundelkhand Region.
5. EEC Funded Project in Ravine Areas.
6. Tharu Tribal Area Development Project.
7. Border Area Development Project
8. DRDA Funded Projects
   i) Drought Areas Development Programme (DADP)
   ii) Integrated Wasteland Development Project (IWDP)
   iii) Other employment oriented schemes

**NWDPRA**

In Uttar Pradesh, NWDPRA begun in 8th five year plan. 9th Plan was operated as yearly work plan scheme. It was fully financed by the Central Government (75 % as subsidy and 25% as loan). It was operated in the development block where irrigation facility was less than 30%. The selected watersheds promoted rainfed agriculture. The objective of the scheme was to control soil erosion and facilitate means of livelihood for all the people in the watershed (Table 11.3 and 11.4).

**Table 11.3: List of watersheds of NWDPRA identified for project implementation during 10th plan (2002-03 to 2006-07) in the State U.P.**

| Nature of soil conservation region | Name of district | Name of block | No. of watersheds | Geographical area (ha) | Effective area (ha) |
|---|---|---|---|---|---|
| Meerut | Saharanpur | i. Sadauli Kadim<br>ii. Muzaffarabad | 10 | 5607 | 5189 |
| Agra | Agra | i. Jagner | 10 | 5293 | 5020 |
| Etawah | Etawah | i. Barhpura | 5 | 2855 | 2500 |
| Barelie | Badaun | i. Khadar Chauk<br>ii. Osawaon<br>iii. Myau | 10 | 5208 | 5000 |
| Lucknow (Usar) | Barabanki | i. Suratganj<br>ii. Puradalai<br>iii. Banikodar | 10 | 5541 | 5091 |
| Kanpur | Kanpur Nagar | i. Ghatampur | 10 | 5510 | 5050 |
| | Kanpur Dehat | i. Amrodha<br>ii. Malasa<br>iii. Derapur | 10 | 5395 | 5020 |
| | Unnao | i. Sikandarpur siroshi | 10 | 5459 | 5175 |
| Lucknow | Sitapur | i. Mahmodabad | 10 | 5718 | 5215 |
| | Lkhimpur | i. Ramiyabehar<br>ii. Nigasan | 10 | 5148 | 5000 |
| Azamgarh | Ajamgarh | i. Koaylsa | 10 | 5327 | 5077 |
| | Ajamgarh (Usar) | i. Thekma<br>ii. Lalganj<br>iii. Mirzapur<br>iv. Phoolpur | 10 | 5428 | 5096 |
| | Ballia | i. Sir<br>ii. Chilkohar<br>iii. Garhwar | 10 | 5909 | 5259 |
| Allahabad | Allahabad | i. Shankargarh<br>ii. Neweda | 10 | 5374 | 5000 |
| | Kaushambi | i. Kaushambi<br>ii. Manjhanpur | - | - | - |
| | Fatehpur | i. Vijaypur<br>ii. Asothar<br>iii. Malwan | 10 | 5290 | 5000 |
| | Fatehpur | i. Hathgaon | 5 | 2807 | 2500 |

| | | | | | |
|---|---|---|---|---|---|
| | Mirzapur | i. Pahari<br>ii. Madihan | 10 | 5540 | 5000 |
| | Sant Ravidas Nagar | i. Bhadohi<br>ii. Suriyawa | 10 | 5500 | 5000 |
| Gorakhpur | Deoria | i. Patthardeva<br>ii. Bhatpur<br>iii. Batahni<br>iv. Desai Deoria<br>v. Rampur Karkhana | 10 | 6022 | 5145 |
| | Kushinagar | i. Khada<br>ii. Hata | 10 | 5568 | 5147 |
| | Maharajganj | i. Nautanwa<br>ii. Maharajganj | 10 | 5579 | 5193 |
| | Siddharthnagar | i. Bardpur<br>ii. Ushka bazar | 10 | 5641 | 5027 |
| Faizabad | Gonda | i. Tarabganj<br>ii. Paraspur<br>iii. Haldharmau<br>iv. Katrabazar | 10 | 5407 | 5152 |
| | Balrampur | i. Balrampur<br>ii. Rehrabazar<br>iii. Utroula | 10 | 5554 | 5174 |
| | Bahraich | i. Chittapura<br>ii. Jarwal | 10 | 5285 | 5000 |
| | Sravasti | i. Harharpurrani<br>ii. Sirsiya | - | - | - |
| | Bahraich | i. Mihipurva<br>ii. Nawabganj | 10 | 5484 | 5075 |
| | Sravasti | i. Jamunaha<br>ii. Risiya | - | - | - |
| Jhansi (Matatila) | Lalitpur | i. Jakhaura | 10 | 5509 | 5121 |
| | Jalaun | i. Konch | 10 | 5268 | 5000 |
| Jhansi (NW) | Jalaun | i. Madhoganj<br>ii. Kuthouand | 10 | 5547 | 5000 |
| | Jalaun | i. Kadora<br>ii. Dakora | 10 | 5523 | 5093 |
| | Jalaun | i. Kadora | 10 | 5464 | 5000 |
| | Jhansi | i. Babina | 10 | 5488 | 5137 |
| | Jhansi | i. Moth | 10 | 5433 | 5024 |
| | Jhansi | i. Bangra<br>ii. Mauranipur | 10 | 5517 | 5082 |

| | | | | | |
|---|---|---|---|---|---|
| Mahoba | Mahoba | i. Jaitpur | 10 | 5475 | 5075 |
| | Mahoba | i. Charkhari<br>ii. Panwari | 10 | 5465 | 5110 |
| | Hamirpur | i. Gohand | 10 | 5190 | 5000 |
| | Hamirpur | i. Sarila<br>ii. Gohand | 10 | 5200 | 5000 |
| Banda | Banda | i. Nareni | 10 | 5234 | 5025 |
| | Chitrakut | i. Manikpur | 10 | 5251 | 5000 |
| | Chitrakut | i. Pahari | 10 | 4655 | 5000 |
| **Total** | | | **400** | **217674** | **202872** |

**Table 11.4: Physical and financial progress of National Watershed Development Programme (NWDP) under 8th and 9th five year plan**

| Duration of the scheme | Watershed No. | | | Geographical progress (ha) | | Financial progress (Rs. in lakhs) | |
|---|---|---|---|---|---|---|---|
| | Barani | Rainfed | Total | Target | Achievement | Target | Achievement |
| 8th Five Year Plan (1990-91 to 1996-97) | 187 | 12 | 199 | 303682 | 303682 | 10040.097 | 8802.44 |
| 9th Five Year Plan (1997-98 to 1999-2000) | 189 | 12 | 201 | 161306 | 170814 | 6500.000 | 6423.22 |
| Proposed Plan 2000-01 | 189 | 12 | 201 | 49000 | 265 | 2000.000 | 98.319 |
| **Total** | | | | **513988** | **474761** | **18540.097** | **15323.979** |

**Centrally sponsored flood prone Gomti and Sone river project**

Gomti river project was implemented under centrally funded river valley projects to reduce sufferings caused by river floods. In this project, integrated watershed programmes were carried out to arrest runoff water, reduce velocity of flow and reduce soil erosion and sedimentation in rivers and Nalas. Gomti basin is spread over 31.47 lakh ha which comprised 164 very high priority and 300 high priority watersheds. Gomti catchment extends in 16 districts of Uttar Pradesh and it was being operated by 14 soil conservation units in 12 districts. These districts were Lakhimpurkheri, Sitapur, Unnao, Lucknow, Barabanki, Hardoi, Gaziabad, Sultanpur, Pratapgarh, Jaunpur, Varanasi and Shah-Jahanpur.

Sone river project started in 1983-84 covers sub-watersheds of very high priority comprising of 1.98 lakhs ha.

The programme contained water and soil conservation, agroforestry, pasture development, horticulture, forstry, landuse, crop demonstration and farmers training. Silt was being monitored by silt monitoring posts (Table 11.5).

**Table 11.5: River valley project on Gomti and Sone: Physical and financial targets and achievements**

| Name of the project | Planning year | Physical progress (Lakh ha) | Financial progress (Rs. in lakhs) | Mode of plan |
|---|---|---|---|---|
| Flood prone Gomti project | 1980-81 to 84-85 | 0.464 | 586.10 | Annual plan |
| | 1985-86 to 89-90 | 0.791 | 1720.36 | |
| | 1990-91 to 91-92 | 0.343 | 849.77 | |
| | 1992-93 to 96-97 | 1.573 | 3424.13 | |
| | 1997-98 to 99-00 | 1.238 | 3627.52 | |
| **Total** | | **4.409** | **10207.88** | - |
| Flood prone Sone project | 1983-84 to 84-85 | 0.056 | 110.72 | Annual plan |
| | 1985-86 to 89-90 | 0.167 | 243.12 | |
| | 1990-91 to 91-92 | 0.052 | 182.26 | |
| | 1992-93 to 96-97 | 0.232 | 1128.36 | |
| | 1997-98 to 99-00 | 0.274 | 1387.85 | |
| **Total** | | **0.781** | **3052.31** | - |

## Centrally sponsored water conservation scheme for Usar land

In Uttar Pradesh 11.52 lakh ha was reported as Usar land (Anonymous, 2010). These Usar lands were under the occupancy of Gram Sabha, and were allotted to scheduled castes and scheduled tribes and landless for cultivation.

The Usar Sudhar Scheme had the following objectives:

1. Allotment of land to scheduled castes and landless and provide ownership.
2. Create opportunity of employment to agricultural labourers.
3. Increase productivity of the Usar land.

In the plains, 40 districts were infested with the problem of Usar lands. The Usar reclamation scheme was in operation in 38 districts. Prescribed works comprised of land development, drainage work, boring, installation of pump sets, land reclamation, green manuring *etc.*

## NABARD funded watershed management project for Bundelkhand

The scheme was sanctioned in 1989-99 to treat 60,790 ha land at a cost of Rs. 3586.53 lakhs. In the scheme, share of NABARD and UP Govt. were 90% & 10%, respectively. Work components included construction of peripheral bund, submergence bunds and water conservation works (Table 11.6).

**Table 11.6: Physical, financial targets and achievements of NABARD funded watershed management projects for Bundelkhand**

| Year | Physical (ha) | | Financial (Rs. in lakhs) | |
|---|---|---|---|---|
| | Target | Achievement | Target | Achievement |
| 1998-99 | 250 | 411 | 15.00 | 15.00 |
| 1999-2000 | 27390 | 30595 | 1615.42 | 1396.68 |
| **Total** | **27640** | **31006** | **1630.42** | **1411.68** |

**EEC funded ravine stabilization projects**

EEC funded ravine stabilization project was taken up in the districts of Firozabad, Kanpur, Jaluan, Hamirpur, Banda and Fatehpur of Uttar Pradesh. The scheme had the target to cover 22,025 ha in 5 years with a budgetary allocation of 4158 lakh. 80% of the fund was contributed by EEC and the rest 20 % by the Uttar Pradesh government. Land development was to be done by farmer. The project is promoting animal husbandary. Provision of Rs. 1800 $ha^{-1}$ as subsidy was given for cultivation of pulses.

**Tharu tribal sub-project**

This scheme started in 1982-83 in Balrampur district. In addition to Balrampur district Lakhimpur Kheeri, Shrawasti (Baharaich) and Maharajganj (Gorakhpur) are included. In the district of Bijnaur and Haridwar tharu tribals are less in number. However, due to lack of funds this scheme operated only in Balrampur district. Under this sub-project Rs. 188.5 lacs was spent to cover 4802 ha in the year 1999-2000. In the year 2000-01, 1000 ha was targeted with an outlay of Rs. 40 lakhs. The scheme aimed at providing employment to the tharu tribals and halting migration, soil and water conservation, enhancement in the productivity of the land. The scheme provided 100% funds on subsidy. Development works, therefore, carried out in the tharu tribal areas has produced 20-25% higher crop production and increased cropping intensity to 130-175%.

**Border area development project**

Scheme was launched to control the problem of soil and water conservation by vegetative measures and structural measures (Table 11.7).

**Table 11.7: Physical and financial target and achievements of border areas project**

| District | Soil conservation unit | Proposed scheme for 2000-01 | | |
|---|---|---|---|---|
| | | Development block | Area (ha) | Estimated amount (Rs. in lakhs) |
| Balrampur | Balrampur | 1. Tulsipur<br>2. Hariya Satdharwa<br>3. Gasdi<br>4. Pachpedwa | 376<br>360<br>355<br>324 | 10.46<br>10.36<br>10.12<br>10.23 |
| Lakhimpur-khiri | Lakhimpur-khiri | 1. Palia<br>2. Nidhasan | 290<br>297.5 | 10.00<br>10.00 |
| Bahraich | Nanpara | 1. Mihipurva<br>2. Nawabganj | 410<br>316 | 10.00<br>10.00 |
| Siddharth Nagar | Siddharth Nagar | 1. Wardpur | 495 | 12.00 |
| Maharajganj | Maharajganj | 1. Nautanwa<br>2. Nichlol | 304<br>300 | 10.14<br>11.26 |
| Shrawasti | Baharich<br><br>Nanpara | 1. Sirsiya<br>2. Hariharpurrani<br>3. Jamunaha | 410<br>457.05<br>342 | 10.05<br>10.04<br>10.00 |
| | | **Total** | **5036.55** | **144.66** |

**Employment oriented, sponsored projects under district rural development engineering schemes**

Under district rural development programme schemes such as 10 lakh well, Jawahar Rojgar Yojna, Vishesh Jawahar Rojgar Yojna, Sunishchit Rojgar Yojna were carried out. These schemes were implemented in soil conservation, usar reclamation and ravine reclamation to generate the required employment opportunity.

**Drought prone areas programme**

This scheme was being operated in 5 districts *viz.* Jhansi, Jalaun, Mahoba, Banda and Allahabad (Table 11.8 and 11.9).

Table 11.8: Employment oriented district level DRDA scheme operated for soil and water conservation in Uttar Pradesh

| Name of the project | 1997-98 | | | 1998-99 | | | 1999-2000 | | | 2000-01 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical progress (ha) | Financial progress (Rs. in lakhs) | | Physical progress (ha) | Financial progress (Rs in lakhs) | | Physical progress (ha) | Financial progress (Rs. in lakhs) | | Physical progress (ha) | | Financial progress (Rs. in lakhs) | |
| | Supply | Available | Expend. | Supply | Available | Expend. | Supply | Available | Expend. | Target | Achiev. | Avail. | Expendi. |
| Employment oriented projects (funded by DRDA) | | | | | | | | | | | | | |
| a. Ten Lakh Well Project | 44521 | 2393.25 | 1744.59 | 55464 | 2348.66 | 1728.38 | 17113 | 645.83 | 529.70 | 0 | 1425 | 0.00 | 23.48 |
| b. Jawahar Ropjgar Yojna | 5186 | 403.73 | 307.90 | 3241 | 155.91 | 125.09 | 1179 | 64.25 | 43.90 | 0 | 180 | 0.00 | 10.85 |
| c. Vishesh Jawahar Rojgar Yojna | 1873 | 70.25 | 67.39 | 360 | 2.66 | 1.61 | 437 | 25.05 | 23.80 | 0 | 0 | 0.00 | 0.00 |
| d. Sunishchit Rojgar Yojna | 62582 | 2924.04 | 1977.60 | 70638 | 2624.97 | 2181.29 | 27762 | 1000.00 | 783.70 | 85000 | 2112 | 3329.00 | 60.48 |
| **Total** | **114162** | **5791.27** | **4097.48** | **129703** | **5132.20** | **4036.37** | **46491** | **1736.13** | **1381.10** | **85000** | **3717** | **3329.00** | **94.81** |
| Integrated ravine reclamation project | 6852 | 458.10 | 301.58 | 4987 | 226.50 | 145.93 | 11500 | 416.92 | 391.84 | 14479 | 1063 | 1028.00 | 50.41 |
| Drought prone Regional Development Programme | 9980 | 503.28 | 401.95 | 6508 | 405.66 | 309.68 | 3476 | 225.26 | 243.84 | 2845 | 81 | 263.00 | 5.84 |

**Table 11.9: Soil conservation programme-Plains of Uttar Pradesh schemewise target and funding shares *etc.* (Physical progress in ha and financial progress in lakhs Rs)**

| Name of the scheme | No. of districts covered. | No. of working units | 1997-98 | | 1998-99 | | 1999-2000 | | 2000-01 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Physical | Financial | Physical | Financial | Physical | Financial | Physical* | Financial** |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Centrally aided Schemes** | | | | | | | | | | 98 |
| a. National Watershed Development | 32 | 40 | 20311 | 1151 | 69947 | 2983 | 80556 | 2289 | 265 | |
| Programme. | | | | | | | | | | 39 |
| b. Floodprone Gomati Scheme | 12 | 14 | 35930 | 1178 | 37301 | 1043 | 50573 | 1406 | 1105 | 15 |
| c. Floodprone Sone Scheme | 1 | 4 | 10124 | 523 | 9746 | 434 | 7526 | 431 | 0 | 2 |
| d. Centrally aided alkaline land development scheme | 14 | 14 | - | - | - | - | - | - | 24 | |
| **Total** | **59** | **72** | **66365** | **2852** | **116994** | **4460** | **138655** | **4126** | **1394** | **154** |
| **State Schemes** | | | | | | | | | | |
| a. Ambedkar Alkaline Land Development | 4 | 4 | 7988 | 1027 | 4108 | 750 | - | - | 0 | 0 |
| Scheme | | | | | | | | | 604 | 0 |
| b. Tharu Tribal Sub-scheme | 7 | 21 | - | - | 220 | 15 | 365 | 14 | - | - |
| c. NABARD Financed Ravine Development Scheme | - | - | 19610 | 1006 | 22590 | 1218 | - | - | - | - |
| d. NABARD supported Integrated Watershed Development Project, Bundelkhand | 6 | 6 | - | - | 411 | 15 | 30595 | 1397 | 0 | 0 |
| e. E.C. | 6 | 6 | - | - | - | - | - | - | 0 | 0 |
| f. U.P.D.F. | - | - | - | - | - | - | - | - | - | - |
| g. Border Area Scheme | - | - | - | - | - | - | - | - | - | - |
| **Total** | **23** | **37** | **27598** | **2033** | **27329** | **1998** | **30960** | **1411** | **604** | **-** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **DRDA Financed Schemes** | | - | | | | | | | | |
| a. Aggreegated Wasteland Develolpment Scheme. | 71 | | 6852 | 302 | 4987 | 146 | 11500 | 392 | 1063 | 50 |
| b. Droughtprone Regional Development Programme (D.P.A.P.) | 13 | - | 9980 | 402 | 6508 | 310 | 3476 | 244 | 81 | 6 |
| **Total** | **84** | **0** | **16832** | **704** | **11495** | **456** | **14976** | **636** | **1144** | **56** |
| **Employment Oriented Schemes (Financed by DRDA)** | | | | | | | | | | |
| a. 10 Lac Well Scheme | 71 | - | 44521 | 1745 | 55464 | 1728 | 17113 | 530 | 1425 | 24 |
| b. Jawahar Employment Scheme | - | - | 5186 | 308 | 3241 | 125 | 1179 | 44 | 180 | 11 |
| c. Special Jawahar Employment Scheme | - | - | 1873 | 67 | 360 | 2 | 437 | 24 | 0 | 0 |
| d. Guaranteed Employment Scheme | - | - | 62582 | 1978 | 70638 | 2181 | 27762 | 784 | 2112 | 60 |
| e. M.P./MLAs Fund | - | - | - | - | - | - | - | - | 0 | 0 |
| **Total** | **71** | - | **114162** | **4098** | **129703** | **4036** | **46491** | **1382** | **3717** | **95** |
| **Others** | - | - | - | - | - | - | - | - | - | - |
| **Soil Survey** | - | - | - | - | - | - | - | - | - | - |
| **Grand Total** | **237** | **109** | **224957** | **9687** | **285521** | **10950** | **231082** | **7555** | **6859** | **305** |

## Soil and water conservation in Bihar

After partition of the state, most of the areas suffering from soil erosion problems are now in the state of Jharkhand. The districts adjacent to Jharkhand have problems of soil erosion. The problem is getting severe during the drought year creating a clear cut contrast in hydrologic regime. The Northern part of Bihar is suffering from high flood because of sedimentation in the river coarse which causes overflow leading to occurrence of large area under inundation whereas Southern Bihar faces drought problem because of drying of river. Therefore, erosion is a cause of flood in Northern Bihar and drought in the Southern Bihar. Soil conservation work in the high rainfall area (1150 mm) comprises of silt detention dams and water harvesting for supplementary irrigation. The watershed management schemes largely NWDPRA have been carried out where people's participation was an essential component (Table 11.10).

**Table 11.10: Statement showing physical and financial achievements of soil conservation treatments in the state (plan use) of Bihar (area in 000 ha, financial Rs. in lakh)**

| Period | State sector | | Central sector | | Total | |
|---|---|---|---|---|---|---|
| | Physical (SCT+SDD+WHT) | Financial | Physical (SCT+SDD+WHT) | Financial | Physical (SCT+SDD+WHT) | Financial (in Lakh) |
| 1st five year plan 1951-56 | - | - | - | - | - | - |
| 2nd five year plan, 1956-61 | 30.99+0+0 | 34.48 | - | - | 30.995+0+0 | - |
| 3rd five year plan, 1961-66 | 75.695+127+0 | 98.53 | 12.468+17+0 | 15.90 | 88.163+214+0 | 34 |
| Annual plan, 1966-69 | 42.187+209+0 | 37.13 | 14.044+88+0 | 28.14 | 56.231+297+0 | 114.43 |
| 4th five year plan, 1969-74 | 77.270+2072+0 | 242.79 | 98.616+1558+0 | 276.86 | 175.886+3630+0 | 65.27 |
| 5th five year plan, 1974-78 | 79.616+1725+0 | 420.11 | 31.692+983+0 | 282.66 | 111.308+2708+0 | 519.65 |
| Rolling Plan, 1978-80 | 39.527+771+0 | 333.25 | 25.102+857+14 | 336.89 | 64.719+1628+14 | 702.5 |
| 6th five year plan, | 95.065+1671+15 | 1169.86 | 72.779+2218+297 | 1688.48 | 167.844+3889+312 | 670.14 |
| 7th five year plan, 1995-90 | 73.072+992+1118 | 1929.61 | 77.462+1270+1442 | 3019.26 | 150.534+2271+2565 | 2853.34 |
| Annual Plan, 1990-1992 | 17.312+126+277 | 554.00 | 15.251+452+313 | 972.87 | 32.563+578+590 | 4948.87 |
| 8th five year plan, 1992-97 | 3.101+61+124 | 261.08 | 12981+693+824+1801 | 1445.98 | 15.282+754+948 | 1526.87 |
| 9th five year plan, 1997-02 | 533.840+7824+1534 | 5080.84 | 359.685+8145 | 8117.04 | 893525+15969+4429 | 13197.88 |

SCT- Soil Conservation Treatments; SDD- Silt Detention Dams (Nos.), WHT- Water Harvesting Tank (Nos.)

The soil conservation and watershed management in Bihar mainly aims on creation of water resources, irrigation facilities and social welfare schemes under both the state and Central sector schemes (Table 11.11).

**Table 11.11: Scheme wise physical and financial achievements during the year 1958-59 to 2004-05**

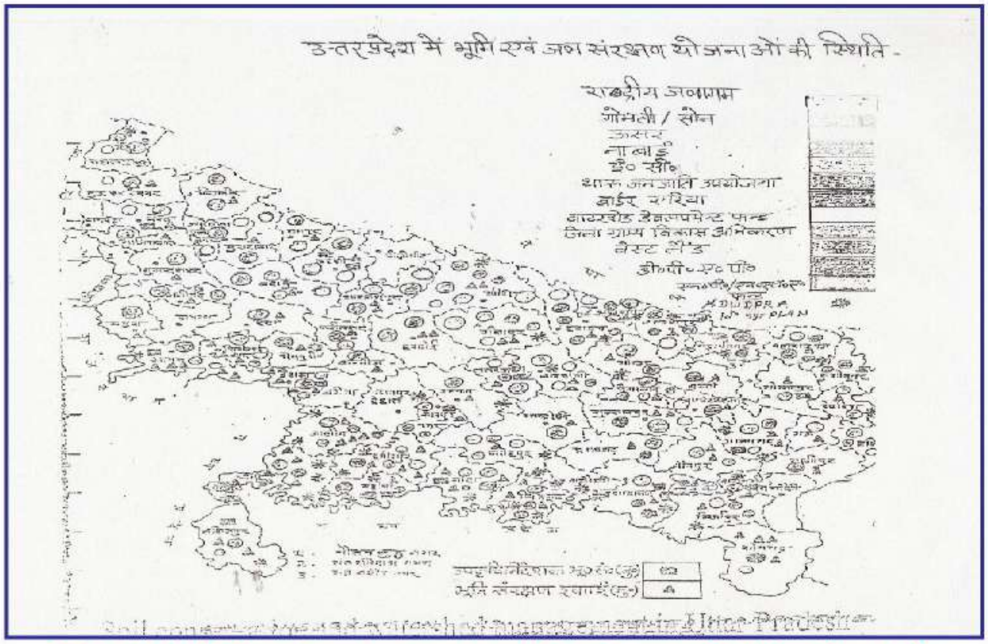
**(a) State scheme**

| Name of scheme | Physical achievement | | Financial (Rs. lakh) |
|---|---|---|---|
| | Treated area (ha) | Structure (in numbers) | |
| Rainfed and irrigation scheme | 431912 | 7181 | 3850.80 |
| Irrigation scheme | 25925 | 357 | 172.74 |
| Special central aided scheme | 49135 | 894 | 802.35 |
| Physical labour scheme | 8395 | 276 | 32.80 |
| Hard labour scheme | 2477 | - | 6.43 |
| Special planning scheme | 6200 | 538 | 43.78 |
| Advance aid scheme | 4475 | 9 | 40.00 |
| Tribal welfare scheme | 907 | 13 | 8.60 |
| Food for work scheme | 826 | 5 | 8.90 |
| Small and marginal farmers profitable scheme | 1593 | 48 | 39.99 |
| **Total** | **531845** | **9331** | **5006.39** |

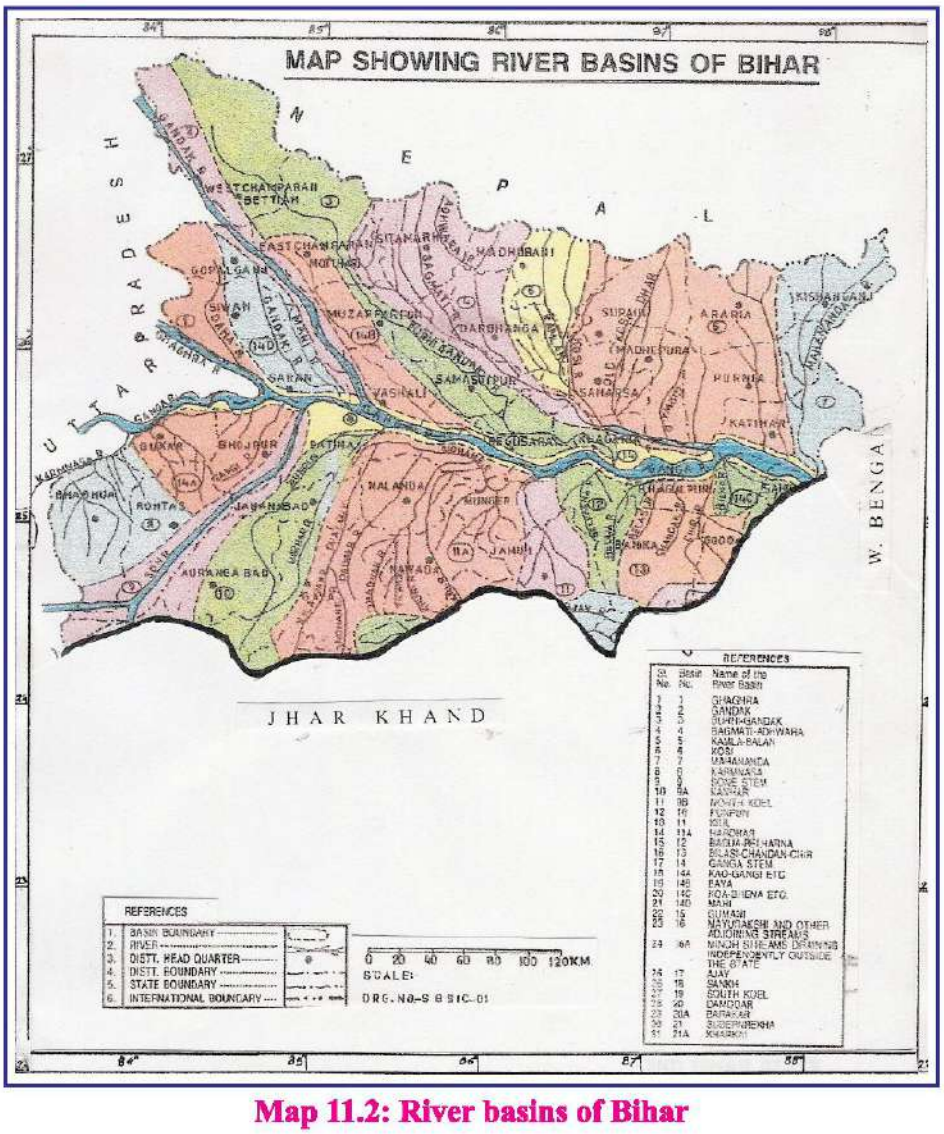
Source: Directorate of soil conservation, Patna, Bihar

**(b) Central government scheme**

| Name of scheme | Physical achievement | | Financial (Rs. lakh) |
|---|---|---|---|
| | Treated field | Untreated field | |
| Drought prone area scheme | 78325 | 5339 | 2165.37 |
| Rivervalley (mayurakshi, damodar & rangali mandira) | 127833 | 3357 | 2726.41 |
| Flood prone area scheme (sone ajay, punpun) | 52429 | 3825 | 2144.06 |
| Rural landless planning guarantee scheme | 28881 | 1777 | 1260.16 |
| Social forestry scheme | 3477 | - | 151.81 |
| Care scheme | 75934 | 1063 | 157.00 |
| National watershed development programme | 34684 | 13160 | 903.85 |
| State land use council | - | - | 31.19 |
| **Total** | **401563** | **28721** | **9539.84** |
| **Grand Total** | **933408** | **38052** | **14546.23** |




**Map 11.1: Soil and water conservation schemes in Uttar Pradesh**




**Map 11.2: River basins of Bihar**

# 12.0 CRITICAL ISSUES RELATED TO SOIL AND WATER CONSERVATION IN THE REGION WHICH NEEDS TO BE ADDRESSED THROUGH RESEARCH

There have been growing concerns over stagnant agricultural production and depleting and degrading its natural resource base soil and water. These concerns are equally valid for ravine regions in Uttar Pradesh and Bihar in the irrigated as well as rainfed areas. The critical concerns requiring immediate and long term planning for research in the region include:

- Though, large part of shallow ravines under the private ownership have been reclaimed by farmers, the medium and deep ravines continue to pose threat of further degradation and extension in to arable lands.
- Ravine lands also experience enhanced denudation threats due to very high biotic pressure of wild life and stray animals thus leading to their further degradation.
- Increased use of submersible water pumps for irrigation during past two decades has lead to alarming levels of drop in the ground water levels in the region.
- The ground water in many places in the region is not fit for irrigation and human consumption thus the instances of chemical degradation of soil are on the rise in the region.
- Change in rainfall pattern especially reduced number of rainy days in a year and increased incidences of high intensity rains during past decades have lead to higher runoff and low ground water recharge.
- The erratic monsoon behaviour has lead to enhanced threat of droughts in the region. High intensity of rainfall, permeability of soils and non-adoption of conservation measures result in excessive runoff from arable lands.
- Despite potential for rain water harvesting, not much emphasis has been given on developing infrastructure for water harvesting on either micro or macro level.
- The increased demographic pressure and fragmented land holdings have increased pressure on land thus leading to further degradation.
- The adoption of agroforestry and horticulture is very slow in this region thus enhancing the threat of crop failures in the face of changing monsoon patterns.
- Large parts of the rural areas in the region depend on fuel wood for cooking from the adjacent forest area. This along with unrestricted grazing has lead to degradation in the adjacent forest lands specially disappearance of several species of flora.
- Similarly use of cow dung cakes for cooking has lead to reduced supply of FYM for agriculture.
- Many times the back flow of Chambal River the major tributary of Yamuna River leads to floods in the villages of district Etawa and adjacent areas.
- The lack of crop diversification especially in Agra region has led to reduced land productivity due to nutrient imbalance in the soil.
- The river Yamuna has experienced reduced flow of water and increased load of pollutants during summers thus making irrigation with polluted water more hazardus.

# WAY FORWARD

The sandy loam soils of this region show excellent production potential with adequate land and water management techniques. Research centre Agra has evaluated land use options for arable and non arable lands and associated package of practices along with suitability of conservation measures and their design specification. This needs to be updated with rapidly changing socio-economic-ecological environment and market opportunities. The research priorities in immediate future shall be:

- Development of physical, chemical and biological indicators for assessment of land degradation and impact of conservation measures on soil health.
- Devising crop diversification strategies by identification of suitable cropping systems which involve crops that require least disturbance to the soil health and quality to produce more biomass for recycling in the Yamuna ravine region.
- Evaluation of conservation agriculture practices for resource conservation under rainfed conditions in Agra region.
- Finding ways for enhancing nutrient use efficiency through integrated use of organic manures and fertilizers for resource conservation and sustained productivity.
- The rain fed farming continues to be highly vulnerable to frequent droughts in this region. There is need to develop and further refine contingent crop plans to mitigate risk of crop failure especially in the backdrop of ever changing market opportunities and climate change scenario.
- Assess rainwater storage potential in the Yamuna ravine region in different terrain conditions and improve rain water use efficiency/water productivity through prolonged storage and multiple water use, especially in the light of climate change impacts.
- Development of appropriate cost effective user friendly rainwater harvesting, conveyance and application interventions under various rainfall scenarios in semiarid region.
- Upscaling of alternate lnduse system, agroforesty with proven fruit tree (ber, bel, amla, and guava) with suitable intercrops of the region.
- Upscale existing agro-forestry systems in degraded lands by conducting trials in Yamuna ravine areas in order to develop location specific technologies relevant to socio-economic scenario.
- Identify suitable fruits, trees and grasses to address the issues of climate change impacts and sustained productivity.
- Development of hi-tech nurseries based on advanced techniques for production of quality planting materials of plant species having high soil conservation value in Yamuna ravine region.
- Study the below ground root biomass for tree-crop interaction and its impact on resource conservation for developing sustainable tree based production systems.
- Improving soil carbon sequestration through identification and evaluation of potential systems for carbon sequestration through best management practices under different land uses and conservation agriculture.
- Identification and application of different C models for assessment of carbon sequestration potential of resource conservation practices.
- Optimal land use planning by employing multi-period and multi-objective dynamic programming techniques covering backward

and forward market linkages.

- Capacity building of various stakeholders through establishment of Skill Development Centre- A Centre of Excellence in the Soil and Water Conservation and Watershed Management for professional training, disseminating and refining NRM technologies at the regional level.
- Assessing impact of irrigation with Yamuna water on quality and productivity of crop.
- Socio-economic and environmental impact assessment of NRM technologies in ravine region.

The long term research priorities may include:

- The present information on the extent of gully erosion is based on the survey carried out by State Forest Department in 1969. This needs to be updated in view of extensive rehabilitation works carried out under River Valley Projects.
- Yield gap analysis between current production levels and potential productivity of major crop and animal/fish based production systems on watershed scale from the watersheds representing major land form, soil characteristic and climatological situations of central Uttar Pradesh.
- Diagnosis of critical elements responsible for yield gaps and develops effective strategies to deal with them.
- Alternate strategies need to be evaluated in close association with farmers for runoff management to maximize crop production under rain fed farming situations.
- Structural designs of mechanical structures need further refinement
- There is need to develop and refine resource conservation technologies targeting at least 20% growth in overall potential productivity of major production systems on watershed basis.
- Off-site effect of erosion at different spatial scales needs to be assessed.
- Availability of surface and groundwater is diminishing at an alarming rate in rain fed areas. There is an urgent need for accurate assessment of water budget components of different land use options and develop strategies for enhancing water use efficiency of prevailing agricultural production systems.
- Analysis of hydro-meteorological data is important for erecting varying types of conservation measures as well as for crop planning. This aspect has been well looked after by the Centre in various studies. In view of the advancement in the field of crop-weather modeling and erosion prediction modeling the hydrometeorological data needs to be re-examined for identifying threshold limits of important parameters for crop planning and deter-mining design specifications for conservation measures.
- Over exploitation of groundwater resources for crop production facilitated by liberal credit facilities has lead to severe decline in groundwater table in the region. Simple strategies for improving the groundwater recharge involving management of rain water through *in-situ* water conservation practices and water harvesting structures need to be developed. Groundwater recharge under different land management options and water harvesting structures need to be quantified.
- The Centre has studied the catchment and capacity relationship for water harvesting pond using gentle sloping arable lands to stabilize production under rain fed farming and identified efficient crops for supplemental irrigation. However, similar information needs to be generated for marginal lands involving agriculture land uses and mildly sloping lands involving horticultural lands uses.
- The centre has generated sufficient information on surface hydrology of small watersheds; however, research on sub-surface hydrology for evolving strategy of ground water recharge and management is yet to be attempted.

- Imbalanced inputs and excessive biotic pressure have resulted in deterioration of soil quality which is a serious concern for sustainable growth of agricultural production systems of this region. Soil organic matter has been identified as a key bio-chemical indicator for assessment of land use impact on soil quality. Long term C-budget studies under different land use and land management options are needed to develop sustainable and healthy land management practices.
- The longer gestation period of tree plantations limits the adaptability of these by farmers. Refinement of technologies aimed at reducing the gestation period e.g. improvement of planting stock for better stress resistance and developing planting techniques for improved resource utilization etc. need to be researched upon.
- The medium and deep ravines are scarcely cultivable due to steep slopes and are characterized by the presence of scanty vegetation. As the soil depth is not a limiting factor, these lands have potential for productive utilization with the adoption of horticulture, horti-pasture, cultivation of medicinal and aromatic plants and silvi-pastoral systems. Several species of trees, shrubs and grasses have been identified for the restoration of ravines as well as for realizing the production potential of these lands by this centre.
- Stress tolerant fruit species and medicinal plants shall be evaluated for different type of degraded lands. Further, studies on use of bio fertilizers for improved establishment as well as improved production under different agroforestry systems need to be conducted.
- Integrated resource management opportunities need to be explored. For example horti-silvipastoral can be integrated with fisheries and dairying in ravinous wastelands.
- To evaluate and improvise the current capacity building and community development activities to ensure effective people's participation and self-sustenance of these activities during post project period.
- The various demonstration projects conducted by the centre offer ample opportunities of research on identifying constraints and possible refinements with respects to various components of project implementation guidelines. Efforts need to be focused on refining and developing methodologies and appropriate decision support systems for effective people's participation and synergistic integration of on-farm and off-farm livelihood activities.
- Constraint analysis for lack of adoption of conservation technologies and develop strategies to overcome these constraints. Studies for developing communications strategies for improved adoption of resource conservation technologies.
- A framework and strategy for improving the liaison between research institutes and state line departments.
- Identification of ITKs in soil and water conservation practices and their refinement
- Restructuring of training programmes in soil and water conservation and watershed management to meet the changing requirements of the clientele.

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