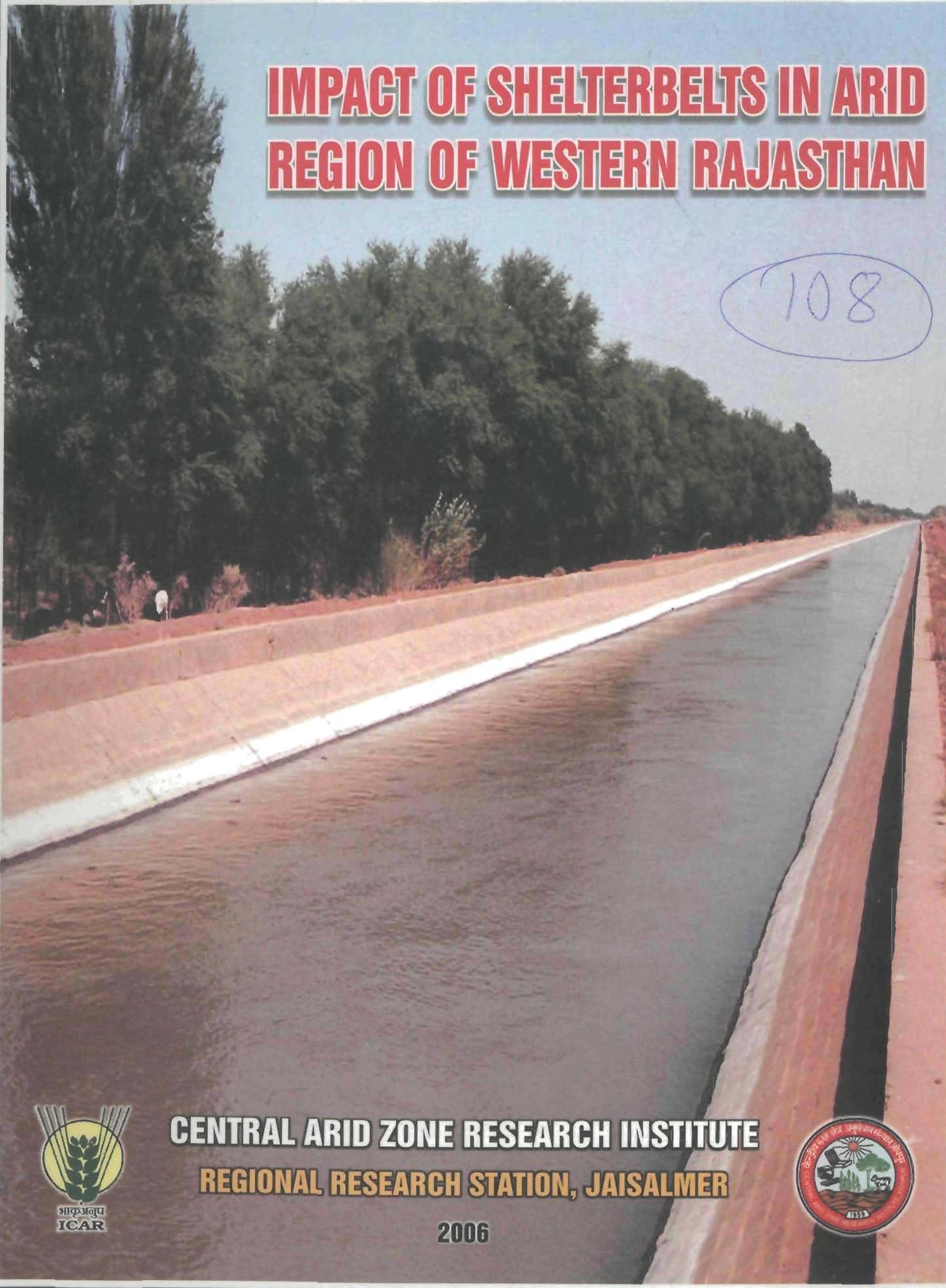
IMPACT OF SHELTERBELTS IN ARID REGION OF WESTERN RAJASTHAN



CENTRAL ARID ZONE RESEARCH INSTITUTE

REGIONAL RESEARCH STATION, JAISALMER

2006

भाकृअनुप
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R.S. MERTIA
RAJENDRA PRASAD
B.L. GAJJA
J.S. SAMRA
PRATAP NARAIN

भाकृअनुप
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Director
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Foreword

The arid regions are usually characterized by inhospitable climatic conditions like scanty and erratic rainfall, extreme temperatures, strong winds, recurrent droughts and sparse vegetation. In our country, the major part of 32 million hectares of hot arid region lies in western Rajasthan, north-eastern Gujarat and adjoining states of Haryana and Punjab. The soils here are predominantly loose sandy and, therefore, highly prone to wind erosion. The frequent movement of sand poses threat to agricultural land, transport and communication links, water bodies and even settlements.

To minimize the harmful effects of strong winds on soils, shelterbelts or vegetative barriers consisting of strips of multiple rows of trees, shrubs and bushes are planted across the prevailing winds. These shelterbelts have been successfully raised on a large scale along roads. railways, open canals, around orchards and field boundaries in the desert areas to reduce movement of sand caused by strong winds. These shelterbelts also improve micro-environment and supplement fuel, fodder and timber resources in the region.

A much-needed study on impact of shelterbelts in the Indian desert has been conducted and the findings are presented in this publication entitled "**Impact of Shelterbelts in Arid Region of Western Rajasthan**" for which the authors deserve appreciation. It is hoped that the information contained in this booklet will be of immense help to planners, forest officials, agricultural development agencies, professionals, environmentalists and farmers for adopting the shelterbelts technology and help in the process of development in arid areas.

(MANGALA RAI)
Secretary, Department of Agricultural Research & Education
and
Director General, Indian Council of Agricultural Research
Dr. Rajendra Prasad Road, Krishi Bhawan, New Delhi 110001, India

December 13, 2006

Preface

Wind erosion and moving sand dunes have been a serious menace in hyper arid and arid agro ecologies of western Rajasthan, northeastern Gujarat and parts of Haryana. Most of sand dunes of Punjab have been leveled after introduction of irrigation. Moving sand affects infrastructure, roads, rails, water bodies, canals, crops and impairs environment. Establishment of CAZRI was conceived to combat desertification and arrest movement of sand/deserts to eastern Rajasthan, Delhi and Uttar Pradesh. Porous shelterbelts or vegetative barriers comprising of strips of trees, shrubs and bushes are planted across the prevailing wind direction. These barriers are first line defence against wind erosion, breakage of branches and shedding of fruits, hot and cold waves and moderate climate as well.

The study was conceived to see impact of shelterbelts in hyper arid areas of Jaisalmer in Rajasthan. The impact of these vegetative barriers was spectacular in preventing choking of canal, minimizing sand deposits on roads, rails, infrastructure and improving crop yields on leeward side. The shelterbelts checked desiccation of crops, improved soil moisture regime, nutrient levels, which ultimately improved productivity. They also moderated adverse effects of cold and heat waves. These belts also provided much needed fuel, fodder and shelter in the arid region. The saving in preventing siltation of canal and maintaining road and rail traffic to exchequer is an eye opener.

It is hoped that forest department, development department, farmers and NGOs take up the adoption of versatile shelterbelt technology on large scale. The purpose of this effort will be fully met if desert people are helped by this publication.

The help extended by Drs. R.N. Kumawat, S.S. Mahajan and B.K. Kandpal is thankfully acknowledged. Thanks are also due to Shri Rajendra Parihar, Daleep Singh Mertia and Chandra Prakash Prajapati for assistance in collection of field data.

We thankfully acknowledge Drs. Amal Kar, A.S. Rao and Balak Ram for generous help.

R.S. Mertia
Rajendra Prasad
B.L. Gajja
J.S. Samra
Pratap Narain

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Executive Summary

The hot arid region of India, covering an area of about 32.7 million ha, is spread in states of Rajasthan (61.9%), Gujarat (19.6%), Haryana and Punjab (8.65), Andhra Pradesh (6.8%), Karnataka 2.7% and Maharashtra (0.4%). Low and erratic rainfall, extreme temperatures, strong wind velocity, low humidity and frequent droughts characterize the hot arid ecosystem with low productivity associated with short length of growing period (less than 60 days) particularly in hyper arid region. The area represents aridisol soil having scarce moisture and hyper thermic soil temperature regimes. The productivity remains restricted due to un-conducive environment, limited choice of crops and aberrant weather conditions. High biotic pressure, deforestation, overgrazing and strong winds are the prime forces of soil erosion, land degradation and desertification. Clear sweep of strong winds across sandy desert is the great hindrance in sustenance of infrastructure, transport system and progress of agricultural activities. The strong blowing winds on one hand take away top fertile soil thus causing irreparable loss to soil productivity, on the other hand deposition of airborne soil particles (sand, silt and clay) block the roads, railways, water bodies, open canals and burry agricultural fields as well.

Shelterbelt plantations, which are vegetative barriers of trees/shrubs/bushes, are used as protective measures to minimize risk and adverse effects of winds particularly in hot arid region. These are designed to reduce wind velocity, soil erosion, provide protection to roads, railways, water bodies, canals etc. and create favorable environment for cropping, horticulture and livestock by moderation of climate. Besides, shelterbelts are also viewed as means to fulfill objectives of social forestry in supplementing local demands of fuel, fodder, timber and shelter.

The present report, based on the findings of a study conducted in the tube well and IGNP canal commands of Lathi and Mohangarh series, respectively in Jaisalmer district of western Rajasthan, embodies various impact of shelterbelt technology in extremely hot arid eco-system. The study revealed that by and large shelterbelt plantations have proved their usefulness in meeting out the twin objectives of reducing hazards of high speed wind and supplementing social needs of fuel, fodder and timber. Besides, these barrier also moderate extremities of climate like cold (frost) and heat waves.

The shelterbelts have been found quite effective in reducing effects of weather extremities viz. cold and heat waves common in arid region. The average losses in crop productivity with shelterbelts was 17% due to cold wave in comparison to 30% on farms without shelterbelts. Similarly, shelterbelt reduced losses of crops affected by heat waves to the extent of 12 to 16% in summer and *kharif* season as compared to

30.5% losses incurred in crops grown without shelterbelts. Among woody plants, *P. cineraria*, *T. undulata*, *Acacia senegal*, *Salvadora oleoides* and *Acacia leucophloea* (Roonj) were found tolerant to extreme cold (frost) and hence, more suitable for shelterbelts or agroforestry in arid region.

Shelterbelts had varied effects in reducing wind velocity and providing shelter on leeward side depending on plant species, structure, height, length and density. Maximum reduction in wind speed was noticed at 2 H, which levelled off up to 20H in decreasing order. The effective sheltered area provided by well grown singe-row and double-row shelterbelt was 20 H and 15 H respectively, in leeward side. Shelterbelt having length of 10-12 times of its height had minimum turbulence effect. Shelterbelts planted along either side of the IGNP main canal and its distributaries have reduced deposition of drifting sand considerably, thus saving millions of rupees, which otherwise used to be spent on de-silting of canals annually to restore smooth flow of water. Similarly, deposition of sand on roads and railways has also been minimized in areas where road/railway side shelterbelts have been planted for protection thus saving huge expenditure on exchequer for keeping transport clear.

Works on shelterbelt plantations have generated employment of about 2.4 million-man days. Labour requirement of farms with shelterbelts has increased by 202% in comparison to those farms which do not have shelterbelts. Out of the total change in labour requirement of farm with shelterbelt, about 76% was due to shelterbelt plantations alone and remaining contributed by other inputs. Due to additional income generated by shelterbelt plantations, the economic status and life style of people has changed. Besides creating assets in the form of pucca houses, vehicles, farm machinery, TV, telephone and other electronic gadgets, the people have started sending their children for higher education in distant places.

Owing to improved micro-climatic conditions and soil quality in sheltered area on leeward side, the productivity of crops has increased. In general, shelterbelts have helped in improving overall economy of those farmers who have adopted these judiciously. If the entire irrigated area under tube well and canal command was covered with shelterbelts, the additional income from crops and trees could have been generated around Rs. 71342 millions in last 15 years at current price. The livestock migration could also be reduced which would have saved millions of rupees spent annually by the state government. In spite of low area covered with shelterbelt plantations, the economic losses, which are estimated for non shelterbelt farms, accounts for Rs. 1142 millions. This fact proves the hypothesis that shelterbelt plantations provide cheapest and long term option against ill effects of high speed winds in hot arid region.

Considering value of shelterbelt in arid region, incentive based policy interventions are required to popularize shelterbelt plantations for alleviating adverse impact of strong winds on crops, transport, canal systems and ecosystem as a whole. This has to be integrated with on going Government programmes like horticulture mission with effective peoples' participation to sustain livelihood and healthy environment.

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1. Introduction

The wind erosion accounts for 13.00 mha land in India, out of which 10.75 mha (82.69%)is in hot western Rajasthan. Wind erosion is the major problem faced in arid western Rajasthan particularly in hyper arid zone of Jaisalmer (Narain et al, 2000) (Fig. 1). It is more pronounced in summer months when strong winds associated with the southwest monsoon sweep across the region. The sand and dust raising winds start blowing from March onwards and continues unabated till the monsoon rain arrives usually by middle of July. Some times in drought years the strong wind continues till August and September. During this period the terrain is absolutely dry and a significant proportion of natural vegetation especially the annuals, are dead. The crop fields also remain nearly barren in absence of any crop. During May and June the wind strength increase manifold and sand storm activities also increases. On arrival of rain the soil gets moistened and there is cohesion between particles offering resistance to the wind erosion. The young plants, which sprout after rains further bind the soil and add to the resistance to the erosive winds. Wind erosion ranks number one in the list of factors responsible for deteriorating land quality and water resources in hot arid region (Fig. 2). It also causes environmental pollution and health hazard to animal and human life. Clear sweep of strong wind across sandy plains of desert region negate production, sustenance and progress of agricultural activities. Strong blowing wind has double edge effects on degradation of land, water and other natural resources.

To minimize erosion hazards of speedy winds and optimize production of agricultural crops, various efforts have been made in the past by adopting different soil conservation measures. Among them the shelterbelt plantations rank high due to its expected effects on reduction in wind velocity. Shelterbelts are the vegetative barriers that are designed to reduce wind speed and provide sheltered area on leeward side. They can decrease wind speed to a level below the threshold value required for lifting and movement of soil particles and hence, are expected to reduce impact of strong wind. The reduction in wind velocity leads to reduction in soil loss, deposition of sand on road, canal and other water bodies. The work on shelterbelt was started way back in 1950s including design of shelterbelt, screening of suitable species for its composition and develop techniques for plantation establishment. Major work on designing of shelterbelt has been carried out in United States of America, Mongolia and PR China.

Protection of roads and railways through side-belt plantations has always been done to reduce the wind effects and provide shelter. The state forest department of Rajasthan has undertaken roadside planting in eleven districts of Western Rajasthan. In Jaisalmer district alone over 2100 ha area has been covered under roadside plantation during last fourty years (Table 1). To check engulfing of railway line from blown sand in part of Bikaner, Sikar, Churu, Jaisalmer, Barmer and Jodhpur districts, a program on railway line plantations was initiated in 1980s. In beginning a section of 100 km along Sikar-Loharu, Sikar-

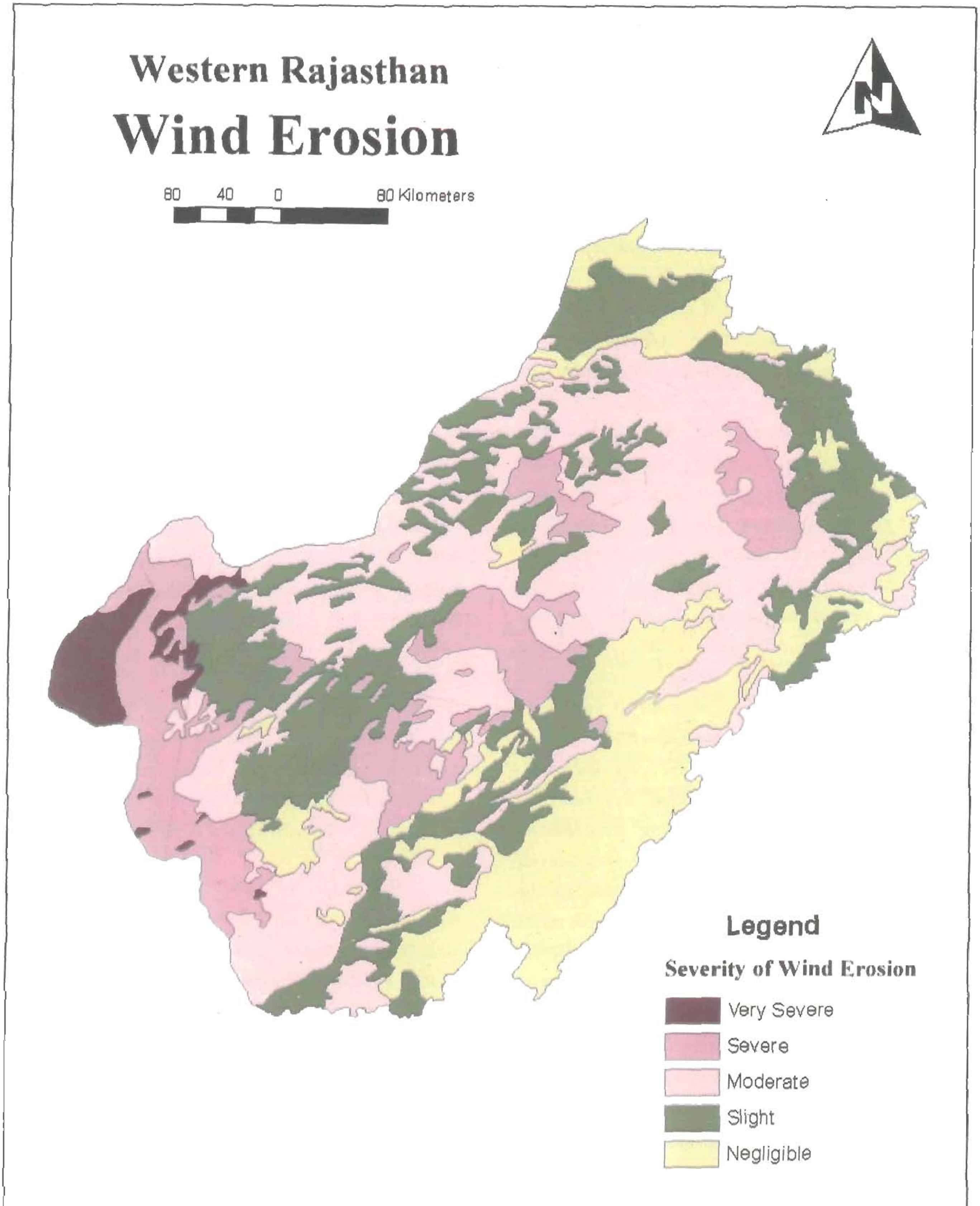

Fig. 1. Wind erosion map of Western Rajasthan

Fatehpur and Palsana-Deshnoke lines was planted with a six row shelterbelt using *Parkinsonia aculeata, Prosopis juliflora* and *Tamarix articulata* (Mann and Muthana, 1984).

With the advent of IGNP in Western Rajasthan, massive shelterbelt plantation work was undertaken to check silting of canal through wind blown sand (Table 2).

Table1. Detail of roadside plantations in Jaisalmer

Time period	Number of sites	Area covered (Running Kilometers)	Total area (ha)
1960-70	5	38	16
1970-80	7	115	56
1980-90	33	1128	564
1990-2000	51	742	1484
Total	96	2023	2120

Table 2. Detail of canal side plantations in Jaisalmer

Year	Number of sites	Area covered	
		(Running kilometers)	(ha)
1991-92	14	1056	352
1992-93	35	2679	893
1993-94	61	3954	1318
1994-95	65	3744	1248
1995-96	60	3714	1238
1996-97	64	4680	1560
1997-98	102	7986	2662
Total	401	27813	9271

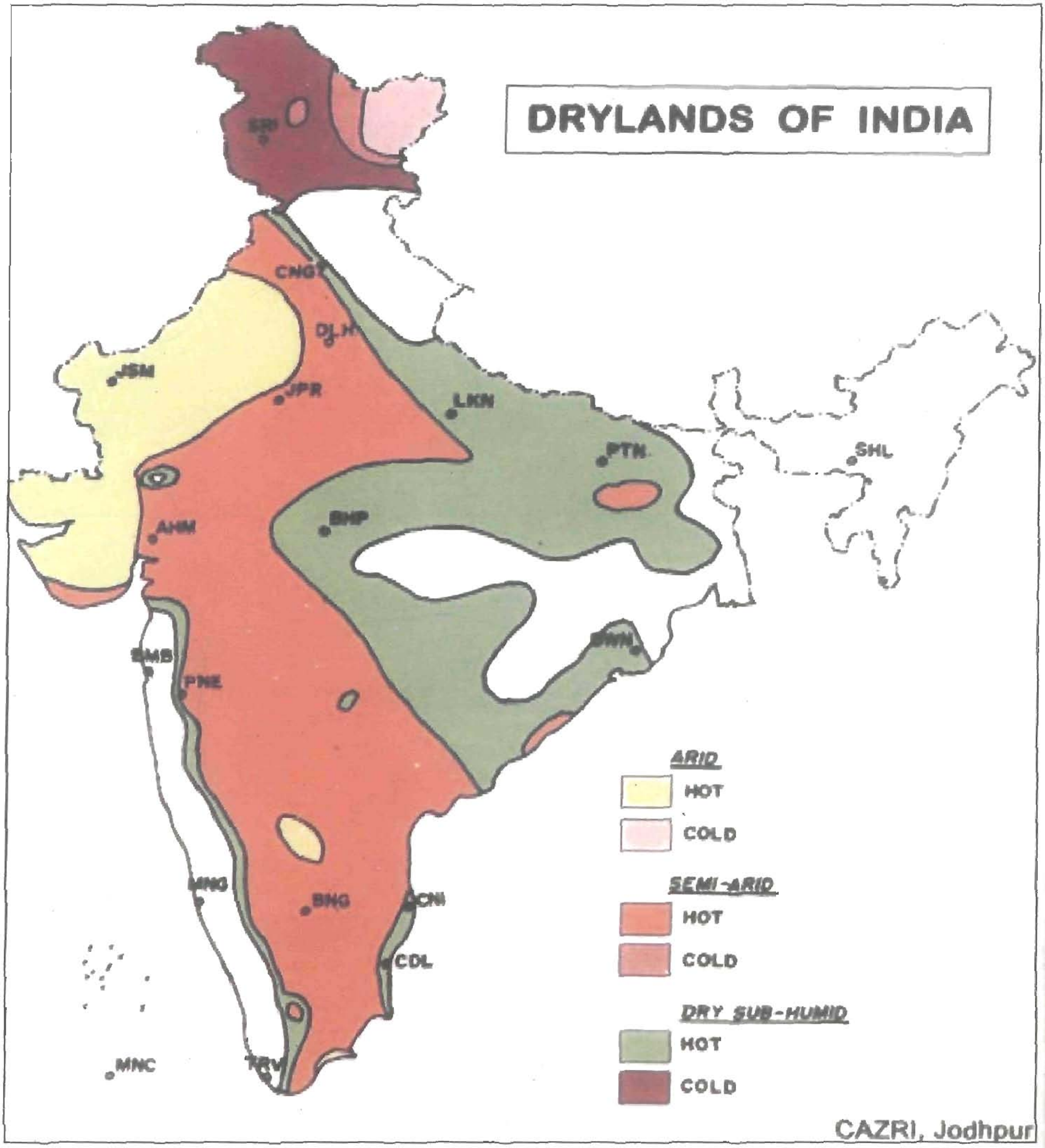

Fig. 2. Map showing dry lands of India

With the passage of time the protective forestry has transformed into productive forestry and accordingly, planting geometry and choice of species have changed. Earlier the protective forestry mainly comprised of shelterbelt plantations for conservation of soil and water, anchoring sand dunes, reducing wind and providing shelter to crops and cattle from wind and scorching heat. However, in productive forestry the objective of producing fodder (top feed), fuel and small timber was also coupled with protective forestry. Thus, shelterbelt plantations were also expected to meet demand of fuel and fodder thereby reducing biotic pressure on existing vegetation/forest/grassland of desert region. Thus shelterbelts would not only hold the processes of degradation of natural resources but will also help in sustainable development of arid ecosystem through microclimate moderation for higher crop production under irrigated farming.

In past 50 years, volume of data has been generated on design, composition, suitable tree species, planting technique etc. for shelterbelts (Mertia, 1986). Although, some patchy information is also available for accounting effects of shelterbelts on wind speed, soil loss, crop yield, microclimatic environment etc. but, no systematic information on impact achieved at the field level is available for which the shelterbelt were conceived, designed and planted in arid ecosystem. The present study is an effort in that direction and to quantify to what extent shelterbelts could fulfill twin objectives of reducing wind erosion, degradation of natural resources (land/water) and sustainable management of arid ecosystem.

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2. Study Area and Environmental Settings

2.1 STUDY AREA

The study has been conducted on selected farms in two situations namely; tube well irrigated areas in Lathi series and IGNP command phase II in Mohangarh of Jaisalmer district of western Rajasthan.

Tube well command area in Lathi series

Lathi series lies in *Lathi sandstone* hydrological formation of the Jaisalmer district, which is the most productive and promising groundwater aquifer due to high permeability and transmissivity as evidenced by drilling of thousands of tube wells in Lathi series in last two decades. With the development of irrigation facilities, agricultural scenario of area has changed. The farmers have started cultivating high value crops like groundnut, mustard, fruit trees and to protect these from hazardous effect of speedy winds planted shelterbelts on their farms.

IGNP command phase II area in Mohangarh

Once full of sprawling pasture of Sewan grass *(Lasiurus sindicus)*, the Mohangarh is now covered under the command area of IGNP phase II at the tail end of main canal (Mertia 1992a, Mertia et al, 2006). The idea of Indira Gandhi Nahar Pariyojana (IGNP) was conceived to enhance agricultural production through irrigation. The project was sanctioned in 1957 after Rajasthan got allotted 8 million-acre feet (MAF) out of 15.85 MAF surplus Ravi-Beas water in January 1955. The IGNP envisages use of 7.59 MAF. Later, according to inter-state decision of December 1981, Rajasthan was allotted 8.6 MAF water. The IGNP is the largest canal systems of the world. The canal system starts at the Harika barrage in Punjab at the confluence of the Sutlej and Beas rivers in the foothills of the Himalayas. The main canal, which traverses through the districts of Ganganagar, Bikaner and Jaisalmer, has a total length of 445km with a feeder canal (called Rajasthan feeder canal) of 204km length. The feeder canal does not irrigate any land on the way with its first 150kms length in Punjab and 19km in Haryana. The feeder canal releases about 523.93 cumecs of water to the main canal of IGNP at the Masitawali Head (0RD). The main canal is 40.8 m wide at the bottom and 6.4m deep. The discharge at head of main canal is 18,500 cusecs. The first water from the canal was released on 11 October 1961.

The IGNP canal system is divided into two stages (Fig. 3). The stage I covers northeastern parts (From Harika barrage to Pungal in Bikaner) and stage II covers southwestern parts (from Pungal to Mohangarh in Jaisalmer) region. The total cultivable command area on completion of the entire project is expected to be 14.78 lac ha (Table 3).

The work of stage I has been completed. The work of main canal of stage II (from Pungal in Bikaner to Mohangarh in Jaisalmer) was completed in the year 1986.

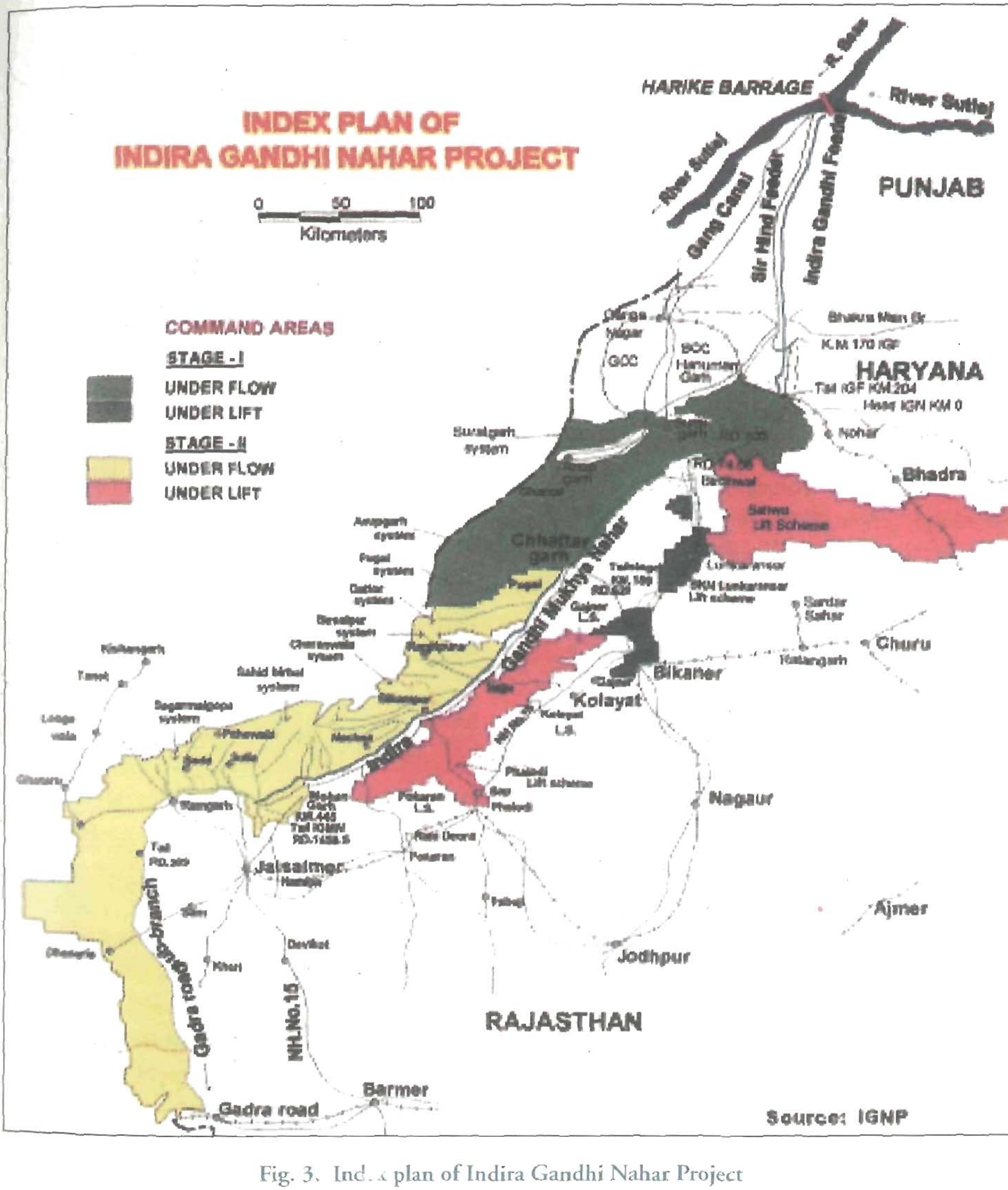

Fig. 3. Index plan of Indira Gandhi Nahar Project

Table 3. Salient features of Indira Gandhi Nahar Pariyojana (IGNP)

Salient features	Unit	Stage I	Stage II	Total
Length of main canal	km	393	256	649
Length of distribution system	km	3454	5606	8190
Cultivable command area	Lac ha	5.53	9.25	14.78
Irrigation potential on full development	Lac ha	5.53	14.10	19.63
Water requirement	M cu m	4428.6	4934	9362.26
Cropping intensity	Per cent	110	80	-

Source : Chief Engineer, IGNP, Jaisalmer.

The completion of full project of IGNP system is likely to be achieved by the year 2009-10. Since its inception till March 2005, a total of Rs. 28019 million have been spent on IGNP project (Table 4) and on full completion, the project expenditures are estimated about Rs. 29000 million. The canal project has become lifeline of Rajasthan's economy. On development of its full irrigation potential, the project is likely to irrigate 14.78 mha and contribute 34 lac tones of food grain, 3 lac tones of cash crops and 60 lac tones of fodder production annually, which may offset total expenditure incurred on the entire project (AFRI, 1994).

Silting of canal, distributaries and irrigation channels is a common phenomena caused by deposition of wind blown sand. From the beginning of constructions of Indira Gandhi canal and its distributaries, it faced an alarming danger from blowing and drifting of sand causing massive siltation which, adversely affected flow of water in the canal (Plate 1). The area on both sides of main canal and its branches are widely open with out any vegetation. Sand dune stabilization, pasture development and shelterbelt plantations on massive scale were considered only options to get rid of silting problem in canal. Keeping this in mind, massive drive for afforestation of shelterbelt plantations along canal and other areas was under - taken .

Plate 1. Wind blown sand engulfing IGNP main canal near Mohangarh

2.2 ENVIRONMENTAL SETTINGS

The arid zone covers 12 per cent of the total geographical area of the India and spread over Rajasthan, Gujarat, Punjab, Haryana, Andhra Pradesh Karnataka and Maharashtra (Table 5). The Rajasthan alone accounts for about 62 per cent of

Table 4. Plan wise expenditure on IGNP Canal (Rs. in million)

Plan	1st Phase	2nd Phase	Total
1st 1951-56	0.3	-	0.3
2nd 1956-61	134.7	-	134.7
3rd 1961-66	329.4	-	329.4
Annual plans (66-67+67-68+68-69)	167.3	-	167.3
4th 1969-64	424.1	53.4	477.5
5th 1974-79	833.1	391.9	1225
Mid term plan 1979-80	82.1	166.4	248.5
6th 1980-85	294.1	1592.6	1886.7
7th 1985-1990	374.1	2354.1	2728.2
Annual plans (90-91+91-92)	132.6	1357.9	1490.5
8th 1992-97	524	6409.8	6933.8
9th 1997-02	559.4	7014.6	7574
10th 2002-07(up to2004-05)	273.3	4549.8	4823.1
Total	4128.5	23890.5	28019

Source : Chief Engineer, IGNP, Jaisalmer.

Table 5. State wise distribution of hot arid land in India

State	Area (km^2)	Percentage
Rajasthan	196150	61.9
Gujarat	62180	19.6
Punjab & Haryana	27350	8.60
Andhra Pradesh	21550	6..80
Karnataka	8570	2.70
Maharashtra	1290	0.40
Total	317090	100.00

the total arid area of the country spread over 12 districts namely Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer, Jalore, Jhunjhunu, Jodhpur, Nagaur, Pali and Sikar in western Rajasthan (Table 6). The hot arid region of western Rajasthan, a part of Thar desert, is highly prone to wind erosion due to its fragile ecosystem resulted from continued effect of various natural processes such as low and erratic rainfall, intense heat, high evaporation, low relative humidity, poor edaphic conditions, high biotic pressure and high wind speed etc.

The Jaisalmer is located between 26° 01"-28° 02" N and 69° 29"-72° 20" E with an elevation of 242m MSL. It occupies 18% of about 20 million ha arid area of arid western Rajasthan (Table 6). Jaisalmer has been categorized as hyper arid region with mean moisture index of -90.7, with highly erratic rainfall spread over 6 to 12 rainy days generally occurring in the month of August. Generally, the monsoon sets in during 1st week of July and recedes by the end of August or 1st week of September. The annual precipitation far exceeds evaporation (2069mm). The relative humidity ranges from 5 to 93% (Chatterji and Kar, 1992). The mean climatic data for Jaisalmer are given in Table 7.

May and June are the hottest months with the mean maximum temperature of 42°C. In some individual years the average may cross 45°C due to severe heat waves. Some time the mercury sores up to 47°C. Similarly, during winter the average minimum temperature falls below freezing point under the influence of severe cold wave which causes frost damage. Strong wind regime prevails from March to September with strong dusty winds during May, June and July. The maximum daily wind velocity in the area frequently reaches 30-45 kmph during June and July with peak wind speed up to 100 kmph during severe dust storm period.

Table 6. District-wise area of arid districts of western Rajasthan

District	Area (km^2)	Percentage
Barmer	28387	13.59
Bikaner	27244	13.05
Churu	16830	8.06
Ganganagar	10931	5.24
Hanumangarh	9703	4.65
Jaisalmer	38401	18.40
Jalore	10640	5.10
Jhunjhunu	5928	2.84
Jodhpur	22850	10.95
Nagaur	17718	8.49
Pali	12387	5.93
Sikar	7732	3.70
Total	208751	100.00

Table 7. Mean monthly climatic data of Jaisalmer (Mean of 25 years from 1981-2005)

Months	Temperature (°C)		Wind speed (kmph)	Rainfall (mm)
	Max	Min		
January	24.0	6.7	4.90	13.9
February	27.4	10.2	5.87	2.4
March	33.1	15.9	7.20	1.4
April	39.5	21.5	9.05	3.4
May	42.2	25.0	13.46	18.5
June	41.8	26.2	17.55	16.6
July	38.3	25.9	17.27	53.6
August	36.9	24.9	14.45	65.3
September	37.4	23.6	11.04	21.5
October	36.6	19.1	5.88	2.1
November	31.3	13.0	4.16	1.8
December	26.0	7.9	3.92	0.6
Mean/Total	34.5	18.3	9.28	190.6

During winter the wind is predominantly from north-east direction while south- west westerly prevails in rest of the year.

The entire Jaisalmer district lies within an acute drought and famine belt. Owing to typical arid zone characteristics, the soils of Jaisalmer are desertic in nature.. Wide range of soils like the course aeolian, sandy soils, gravely skeletal and the bare rocky outcrops are found in Jaisalmer. The highly efficient aeolian processes in the region have produced vast areas of sand dune and sandy hummocks. In fact, sand dunes, interdune planes and other sandy undulating terrain cover more than 60% area of Jaisalmer district. Soil cover is generally very thin in central plataeu where the terrain is rocky and shallow gravely with occasional hills. Natural vegetation in the region is quite sparse with limited number of species (Mertia, 1976) consisting of grasses and shrubs and trees are rare. Jaisalmer region remains extremely vulnerable to wind erosion (Table 8) and tops the list of wind erosion index (Kar, 1993). Serious losses of fertile topsoil through wind erosion have been observed.

Table 8. Wind erosion categories for western Rajasthan

Wind erosion index	Category	Station
480 and above	Extremely high	Jaisalmer
120-479	Very high	Phalodi
60-119	High	-
30-59	Moderate	Bikaner, Jodhpur, Pachpadara, Barmer
15-29	Low	Ganganagar, Churu, Nagaur
1-14	Very low	Hissar, Sikar, Sambar, Ajmer

Srudies conducted at Central Arid Zone Research Institute (CAZRI) to assess sediment loss due to wind erosion over sand dune revealed that sand grain up to 0.2 mm size were eroded at the rate of 46 kg/m^2/hour during severe dusty wind (Ramakrishna et al, 1990). The rate of movement of an isolated barchans of 2.25 m height was found to be 1.7 m in 3 days of sand storm, when the average wind speed was 29 kmph (Kar, 1994). According to Ramakrishna et al (1990), the minimum daily wind speed that initiated sand movement was 4 kmph. Beyond 9 kmph the sand movement increased rapidly and over 14 kmph the mobility was very high. On one hand, the erosive winds take away loamy fertile surface soils from agricultural fields and make them barren, while on the other hand, deposition of air borne soil particles (sand, silt and clay) block roads (Plate 2) choke drains, bury the agricultural fields, encroach canals (Plate 3) and make daily life very difficult.

The deposition of wind borne sand create hummocks in khadins, which are traditional water harvesting structures for cultivation of crops on conserved soil moisture (Prasad et al, 2004).

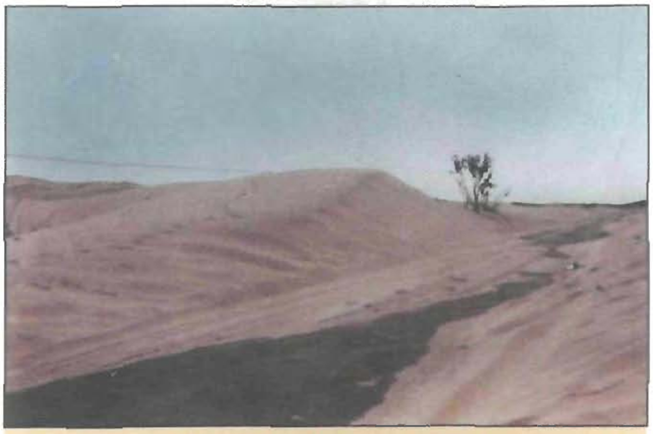

Plate 2. Engulfing of road due to deposition of wind blown sand in absence of shelterbelt plantations

Plate 3. Encroachment of canal by deposition of wind blown sand at SBS 85 RD

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3. Methodology

3.1 ASSESSMENT OF BIO-PHYSICAL IMPACT

For spacial variability and design of shelterbelt plantations, both study areas in Lathi series and Mohangarh were extensively traversed and spot verification were done. To assess impact on farm land quality, microclimate and wind regime etc., observations were taken from three selected farms having shelterbelt in each study area viz tube well command in Lathi series and IGNP command in Mohangarh. Physical characters of shelterbelts like its length; direction, composition, species etc were recorded. For growth of shelterbelts, tree height and girth of trees were measured. Age of plantation was assessed from the farmers. In Lathi series observations were taken in November 2005 whereas, in Mohangarh it was done in June 2006. Besides generation of basic data from selected shelterbelts, information were obtained from officials of State Forest Department, IGNP, General Reserve Engineering Force (GREF), district authorities etc to assess impact of shelterbelts on various aspects.

3.2 ASSESSMENT OF IMPACT ON EXTREME WEATHER EVENTS

To assess protective effects of shelterbelts against extreme weather events viz. cold and heat waves, preliminary survey of affected areas was conducted. The impact on cold wave was assessed in January, 2006 after the region experienced severe cold wave during 15th December, 2005 to 12th January, 2006. Similarly effects of heat wave was assessed in June, 2006.

3.3 ASSESSMENT OF SOCIO-ECONOMIC IMPACT

To assess socio-economic impacts of shelterbelt plantations, 40 farmers with shelterbelt and 40 farmers without shelterbelt (control) were selected randomly in each area of tube well command in Lathi series and canal command in Mohangarh. All these farmers were surveyed and primary information collected as per pre-designed schedule (Annexure-I). During survey, discussion with farmers was made in participatory mode and efforts made to involve more members of farm family including farm women and children in extracting information on various socio-economic aspects. The data on various aspects such as cost of inputs used for crop production, returns from crops, and production from shelterbelt like fodder, timber, fruits etc. were recorded. The information on change in assets and livestock composition was also collected to find out changes in livelihood. The economic losses were estimated by difference in crop productivity of farms covered with shelterbelt and average crop productivity of the district. To know the contribution of shelterbelt in net farm returns and additional employment generation, decomposition models were used Bisaliah (1977, 1978).

Net Profit Decomposition Model

Separate crop production functions were estimated for modern and traditional technologies to decompose total change in output (Bisaliah 1977; Thakur and Kumar, 1984; Hussain and young, 1985 and Kiresur, et al 1995). The specification of production functions used in decomposition analysis is as follows:

$$\text{Ln } Y_t = \text{Ln } A_t + a_1 \text{ Ln FERT}_t + a_2 \text{ Ln } HL_t + a_3 \text{ Ln } OE_t + U_1 \text{ ------ (1)}$$

$$\text{Ln } Y_m = \text{Ln } A_m + b_1 \text{ Ln FERT}_m + b_2 \text{ Ln } HL_m + b_3 \text{ Ln } OE_m + U_2 \text{ --- (2)}$$

Where,

Y = Net profit per farm of 5 ha.

FERT = Expenses on fertilisers and manures (Rs per farm)

HL = Human labour (man days/farm)

OE = Other expenses including value of seeds, irrigation, pesticides, farm machinery etc. (Rs. per farm)

Subscript 't' and 'm' indicate traditional (farms without shelterbelt) and modern technology (farms with shelterbelt) systems, respectively.

In addition to fitting crop production functions for traditional and modern technologies, a pooled function was also fitted using dummy variable for variety. The following model was used to decompose the total change in crop output

$$\text{Ln } Y_m \text{ Ln } Y_t = (\text{Ln } A_m - \text{Ln } A_t) + [(b_1 \; a_1) \text{ Ln FERT}_t + (b_2 \; a_2) \text{ Ln } HL_t + (b_3 \; a_3) \text{ Ln } OE_t] + [(b_1 \; (\text{LnFERT}_m \text{ Ln FERT}_t) + b_2 (\text{Ln } HL_m \text{Ln } HL_t) + b_3 (\text{Ln } OE_m \; \text{Ln } OE_t)] + (U_2 \; U_1) \text{ ----- (3)}$$

The decomposition equation (3) measures the per cent change in output with the interaction of modern technology. The expression on right hand side is a measure of per cent change in output due to shift in scale parameters (A) of the production function(first bracket), the effect of change in slope parameters (second bracket) and these two terms sum up to the total effect of modern technology. The third bracketed term measures the contribution of change in input use.

Labor Decomposition Model

The Cobb-Douglas production function of the following form was used :

$$\text{Ln } Y = \text{Ln } A + a_1 \text{ Ln } HL + a_2 \text{ Ln FERT} + a_3 \text{ Ln } FL + a_4 \text{ Ln OWN} + Ui \text{ ---------(1)}$$

Where,

Y = Output of crop measured in quintal per farm.

HL = Hired labour employed (man-days/farm).

FERT = Value of fertilizer and farm yard manure per farm.

FL = Family labour employed (man-days/farm).

OWN = Value of other expenditures i.e., expenditure on seeds, ploughing unit, irrigation charges, etc. (Rs. per farm)

A = Constant term of scale parameter.

a's = Partial output elasticities of hired and family labour, fertilizer and other Expenses.

Following Lau and Yotopoulos (1971), a UOP profit function in logarithmic form is specified as :

$$\text{Ln } \pi = \text{Ln } A + b_1 \text{ Ln } W + b_2 \text{ Ln FERT} + b_3 \text{ Ln } FL + b_4 \text{ Ln OWN} \quad \text{--------- (2)}$$

Where,

$A^* = A^{\theta}(1-a_1)^{a1\theta}$

$b_1 = -a_1^{\theta} < 0$; $b_2 = a_2^{\theta} > 0$; $b_3 = a3^{\theta} > 0$ and $b_4 = a_4^{\theta} > 0$ Let $1/1-a_1 = \theta$

Definitions of FERT, FL, OWN are the same as in I and II and defined profit/per hectare.

If one compare the parameters of UOP profit function, and Cobb-Douglas function, it is evident that both are closely related. The crucial feature in function (2) is that it assumes firm to behave according to same decisions like profit maximization given the price for output, and labour and given the quantities of other inputs. The employment decomposition model is formulated with the help of labour demand function and it was worked out as follows:

$$WN/\pi = (-b_1)$$

$$\text{Ln } N = \text{Ln } (-b_1) - \text{Ln } W + \text{Ln } \pi$$

Substituting the value of (Log π - Log W) from equation (2) :

$$\text{Ln } N = \text{Ln}(-b_1) + \text{Ln } A + (b_1-1) \text{ Ln } W + b_2 \text{ Ln FERT} + b_3 \text{ Ln FL} + b_4 \text{ Ln Own} \quad \text{-----(3)}$$

An employment decomposition model is formulated by using labour demand function and the final equation is of the following form:

$$dN/N = [\theta\, dA/A] + [\theta\, da_1/a_1 + \theta^2(\text{Log } A + \text{Log } a_1)\, da_1 - \theta^2(\text{Log } W)\, da_1 + \theta^2\{(1-a_1)\, da_2 + a_2 da_1\} \text{ Log FERT} + \theta^2\{(1-a_1)da_3 + a_3 da_1\}\text{Log FL} + \theta^2\{(1-a_1)\, da_4 + a_4 da_1\}\text{Log Own}] - [(\theta\, a_1+1)\, dW/W] + [\theta\, a_2\, dFERT/FERT + \theta\, a_3\, dFL/FL + \theta\, a_4\, dOWN/OWN] \quad \text{..............(4)}$$

Equation (4) permits to decompose per hectare change in employment (dN/N) into three components.

1. Technology effect : This include the effects of shift in scale parameters (A) and slope parameters in production function used for equation (1), given W, FERT, FL, OWN under old technology and is captured by adding the values of first two bracketed expressions of employment decomposition equation (4).
2. Normalized wage rate effect: This is measured by third bracketed expression in employment decomposition model (4).
3. Complementary inputs effect: This effect (further bracketed expression) includes the employment effects of differences in quantities of inputs given the new technology elasticities.

The employment decomposition model (4) measured the sources of change in employment between farms with shelterbelt and farms without shelterbelt. The output elasticities with respect to various inputs are the same in separate regression models for shelterbelts, indicating existence of Hicks - neutral type of technical change. This was further indicated by $da_1, = da_2 = da_3 = da_4. = 0$ in the employment decomposition equation (4).

$$dN/N = [\theta\, dA/A] - [(\theta\, a_1+1)\, dW/W] + [\theta\, a_2\, dFERT/FERT + \theta\, a_3\, dFL/FL + \theta\, a_4 (\, dOWN/OWN \quad \text{..............(5)}$$

For simplicity in calculation, equation (5) can be written as:

$$\Delta N/N = [\theta\Delta A/A] - [(\theta a_1+1)\Delta W/W] + [\theta a_2\Delta FERT/FERT + \theta a_3\Delta FL/FL + \theta a_4\Delta OWN/OWN] \quad \text{...(6)}$$

Normal wage rate W = Pn/Py

Where,

Pn = Money wage rate

Py = Price of output per unit

Since the price of Pn and Py is same in the study area, the change in normal wage rate was assumed as zero. Thus the final decomposition equation becomes:

$$\Delta AN/N = \theta \Delta A/A + \theta a_2 \Delta FERT/FERT + \theta a_3 \Delta FL/FL + \theta a_4 (\Delta OWN/OWN) \quad \text{-------(7)}$$

Equation (7) was the last decomposition equation for working out employment change. For estimating employment change, the parameters of function and per farm input levels were worked out. Similarly, to maintain constant returns to scale and Hicks-neutral technical change, a pooled least square regression model was estimated. It has been argued that ordinary least squares applied to the UoP profit function (2) and the labour demand function separately are consistent. However, these estimates are to be inefficient because they appear in both the equations. So a more efficient approach to estimate (2) and (3) jointly, imposing the conditions that bias are equal, by Zellners' method, which reduces the standard errors in comparison to a single equation of least squares. Therefore, the estimation procedures in the present study are likely to produce some bias in the values of coefficients.

❑ ❑ ❑

4. Bio-physical Impact of Shelterbelts

4.1 DESIGN AND COMPOSITION OF SHELTERBELTS

The shelterbelt technology has been introduced and adopted well by the farmers in both study area of Lathi series (tube well command) and Mohangarh (IGNP command). In villages of Lathi series most of the farmers have planted shelterbelts on their farm bunds to minimize effects of speedy winds to protect their crops. The main species which are preferred by farmers include *A. tortilis, E. camaldulensis, D. sissoo, A. nilotica, T undulata Cordia myxa* and *Z. mauritiana*. The integration of last two species yield fruits and provide additional income to the farmers. Normally, farmers have planted shelterbelts along the farm boundary and hence, length of most of the shelterbelt equals the length of the field bund (Plate 4). In some cases, tree rows are planted along water or irrigation channels. Irrespective of their length, most of the shelterbelts were continuous throughout their length with out any interruption or gaps. On some farms, the ends of two belts were joined at right angle to minimize turbulence or tunneling of wind at the ends (Plate 5). The species like *E. camaldulensis* has been planted at closer spacing of 2m apart in single row. The other species like *A. tortilis, A.nilitica* and *D. sissoo* are planted either 3 or 5m apart in the rows. In double row shelterbelts, the rows are spaced 4 to 5 m apart. The species like *Cordia myxa* and *Z. mauritiana* are planted along the shelterbelt plantations in leeward side. In some cases 2-3 rows of ber are planted in leeward side near the belt. In IGNP command, most of the farmers have planted *D. sissoo* as shelterbelt either along water channel or on field bund. Few farmers have planted *E. camaldulensis, T. undulata* and *Z. mauritiana* as shelterbelt. Planting of *D. sissoo* is done 5m apart in single-row belt while rows are placed closer (4-5m apart) in double-row shelterbelts. In some fields, staggered planting was observed in double row shelterbelts. Physical characteristics of selected sbelterbelts are given in Table 9. On some farms in tube well command in lathi series, the farmers use micro windbreaks to protect their crops. These vegetative barriers generally consist of strip (4-6m wide) of fodder crop like millet and sorghum, which are usually sown at least 1-2 months in advance of sowing of main crop to which they are suppose to provide protection from winds (Plate 6).

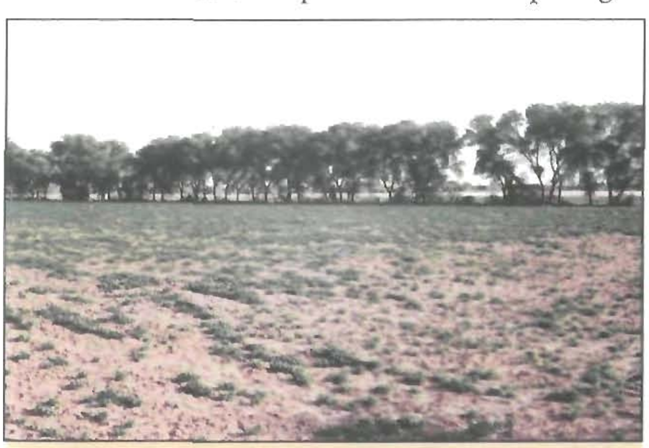

Plate 4. Single-row shelterbelt planted along field bund.

Plate 5. Two shelterbelts joined at right angle to minimize turbulence at the ends and maximize efficacy

Table 9. Characteristics of Shelterbelts in tube well command, Lathi series and IGNP command, Mohangarh

Type of shelterbelt	Direction and number of rows	Age (yr)	Length (m)	Mean height (m)	Mean GBH* (cm)
Tube well command, Lathi series					
Acacia tortilis	S-W/ 2	18	116	8.9	112.6
Eucalyptus camaldulensis	S-W/ 1	20	66	18.5	116
Dalbergia sissoo	S-W/ 2	6	85	7.8	58.6
IGNP command, Mohangarh					
Dalbergia sissoo	S-W/1	10	100	6.2	61.6
Dalbergia. sissoo	S-W/ 2	15	73	8.8	70.3
Tecomella undulata	SW/ 1	20	75	10.2	93.4

*Girth at Breast Height

By and large, strips of micro windbreaks are created at a distance of regular intervals of 15H (H is the average height of micro windbreak i.e. 2m) distance against the direction of blowing winds. Some time the whole field is encircled by raising 3-4 m wide strips of micro windbreak along the field bund to ensure safety and security of those crops, which are highly sensitive to hot or cold winds and damaged by the wild animals. Most of the vegetable crops are provided with such windbreaks.

According to an estimate, about 20% of the total 20000 ha tube well irrigated area in villages of Lathi series has been put under shelterbelts whereas, only 5% of 9.25 lac ha area of IGNP phase II is covered with such plantations. In canal side, multi-rows or strip plantations have been raised on either side of main canal and its branches (Plate 7). The main species which are planted include *A. nilotica, Eucalyptus* spp. *T. undulata, A. tortilis, P. juliflora, D. sissoo, P. cineraria* and *A. nubica* .

Besides on farmer's fields, varieties of shelterbelt plantations exist on either side of roads/railways and canals. The planting pattern reflect the adoption of output of early research work (in late fifties and early sixties) on shelterbelt that was taken up to develop its suitable design having optimum planting geometry, porosity, thickness (Number of rows) and shape. For providing maximum sheltered zone, the shelterbelts having 40-50% penetrability with

Plate 6. Micro-windbreaks for protecting crops from winds

Plate 7. Shelterbelts along IGNP main canal near tail end, Mohangarh

evenly distributed gaps were assessed to be the best (Nageli, 1946). For arid condition in Thar Desert, Kaul (1969) suggested five row shelterbelt with a pyramidal shape having one row of tall trees such as *Acacia tortilis, Tamarix articulata, Azadirachta indica* followed by two rows of smaller trees like *Acacia senegal, Prosopis juliflora, Parkinsonia acculeata* etc. and then followed by two rows of shrubs such as *Aerua tomentosa, Zizyphus spinachristi* and *Calligonum polygonoides* at the edge in flank rows. Choices of species and planting techniques have always been crucial factors for establishment of shelterbelt plantations. Based on earlier work, it has been recommended that seedlings raised in sun dried bricks or poly tubes and well adapted in nursery, when planted in pits of 45 cm^3 or 60 cm^3 prove very successful. Such deep planting facilitates root access to moisture from lower depths. Seedlings raised in galvanized iron containers were suggested for raising plantation in duny areas.

The tree species such as *Acacia tortilis, Albizzia lebbek, Dalbergia sissoo* and *Prosospis juliflora* have been raised successfully using above techniques. Pre-sprouted branch cuttings of certain species like *Calligonum polygonoides* and *Tamarix articulata* have also been planted successfully. To keep livestock away from the trees, surrounding of central planting pit with 30cm wide and 30cm deep circular trench was found most suitable. However, in loose sandy areas, tree guards were found more appropriate because trenches collapse in sandy dunes. Now a days, fencing with an iron angle post and barbed wire has been adopted to protect seedlings from cattle, sheep, goats and camel (Mertia, 1992). For different purposes, the recommended species and design of shelterbelt are given in Table 10.

Table 10. Design and species for shelterbelt plantations

Purpose	Design	Suitable species
Road side	3 to 5 staggered rows	*A tortilis, A. lebbek, A. indica, D. sissoo, P. acculeata, P. Juliflora and Tamarix articulata*
Railway side	6 rows	*P. acculeata, P. juliflora, T. articulata*
Canal side	6 rows	*A. nilotica, Eucalyptus spp. T. undulata, A. tortilis, P. juliflora, D. sissoo, P. cineraria A. nubica*
Farm boundary (rainfed)	1 / 2 / 3 rows	*Acacia tortilis, A. lebbek, A. indica, D. sissoo, P. acculeata, P. juliflora (most common)*
Farm boundary (irrigated)	2 rows	*A tortilis, A. lebbek, Dicrostachys cineraria, P. juliflora*

4.2 WIND REGIME

Data pertaining to effects of shelterbelt on wind regimes on leeward side of the shelterbelt plantations is presented in Table 11. The data reveals that different shelterbelts had varying effects on reduction of wind speed on leeward side of the belt. The maximum extent of reduction in wind speed of leeward side was observed at a distance of 2H (H is the average height of the shelterbelt in meter), which slowly got nullified up to 20H. On an average, irrespective of the species, double-row shelterbelts were more effective in reducing wind speed (Fig 4) as compared to single-row belt. However, single row belt provided more protected area in comparison to double-row belts.

It appears that canopy, structure, density (density refers to the proportion of solid material such as foliage, branches etc), age, height and direction of the shelterbelt plantations are major factors, which decide its effectiveness in controlling the wind flow. Fairly tall and dense double-row *D. sissoo* reduced maximum wind speed in IGNP area but its effectiveness was only up to distance of 15H whereas, 20 years old single-row *E. camaldulensis* had provided sheltered area up to distance of 20H in tube well command area of Lathi series. In other shelterbelts, the reduction in wind speed in leeward side was more pronounced up to distance of 10 H and limited to distance of 15 H. For maximizing effectiveness of shelterbelt plantations for providing large sheltered area on leeward side, it is desirable to plant those species which, can

Table 11. Effect of shelterbelts on wind speed in leeward side of the belt

Shelterbelt	Direction and number of rows	Mean height (m)	Per cent reduction in mean wind speed				
			2H	5H	10H	15H	20H
Tube well command, Lathi series (November 2005)							
Acacia tortilis	S-W/ 2	8.9	29.6	24.5	10.7	3.3	0
Eucalyptus camaldulensis	S-W/ 1	15.5	24.8	18.6	12.5	9.4	7
Dalbergia sissoo	S-W/ 2	7.8	32.4	17.9	5.5	1.5	0
IGNP command, Mohangarh (June 2006)							
Dalbergia sissoo	S-W/ 1	6.2	21.5	14.2	6.2	3.2	0.2
Dalbergia. sissoo	S-W/ 2	8.8	36	28.7	12.2	1.4	0
Tecomella undulata	SW/ 1	10.2	24	19.7	9.7	3.5	2

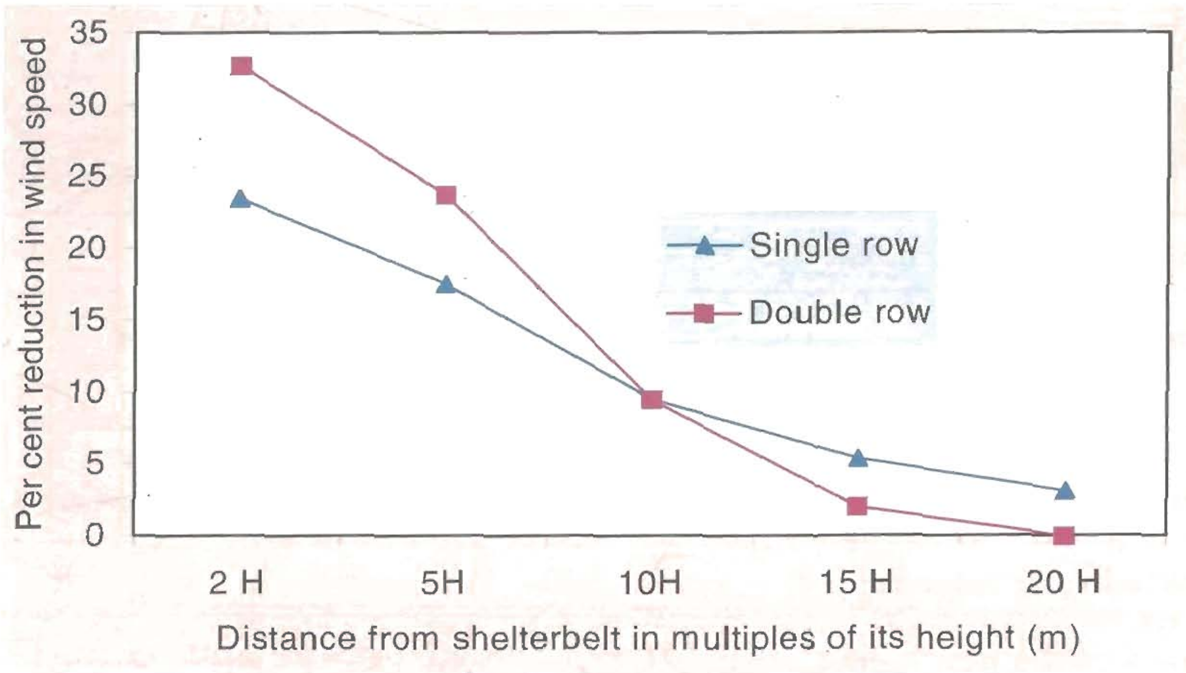

Fig 4. Effect of type of shelterbelts on reduction in wind speed on leeward side

grow fast and attain maximum height in short period. Belt of multiple rows apparently provided more resistance due to dense canopy resulting in decrease of sheltered area in the leeward side of the belt. It is evident that in providing maximum shelter toward leeward side, the taller and fairly dense single-row shelterbelt plantations were more effective than those, which are double-row with lesser height. This reason probably has attracted many farmers in tube well irrigated area in Lathi series to plant single-row shelterbelt plantations of *E. camaldulensis* along their farm boundary.

The height of shelterbelt plays an important role in providing sheltered area in leeward side of a belt. Shelterbelt plantations of lesser height created a sand deposited ridge at approximate distance of 6 to 8 H (Table 12). This phenomenon is more encountered at initial stage of belt plantation when the trees are of lesser height and having comparatively dense canopy. This necessitates planting of shelterbelt plantations at regular interval of 8-10 times of the height of the belt if better results are to be obtained.

The turbulence or tunneling effect was more pronounced at both ends of shelterbelt plantations of more height, density and short in length (Table 13). The length of shelterbelt directly controls its turbulence effects on ends (Fig 5). Single-row belt having length of 100 m or more did not show any sign of turbulence or tunneling effect on ground. It suggest that (considering average 10m height of well grown shelterbelt plantations) length of shelter belt should be 10-12 times of its heights for better efficiency and effectiveness in controlling wind borne hazards. Uninterrupted and uniform shelterbelt plantations appear to be more effective than those with interruption or gaps. These gaps provide space for passage of wind with higher speed and turbulence causing more soil erosion. As wind approaches belt, some goes around the ends of belt, some goes through the belt and most goes over top of the belt. The air pressure builds up

Table 12. Effect of different shelterbelts on creation of sand deposited ridge on leeward side of the belt

Shelterbelt	Direction and number of rows	Mean height (m)	Sand deposited ridge at distance from belt
Tube well command, Lathi series			
Acacia tortilis	S-W/ 2	8.9	11H (mild)
Eucalyptus camaldulensis	S-W/ 1	18.5	No ridge formation
Dalbergia sissoo	S-W / 2	7.8	6H (well defined ridge)
IGNP command, Mohangarh			
Dalbergia sissoo	S-W/ 1	6.2	8H (mild ridge)
Dalbergia. sissoo	S-W/ 2	8.8	6H (well defined ridge)
Tecomella undulata	SW / 1	10.2	Negligible ridge at 12H

Table 13. Effect of shelterbelt on wind turbulence at the ends

Shelterbelt	Length of shelter belt	Direction and number of rows	Percentage increase in mean wind speed at the ends	
			I	II
Tube well command, Lathi series				
Acacia tortilis	116	S-W/ 2	0.5	1.6
Eucalyptus camaldulensis	66	S-W/1	16.4	7.6
Dalbergia sissoo	85	S-W/2	12.3	11.5
IGNP command, Mohangarh				
Dalbergia sissoo	100	S-W/1	3.4	8.2
Dalbergia. sissoo	73	S-W/2	17.8	13.2
Tecomella undulata	75	SW /1	12.5	17.0

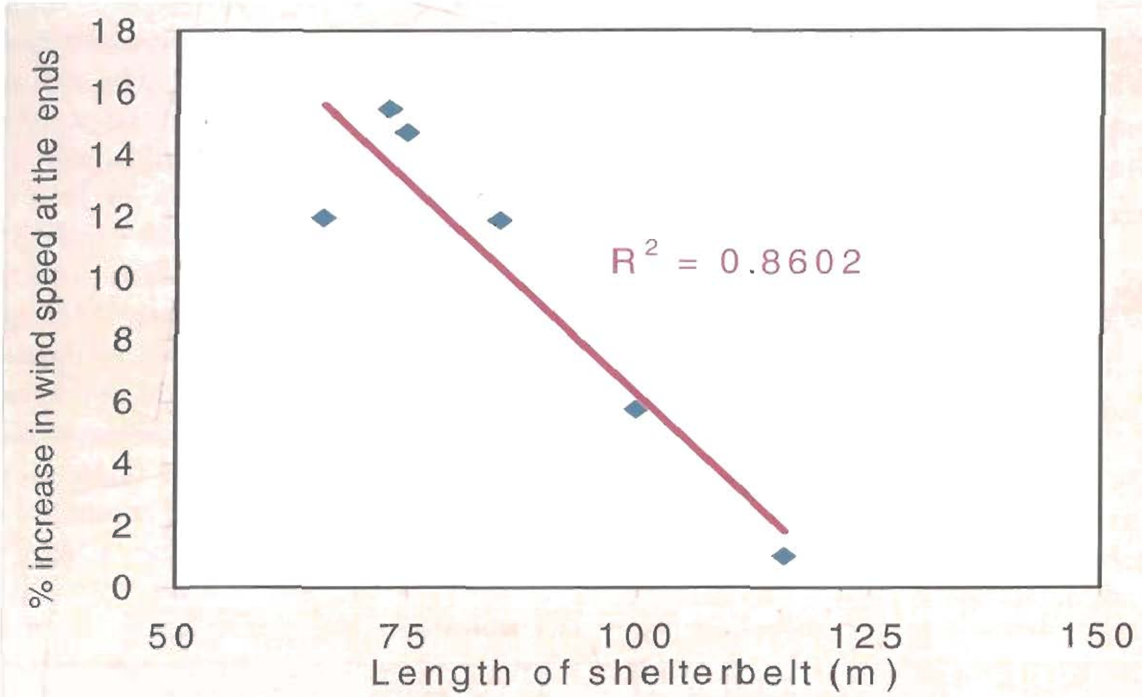

Fig. 5. Effect of length of shelterbelt on wind tunneling

on windward side and decreases on leeward side. The difference in air pressure causes shelter effect, determines reduction in wind speed and creation of turbulence. Difference in air pressure depends on density of shelterbelt plantations. Generally, dense shelterbelts yield more air pressure difference between windward and leeward sides.

Tree Shelterbelts have been found effective in reducing wind speed and thus soil erosion (Mertia, 1992b). Gupta et al. (1984) reported that wind speed reduction was higher during monsoon season than in summer due to thicker canopy growth (Table 14). Different shelterbelts have reportedly been associated with different degrees of

Table 14. Per cent reduction of mean wind speed at different distances on the leeward side of different Shelterbelts (1977-79) at Jodhpur.

Species	Distance from shelterbelt					
	Summer season			Monsoon season		
	2 H	5 H	10 H	2 H	5 H	10 H
Prosopis juliflora	33	17	12	38	26	21
Cassia siamea	36	17	13	46	36	24
Acacia tortilis	36	25	13	46	36	20

wind reduction in different seasons and over the surrounding area. Due to reduction of wind speed the soil loss in sheltered area was reduced by 50 per cent as compared to that in an unsheltered area. The shelterbelt based on *Cassia siamea* proved most effective in conserving soil.

4.3 MICROCLIMATE

Moderation of microclimatic studies revealed considerable reduction in air temperature in sheltered area on leeward side, which varied with the type of shelterbelt plantations. Maximum reduction in air temperature was observed beneath the shelterbelt. The effectiveness of shelterbelt plantations was noticed up to distance of 10H in the month of November in tube well command area of Lathi series whereas, effects of shelterbelt on air temperature were noticeable only up to the extent of 5H in the month of June in IGNP command area of Mohangarh (Table 15). The reduction in temperature reduces water loss from the soil through evaporation. Muthana et al, (1984) reported that the evapotranspiration (PE) is largely influenced by the wind in arid region and shelterbelt reduced 5-14% pan evaporation values on either side of the belt (Table 16). Mertia (1992b) has also reported positive effects of

Table 15 Effect of different tree shelterbelts on daily air temperature (°C)

Shelterbelt	Direction and rows	Daily air temperature (^{0}C)				
		0H	1H	2H	5H	10 H
Tube well command, Lathi series (November, 2005)						
Acacia tortilis	S-W /2	22.5	23.4	24.2	24.8	26.5
Eucalyptus camaldulensis	S-W /1	22.0	23.5	24.6	25.0	26.5
Dalbergia sissoo	S-W /2	23.0	24.5	25.8	26.4	26.5
IGNP command, Mohangarh (June 2006)						
Dalbergia sissoo	S-W/1	41.0	43.2	44.1	44.5	44.5
Dalbergia sissoo	S-W/2	36.2	42.8	43.8	44.0	44.1
Tecomella undulata	SW /1	40.4	40.0	42.5	44.0	44.0

Table 16. Effect of Cassia siamea shelterbelt on pan evaporation

Location	Pan evaporation (mm day^{-1})			
	April	May	June	July
Windward side	11.0	14.5	13.4	6.0
Leeward side	9.5	13.4	12.5	5.7
Per cent decrease	14	8	8	5

shelterbelt on conservation of soil moisture on its leeward side. The microclimatic moderation within shelterbelts and their modification with respect to seasons have significant impact on associated agricultural crops (Table 17).

4.4 SOIL QUALITY

Shelterbelt plantations have significantly influenced soil characteristics of sheltered area on leeward side. Though, the shelterbelt plantations are 10-15 year old and it may take some more time to observe perceptible effects on soil quality, however, some trends have emerged. In general increase in soil organic carbon (OC) (Table 18) and electrical conductivity (Table 20) and reduction in soil reaction (Table 19) was observed near the shelterbelt plantations. These effects were more pronounced up to the distance of 2H and leveled off after distance of 5H. Maximum accumulation of OC was found in sheltered area of *A. tortilis* in tube well command in Lathi series followed by *T. undulata* and *Dalbergia sissoo* in IGNP command, Mohangarh. Maximum OC was observed up to 2H distance from shelterbelt and decreased with increase in distance from the belt (Fig 6). As expected OC decreased with the depth of soil in sheltered area of all the shelterbelt (Fig 7), however, on an average a higher OC was seen up to 60 cm depth in sheltered area even up to 10H distance. This was again more conspicuous in 0-15cm surface layer. It is because litter carried away by wind from near the shelterbelt gets deposited on surface at distance away from the tree rows and increases organic carbon there. The built up of OC in sheltered area may be due to tree leaf litter and its decomposition in sheltered area. Reduction in air temperature and increased moisture in sheltered area on leeward side perhaps, boosted microbial activities facilitating decomposition of litter (Prasad and Mertia, 2005). This has also resulted in decrease in soil pH due to increase in OC (Table 19).

Increase in EC near the trees may be due to evapotranspiration pull of tree vegetation and being crops on leeward side, which help redistribution and deposition of native salt at the surface (Table 20). However conductivity is not a serious matter in arid zone as all values are very low and well with in the permissible limits.

Table 17. Effect of shelterbelt on yield of pearl millet

Distance from	Pearl millet shelterbelt	Control yield (q ha^{-1})	Consumptive use (mm)	Water use efficiencies (kg ha^{-1} mm^{-1})
5 H	3.7	-	174	1.5
10 H	6.1	-	223	1.51
15 H	6.3	-	216	3.09
20 H	8.8	-	216	3.79
25 H	9.8	-	227	5.62
30 H	5.9	-	194	2.65
		4.8		

Table 18. Effect of different shelterbelts on organic carbon content of soil in sheltered area of leeward side

Shelterbelt	Location	Depth (cm)	Organic Carbon content (%) at distance multiples of shelterbelt height				
			0 H	1 H	2 H	5 H	10 H
Dalbergia sissoo	IGNP command, Mohangarh	15	0.11	0.08	0.05	0.04	0.04
		30	0.07	0.06	0.07	0.05	0.05
		60	0.07	0.05	0.04	0.04	0.03
		Mean	0.08	0.06	0.05	0.04	0.04
Tecomella undulata	IGNP command, Mohangarh	15	0.37	0.21	0.05	0.08	0.07
		30	0.12	0.11	0.03	0.06	0.06
		60	0.09	0.06	0.04	0.03	0.03
		Mean	0.19	0.13	0.04	0.06	0.05
Acacia tortilis	Tube well command Lathi series	15	0.46	0.21	0.16	0.14	0.15
		30	0.22	0.17	0.12	0.11	0.07
		60	0.17	0.12	0.12	0.12	0.13
		Mean	0.28	0.17	0.13	0.12	0.12

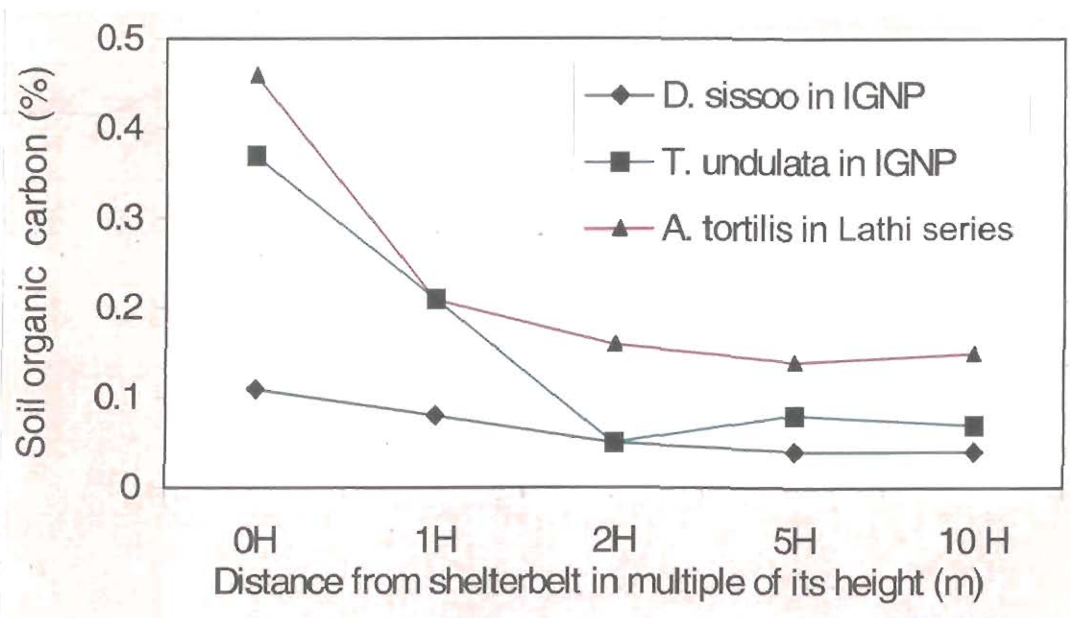

Fig. 6. Effect of different shelterbelts on organic carbon content of surface soil in sheltered area of leeward side.

Table 19 Effect of different shelterbelts on reaction (pH) of soil in sheltered area of leeward side

Shelterbelt	Location	Depth (cm)	Soil pH at distance multiples of shelterbelt height				
			0 H	1 H	2 H	5 H	10 H
Dalbergia sissoo	IGNP command, Mohangarh	15	7.84	7.84	7.93	7.9	8.05
		30	7.82	7.88	8.00	7.94	7.99
		60	7.87	7.92	8.03	8.09	8.10
		Mean	7.84	7.88	7.99	7.98	8.04
Tecomella undulata	IGNP command, Mohangarh	15	7.60	7.76	7.98	7.95	8.05
		30	7.81	7.76	7.92	7.95	8.08
		60	7.84	7.88	7.99	7.99	8.01
		Mean	7.75	7.8	7.96	7.96	8.05
Acacia tortilis	Tube well command, Lathi series	15	7.50	8.50	8.92	8.99	8.93
		30	8.53	8.59	8.92	8.89	8.73
		60	8.66	8.57	8.94	8.97	8.86
		Mean	8.23	8.55	8.93	8.95	8.84

Table 20. Effect of different shelterbelts on soil electrical conductivity in sheltered area of leeward side

Shelterbelt	Location	Depth (cm)	Soil EC dSm^{-1} at distance multiples of shelterbelt height				
			0 H	1 H	2 H	5 H	10 H
Dalbergia sissoo	IGNP command, Mohangarh	15	0.40	0.38	0.28	0.27	0.28
		30	0.39	0.34	0.23	0.27	0.27
		60	0.36	0.33	0.22	0.24	0.25
Tecomella undulata	IGNP command, Mohangarh	15	0.88	0.42	0.22	0.21	0.21
		30	0.45	0.41	0.22	0.24	0.25
		60	0.43	0.36	0.21	0.21	0.21
Acacia tortilis	Tube well command, Lathi series	15	0.67	0.34	0.34	0.36	0.34
		30	0.41	0.38	0.34	0.36	0.39
		60	0.4	0.37	0.36	0.36	0.42

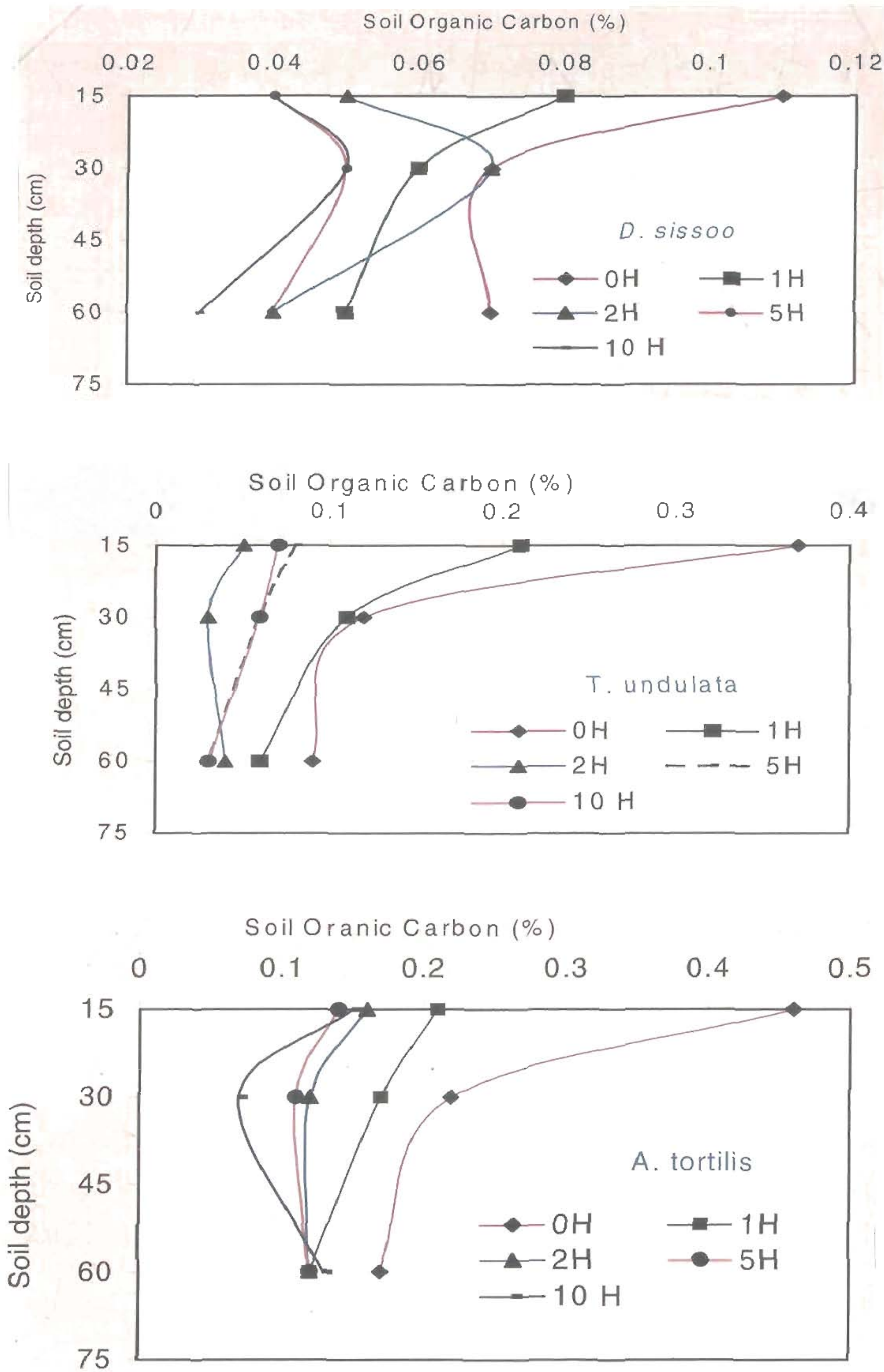

Fig. 7. Effect of different shelterbelts on distribution of organic carbon in soil profile in sheltered area of leeward side

The increase in carbon built up in sheltered as compared to unsheltered area has also been observed due to shelterbelt plantations on roadside and canal side (Table 21). The old plantations provided good sheltered zone as compared to younger ones.

4.5 SILTING OF CANAL

Shifting dunes, in the absence of any check in the form of plantations, deposit huge quantities of blowing sand in the main canal and its distributaries there by either completely choking or reducing the flow of the water. In order to de-silt the canals to restore flow of water, huge expenditures were incurred. The seriousness of the problem can be judged from the fact that about 0.57 million m^3 of blown sand had to be removed from the main canal (RD 383.2 to RD 444. 8) at an approximate cost of Rs. 72 lacs in December 1986 (Bithu, 1989). Sand deposition in canal has been considerably reduced owing to plantation along canals and it appears that canal side belt plantations have been able to achieve their main objective for which they were raised (Plate 8 & 9).

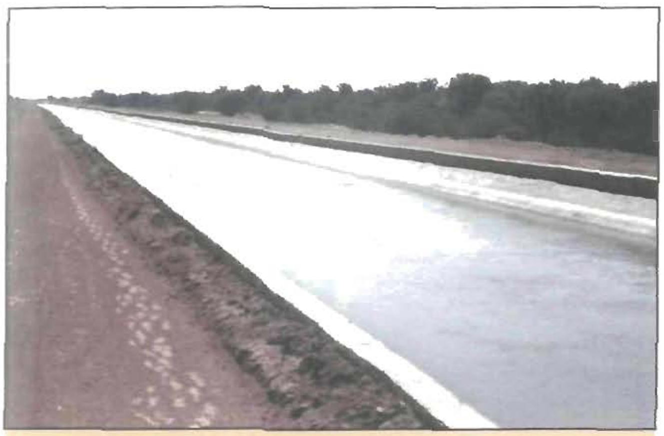

Plate 8. Canal side plantations to control deposition of wind blown sand

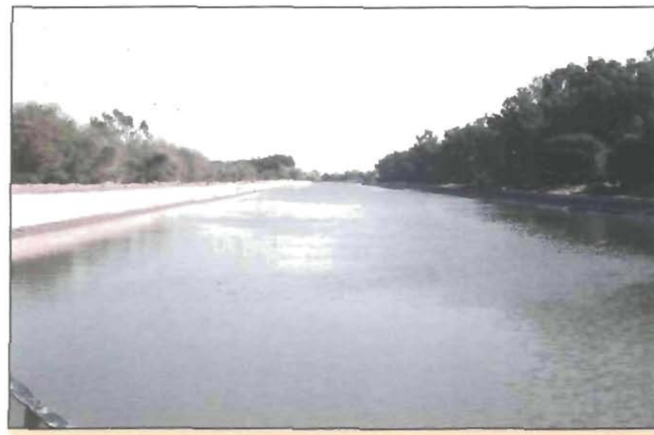

Plate 9. Protected Canal with canal side shelterbelt plantations

Table 21. Impact of roadside plantations on soil properties

Soil properties	Depth of soil (cm)	Road side plantations		Canal side plantations	
		2 years	8 years	2 years	8 years
PH	15	8.32	8.43	8.51	8.98
	45	8.83	8.80	8.42	8.65
	90	8.88	8.75	8.32	8.88
EC (dS m^{-1})	15	0.13	0.13	0.18	0.25
	45	0.16	0.18	0.20	0.19
	90	0.12	0.14	0.30	0.15
OC (%)	15	0.23	0.29	0.21	0.27
	45	0.22	0.18	0.15	0.23
	90	0.02	0.18	0.12	0.15

The pre-plantation scenario (before 1991) in the area, where now 12-15 years old shelterbelt plantations exist, has drastically changed (Plate 10). A study of Upadhyaya, (1991) in IGNP stage II area in Jaisalmer has revealed that quantum of sand deposited in canal was reduced by 513 m^3 and 1023 m^3 per km with one and two years old canal side tree-belt plantations, respectively as compared to unplanted sites (control). The corresponding savings on de-silting of deposited sand was estimated to be in the tune of Rs 6,156 and 12,276 per km. The study further revealed that quantum of sand movement varied significantly during different months of a year (Table 22) and maximum deposition was observed in the month of June (Fig. 8).

Information on removal of blown sand from canal beds has revealed inverse relationship between the age of shelterbelt plantations and the quantity of sand deposition. Older the plantations lesser the quantity of sand deposited in canals (Table 23). Data on net savings accrued on de-silting of canal are given in Table 24.

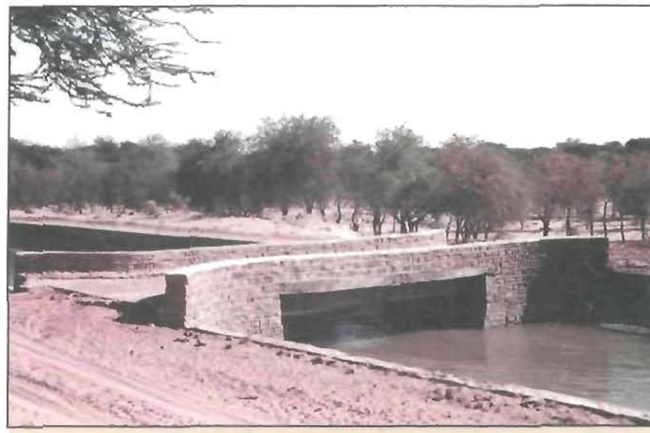

Plate 10. Block plantations of *T. undulata* on canal side near tail end of main canal, Mohangarh

Table 22. Effect of canal side plantations on sand deposition (m^3 Rm^{-1} of canal) in canal

Month	Control	One year old Plantation	Two years old plantation
Nov. 89	0.089	0.071	0.041
Jan.90	0.094	0.068	0.041
March 90	0.150	0.109	0.069
May 90	0.261	0.225	0.141
June 90	0.323	0.289	0.157
July 90	0.198	0.101	0.051
Sept. 90	0.068	0.041	0.021
Oct. 90	0.039	0.033	0.016

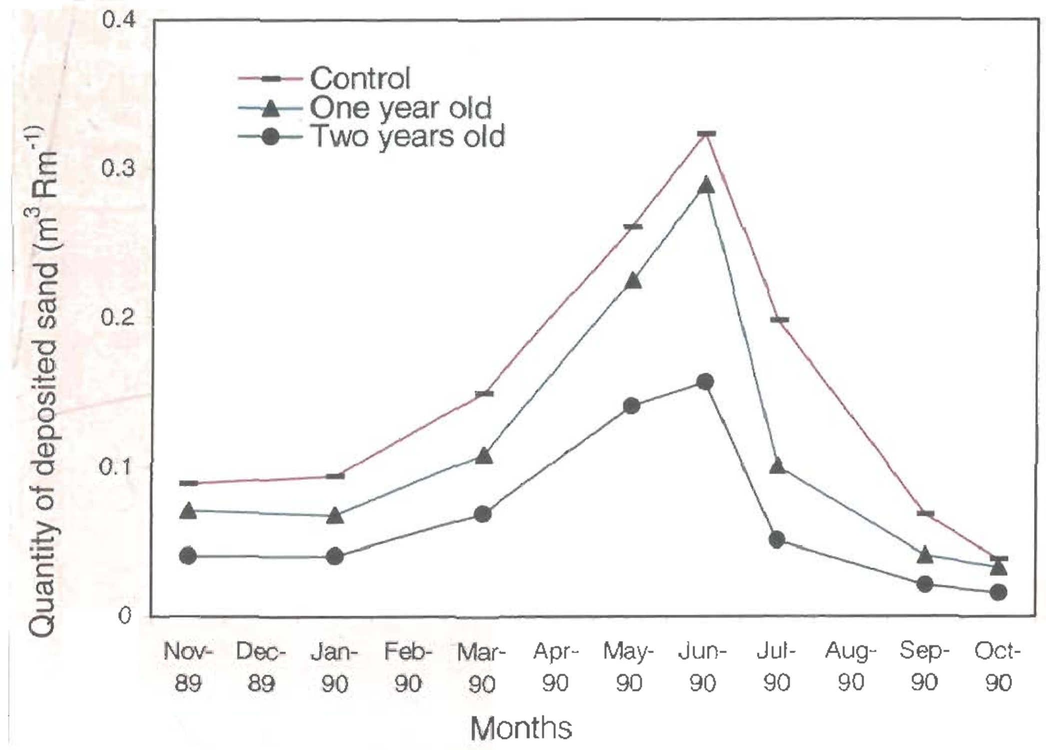

Fig. 8. Effect of age of canal side plantations on sand deposition pattern in canal

Table 23. Reduction in sand deposition and cost of de-silting of canal after canal side plantations

Branch/Distributories/ Minors	Sand deposition in canal ($m^3\ km^{-1}$)				Cost of removal of deposited sand (Rs. km^{-1})			
	1996	1997	1998	1999	1996	1997	1998	1999
Sagarmalgopa Sakha	4125	2877	2079	1269	85181	59410	44948	31065
Mandau Distributry	2296	777	373	718	47412	16046	8064	17577
Sankhla minor	1949	1165	1009	388	40247	24057	21815	9498
Tibrewala Minor	1875	563	1250	1250	38719	11626	27025	27025
Mean	2561	1346	1178	906	52890	27780	25460	21290

Source: Chief Engineer, IGNP, Jaisalmer

Table 24. Effect of canal side plantations on cost of de-silting of deposited sand

Branch/Distributaries/Minors	Cumulative reduction in sand deposition in canal ($m^3\ km^{-1}$) as compared to base year 1996			Cumulative net savings on de-silting of canal (Rs. km^{-1}) as compared to base year 1996		
	1997	1998	1999	1997	1998	1999
Sagarmalgopa Sakha	1248	2046	2856	25771	43024	62853
Mandau Distributary	1519	1923	1923	31367	40101	40101
Sankhla minor	248	404	1025	5865	9238	24440
Tibrewala Minor	1312	1312	1312	27093	27093	27093
Mean	1082	1421	1779	22524	29864	38622

Source: Chief Engineer, IGNP, Jaisalmer

4.6 SAND DEPOSITION ON ROAD

The main objective with which roadside plantation or shelterbelts along roads were raised was to abate deposition of sand on the road and reduce the velocity of moving wind. Based on the information provided by the General Reserve Engineering Force (GREF) for selected road side in Jaisalmer, it can be inferred that road side plantations have been effective (Plate 11) in

Plate 11. Effectiveness of Shelterbelt in protecting roads from drifting sand

achieving the objectives for which they were raised and sand deposition has been controlled to a great extent. Road blockages by blown sand, which were common features in absence of any shelterbelt along roads, have decreased in areas where road side plantations have come up (Table 25).

Table 25. Road blockages due to deposition of sand in absence of roadside shelterbelt plantations

Sr. No.	Name of Road	Location (km)	Length (m)	Height (m)
1	Ramgarh - Longewala	11.20 to 11.50	300	3
		14.00 to 14.35	350	3
		28.20 to 28.30	100	1
2	Ramgarh Ashutar -Ghotaru	37.10 to 37.50	400	3
		44.60 to 44.80	200	1

❑ ❑ ❑

5. Shelterbelts for protection against extreme weather events

Occurrence and intensity of extreme weather events has increased due to global warming and are major concern of farmers distress. Weather event based insurance systems are being contemplated to reduce risks. This, however, requires bench marking of critical levels of various events for different crops or commodities and rate of reduction in productivity and income due to deviations from the normal value say of minimum or maximum temperature, rainfall, etc. The other alternative is to moderate or mitigate adverse effects by applying irrigation, mulches or shelterbelts particularly in arid ecosystems. Tree and micro-shelterbelts are very effective in arid Rajasthan for minimizing the impact of extreme weather conditions like heat waves, cold waves, high velocity winds that are common in the arid region. Besides reducing the wind speed, thereby, resulting low evapotranspiration rates, higher moisture use efficiency, reduced wind erosion and finally maintaining better soil health and productivity, shelterbelts provide protection to various extreme events encountered in arid region. Planting tall growing trees around orchards for reducing wind velocity, breakage of branches and fruit shedding is a well known practices of horticulture. A detailed study on the impact of cold waves and heat waves on Indian agriculture were studied by Samra et al., (2003) and Samra and Gurbachan Singh (2004). The aberrant weather extremities frequently encountered in hot arid region poses great threat to growth and productivity of agricultural crops, horticulture and even to some sensitive tree species in both kharif and rabi season. These extremities follow in sequence one after another engulfing crops at various stages of growth. Extreme weather conditions recorded in arid region (Table 26) show that the air temperature rises up to 50°C in summer months and on the contrary the

Table 26. Extreme weather conditions in arid Rajasthan

Location	Air temperature (°C)		Relative humidity (%)		Wind speed (kmph)	Dust storms frequency (Number)
	Maximum	Minimum	Morning	Afternoon		
Barmer	48.9	-1.7	59	18	14.2	3
Bikaner	49.4	-2.8	53	16	13.3	8
Ganganagar	50.0	-2.8	61	16	10.7	17
Jaisalmer	47.8	-4.4	63	19	27.2	2
Jodhpur	48.9	-2.2	52	16	18.5	6
Sikar	47.8	-3.9	66	19	11.6	1

minimum temperature falls below -4.4°C in winter period causing frost injuries. Low specific heat of sand and lack of vegetative cover drive the extreme fluctuations in arid ecosystems.

5.1 INTENSITY AND SPREAD OF COLD WAVE IN RAJASTHAN (A CASE STUDY)

In association with passing western disturbances, severe cold wave conditions prevail during December-January over the entire northwestern and northern parts of India, covering states of Punjab, Haryana, Delhi, Rajasthan, Uttar Pradesh, Bihar and West Bengal (Fig. 9). Fluctuations in the minimum temperature at Delhi during first two weeks were quite bumpy (Fig. 10).

Severe cold wave conditions prevailed during 2005-06 *rabi* season for 13 to 15 days over north-northwestern parts of Rajasthan. The first cold spell of very severe nature occurred as early as 15th

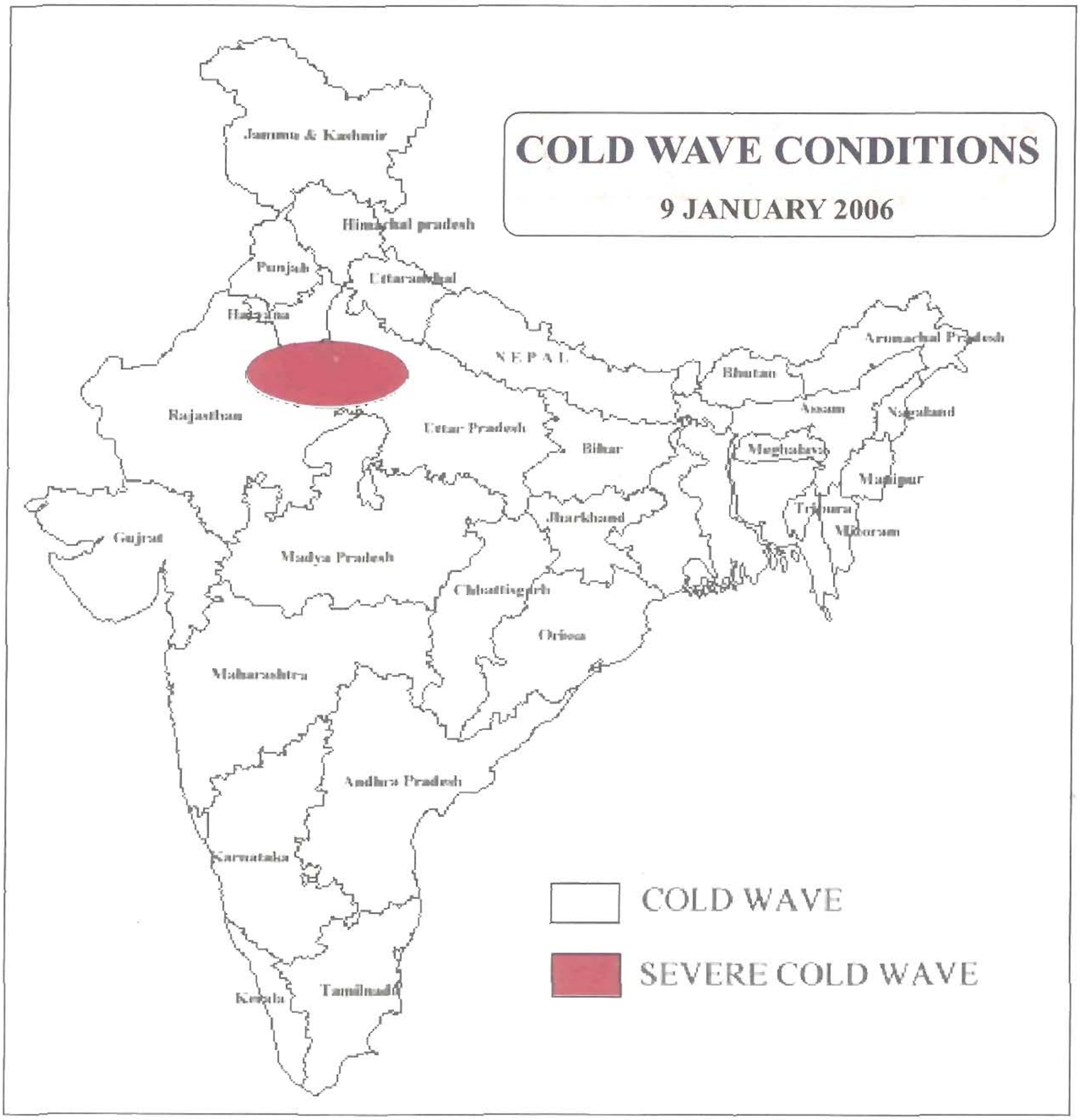

Fig. 9. Cold Wave Conditions

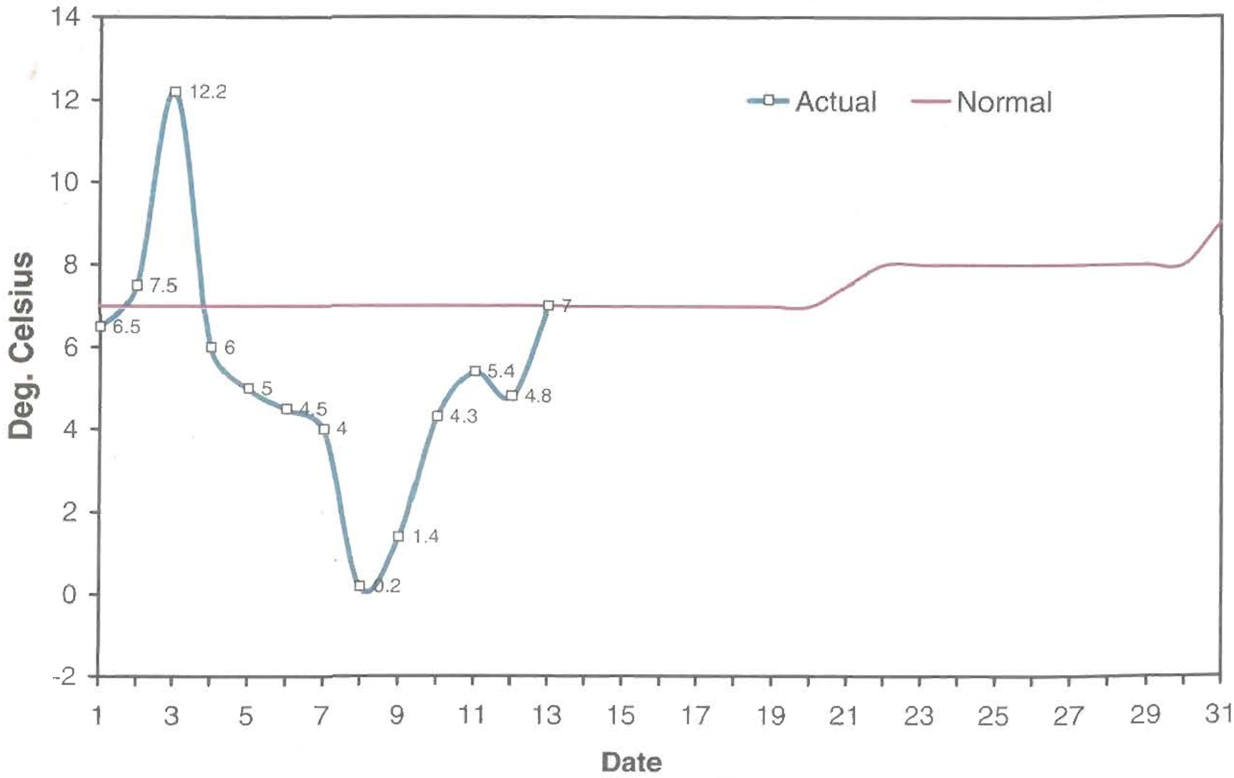

Fig. 10. Delhi Minimum Temperature (January 2006)

December, 2005 and continued for 12 days. The second spell of severe cold wave again set in from 4th January and continued for a period of two weeks.

The Districts of Churu, Jhunjhunu, Sri Ganganagar, Hanumangarh, Sikar, Jaisalmer and Bikaner were affected by intense cold wave conditions (Fig. 11). Fatehpur (Sikar) recorded lowest minimum temperature of -5.5°C on 8th January, 2006. Churu recorded lowest night temperature of -3.4°C on 7th January, which was below normal by 7°C. Pilani in Jhunjhunu district also recorded as low as -2.1°C on 8th January, which was 6°C below the normal. In the extreme northwest, Sri Ganganagar and Hanumangarh also experienced freezing temperature (-0.8°C). On the western side, Bikaner recorded lowest of -2.8 °C on 7th January with Jaisalmer and Chandan also touching mercury below 0 °C during the period.

Normally cold waves occur in western Rajasthan for 10-12 days in the month of January and that too intermittently. The number of days with severe and moderate cold wave conditions, when crop damages were also reported heavily, are given in Table 27. Severe cold wave conditions (with departure of ≥ 5°C from normal minimum temperature) prevailed for 4 to 8 days and moderate cold wave (with departure of 3-4°C from normal minimum temperature) prevailed for 6 to 10 days at these locations. The daily minimum temperature with normal for severely and moderately cold wave affected areas from 15th December, 2005 to 12th January, 2006 are shown in Fig. 12 and 13.

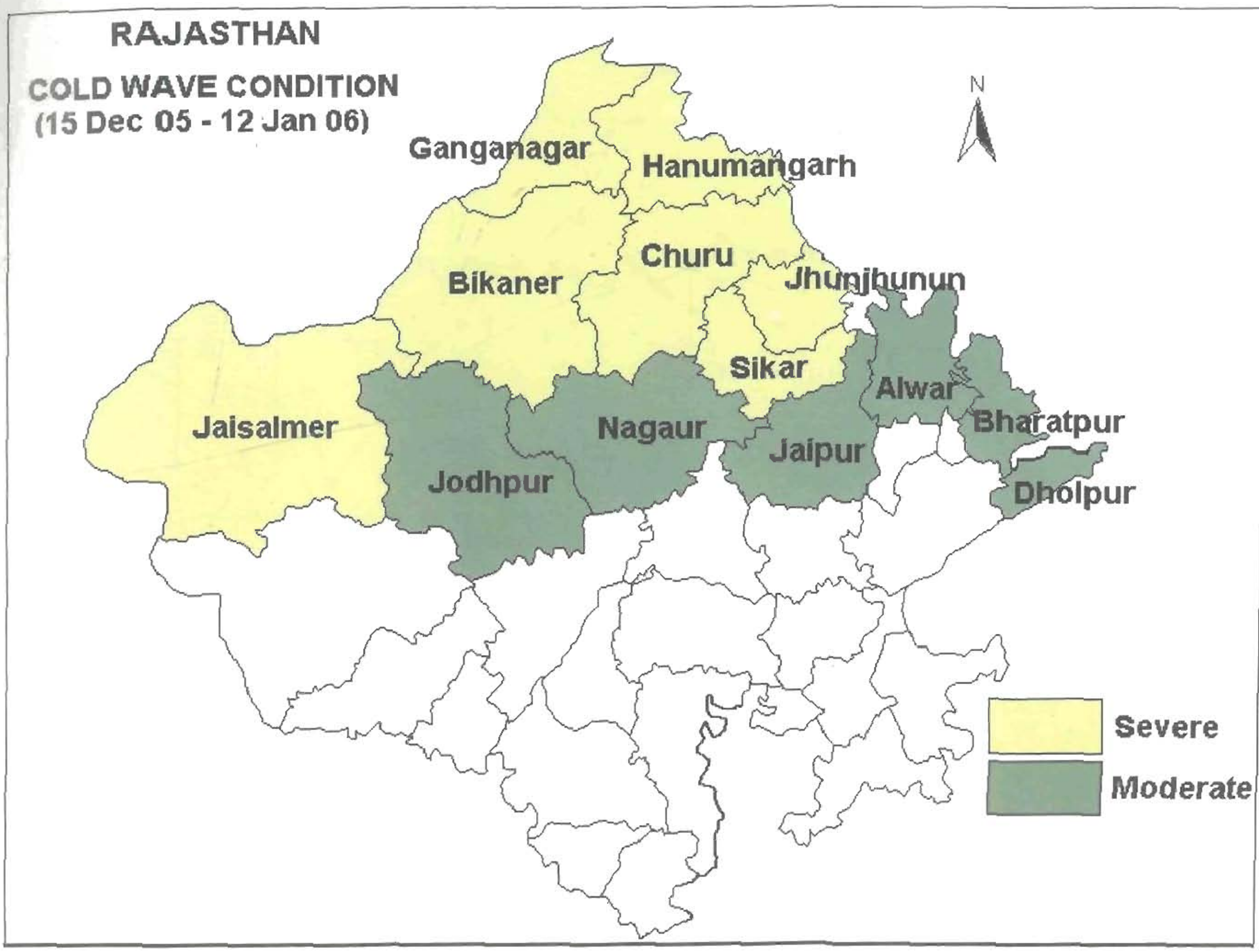

Fig. 11. Cold wave conditions over Rajasthan during 2005-06

Table 27. Cold wave conditions over western Rajasthan (15th December, 2005 to 12th January, 2006)

Location	Number of days		Total duration
	Severe cold wave	Moderate cold wave	(days)
Churu	8	7	15
Pilani, (Jhunjhunu)	5	10	15
Bikaner	7	6	13
Jaisalmer	4	9	13
Chandan (Jaisalmer)	0	9	9
Sri Ganganagar	1	7	8
Dholpur	2	0	2

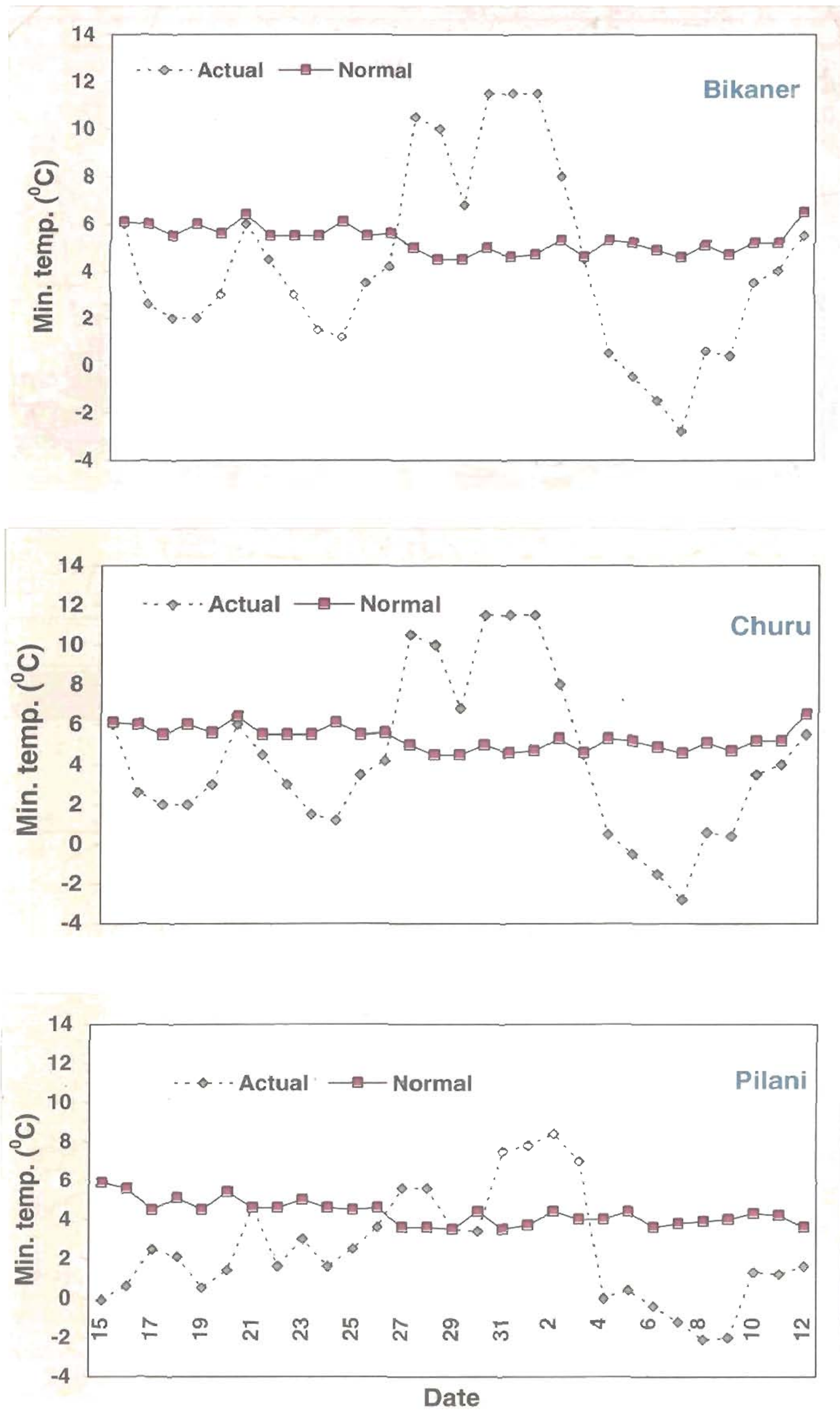

Fig. 12. Deviations from normal minimum temperature at Bikaner (a), Churu (b) and Pilani (c)

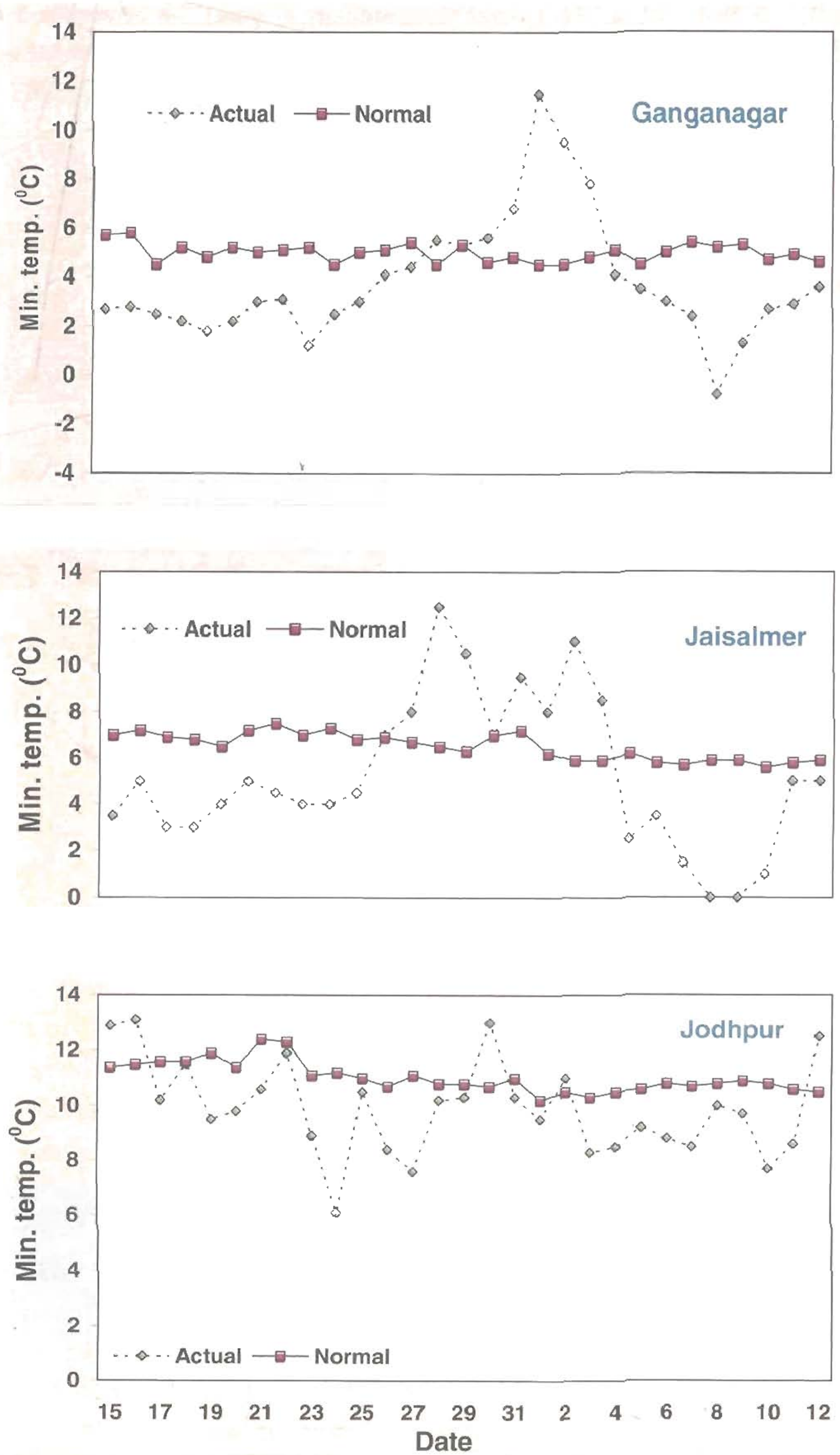

Fig. 13. Minimum air temperature and its normal at moderate cold wave affected locations in western Rajasthan from December 15, 2005 to January 12, 2006

5.2 IMPACT OF COLD WAVE ON WOODY PLANTS AND RABI CROPS

Impact of cold wave on woody plants

Preliminary survey was carried out in January, 2006 after cold in the Sikar district of Rajasthan and a range in tolerance of different species is evident from Table 28. Species in the last column of Table 28 would be ideal for creating shelterbelts due to their tolerance. Recovery of damaged tree was again evaluated in March, 2006 starting from different parts of the trees (Table 29). On an average there was 40-80% revival of growth in woody plants. However, fruit yield was reduced by 44 to 68%.

Impact of cold wave on rabi crops

The cold wave of 2005-06 severely affected *rabi* crops like mustard, cotton, castor, fruit plantations and vegetables. Heavy crop losses due to cold wave in the arid districts of Churu, Jhunjhunu, Hanumangarh, Sri Ganganagar, Sikar, Jaisalmer and Bikaner and moderate losses from districts of Jodhpur and Nagaur were observed.

The minimum temperature went down as low as -2.0 to -5.5 °C at Fatehpur continuously during 4th to 9th January 2006. Due to this cold wave, castor crop was totally damaged (100%). Early sown (before 10th Oct. 2005) mustard crop at grain development stage was also damaged and grain was shrunk in 90% of the cropped area in villages of Bimasar, Harsawa, Kayalnpur, and Mandawa areas.

At Gaurisar village of Churu district, Ber orchard was damaged and all leaves became dry and turned whitish. Farmers tried remedial measures like spraying of 0.1% sulphuric acid and smoking around the ber orchard in night but all efforts failed to save the orchard against the severe frost. However, sprinklers were quite effective (Plate 12). At the same location, cabbage and wheat crops were not affected by frost.

Plate 12. Sprinkler irrigation turned effective in saving crops from cold wave

In the extreme western part of Jaisalmer district, the occurrence of cold waves and frost injuries are a common phenomenon. The minimum temperature dipped to 1.5°C in the first week of December, 2005, damaging vegetable crops like chillies and brinjal. The low temperature was around 0°C in rocky terrain nearer the city of Jaisalmer between January 5-8, 2006, whereas it dropped sharply from 7°C to 1°C at Chandan in the heart of irrigated and sandy tract on January 3, 2006. Temperature dropped continuously and remained below 0°C and mercury further dipped to -2.5 to -3.0°C on January 6 and 7, 2006, which caused severe damage to *rabi* crops in entire area under canal and tube well irrigation in the district. About 50% of chillies crop had been harvested by the end of December 2005, but remaining 50% crop in the field was damaged completely (Plate 13). Similarly 100% damage was observed in vegetables like brinjal and onions in nursery stage. Severe damage in castor, ranging from 50%

Table 28. Cold wave effect on woody plants in Fatehpur Shekhawati, Rajasthan (Sikar District)- A preliminary survey (25.12.05 to 10.01.06)

Severely damaged (more than 75 %, all age groups affected)	Partially damaged (25 % young plants upto age of 3-4 yrs affected)	Not damaged (less than 5 %)
(A) Trees		
Prosopis juliflora	*Hardwickia binata*	*Prosopis cineraria*
Acacia tortilis	*Acacia nilotica*	*Tecomella undulata*
Moringa oleifera	*Capparis decidua*	*Acacia senegal*
Azadirachta indica	*Dalbergia sissoo*	*Salvadora oleoides*
Cordia myxa		*Acacia leucophloea (Roonj)*
Ailanthus excelsa		
Ficus religiosa		
Albizzia lebbek		
Melia azadirachta		
(B) Fruit Trees		
Aonla	Mango	Citrus species
Guava		Bael
Karunda		
Ber		
(C) Shrubs		
Jatropha	*Leptadaenia pyrotechnica*	*Crotolaria burhia*
Calotropis procera	*Tephrosia purpuria*	*Kochia viscosa*
Mopen		

Table 29. Revival of frost damaged woody plant surveyed in March, 2006

S.No.	Name of the trees	Plant part of revival\rejuvenation	Percentage
1	*Prosopis juliflora*	(i) Collar region (<5 cm diameter)	40-60
		(ii) Crown region (5-15 cm diameter)	50-70
		(iii) Crown and branches up to 5 cm diameter (> 15 cm diameter)	80-100
2	*Acacia tortilis*	Similar as *Prosopis juliflora*	
3	*Acacia nilotica*	(i) Collar region (<10 cm diameter)	40-60
		(ii) Crown region (10-20 cm dbh)	60-80
4	*Azadirachta indica*	(i) Collar region (<10 cm diameter)	30-50
		(ii) Crown region and branches upto 5 cm diameter (20 cm dbh)	60-80
5	*Ailanthus excelsa*	Similar as *A .indica*	
6	*Albizzia lebbek*	Crown region (>15 cm dbh)	50-60
Fruit Trees*			
1.	Aonla*	Crown region	70-90
2.	Guava	Crown region	80-90
3.	Ber (*Zizyphus auritiana**)	Crown region	80-100
Shrub			
	Jatropha	Collar region	< 5

*Fruit yield was reduced by 44-68%

Plate 13. Chilli crop damaged due to frost at Bherwa village

to 80%, was observed where crops were completely damaged (Plate 14). The fruit crops, including improved Ber Cv. Gola and Seb, Anola and Gonda, were damaged up to 50-80% (Plate 15, 16 & 17) and more in fields where less irrigation was given. Heavy damage (20-80%) in early-sown mustard, cumin and Isabgol was observed. The recently popularized medicinal plant species *Cassia angustifolia* (Senna or Sonamukhi) was completely burnt by low temperature (Plate 18).

Plate 14. Castor crop damaged due to frost at Sodakor village (Jaisalmer).

Cold wave of 2006 also damaged potatoes, tomatoes and brinjals in Haryana, Punjab and Delhi areas bordering Rajasthan. Even mortality of tropical fish species was reported as far as Patna in Bihar.

In Ludhiana early (October) planted potatoes yield was reduced by 20 to 40% as compared to 40-70% in the late planted (November) due to chilling waves of 2006. Tree belts along G.T. Road, railways and canals protected crops upto 100 metre distance from the shelterbelt.

Plate 15. Ber orchard damaged due to frost

5.3 IMPACT OF SHELTERBELTS ON COLD WAVE IN JAISALMER REGION

Shelterbelts are helpful in protecting crops from cold weather extremities by virtue of their capacity to minimize desiccating and freezing effects of extremities on crops. Survey in the

Plate 16. Aonla orchard damaged due to frost at Sodakor village (Jaisalmer).

Plate 17. Gonda (*C. myxa*) orchard damaged due to frost at Sodakor village (Jaisalmer).

irrigated area of Lathi series revealed that when night temperature fell up to freezing point along with chilly wind, the shelterbelt were found effective in protection of crops up to a distance five times the height of trees (5H) on leeward side Plate (19 & 20). During *rabi* season, the average loss on crop productivity with shelterbelts was 17 percent due to cold wave in comparison to 30% on farms without shelterbelts (Table 30). In new Khadins without any tree-belt on bunds the loss was 41%. The cash crops namely, cumin, castor, chillies and vegetables which are sensitive to cold waves could be saved up to 30% due to shelterbelts during a severe cold wave that occurred in the first week of January, 2006, when temperature remained below 0^{0}C for 4-5 days and lowest recorded was -4^{0}C.

Plate 18. Sonamukhi (*Cassia angustifolia*) damaged by frost at Bikaner

Table 30. Effectiveness of tree-belt on khadin-bund in protecting crops from cold wave

Crops	Extent of damage (%) in different khadin							
	Fields of *Khadin* near the tree-belt on bund (within 5 H of tree-belt)			Fields of *Khadin* away from the tree-belt on bund (beyond 5 H of tree-belt)			New *Khadin* with out tree-belt	
	Baramsar (Poda)	Damodra (Masoordi)	Rupsi	Baramsar (Poda)	Damodra (Masoordi)	Rupsi	Barmsar (new)	Benjai (dudhwala)
Mustard	22.5	45.0	5.0	56	90	10	60	100
Wheat	5.0	7.5	12.5	7.5	12.7	25	-	25
Gram	7.5	32.5	17.0	-	51.1	20	-	60
Average		17			30			41

Plate 19. Shelterbelt plantations provide protection to mustard crop from cold wave

5.4 HEAT WAVES OVER WESTERN RAJASTHAN

High air temperatures combined with dry environment (humidity <16%) and high velocity winds reaching 50-60 kmph with daily mean up to 27 kmph create heat wave. This causes excessive evapotranspiration particularly in summer growing vegetables and leads early maturity with poor grain filling that results in low crop yield. The arid Rajasthan experiences high air and soil temperatures during summer considerably influencing the vegetation and crops due to high water requirements. The air temperatures sharply increase from April onwards and stands highest during May till pre-monsoon showers sets in the area. The summer air temperatures vary between 36.0°C and 42.9°C in the east to 38.8°C and 45.5°C in the western parts of arid Rajasthan (Fig. 14). The region recorded as high as 49°C in summer and -5.7°C during winter months. The temperatures fall during the monsoon period (June-September), but however rise after recession of the monsoon by about 3 to 5°C before again falling from December onwards due to winter conditions. Rise in temperature around 1st and 2nd week of February is highly detrimental to wheat crop since it induces early senescence, affects grain filling with reduced productivity. Frequent irrigation especially with sprinkler is important remedy which not be feasible in water deficit area of arid agro-ecologies.

The heat wave conditions during May 2002, at four locations in arid Rajasthan are shown in Fig 14. The heat wave unabated during the first week with air temperatures shooting above normal by 4-6°C at Jodhpur and Pali and 6-9°C above normal at Bikaner and Jaisalmer. Sometimes, the conditions continue or revive after a break of few days.

Plate 20. Shelterbelts providing protection to crops from cold wave: Crop near the Tree- belt survives whereas, crops away from belt are damaged.

The effect of heat wave on summer crop (groundnut and vegetable) is devastating. Many times farmers have to do re-sowing as crop fail to germinate due to burial of seeds with windborne sand and burning of young seedlings. The heat wave sets in the month of April and continues till July. During second fortnight of September the direction of winds intermittently changes from southwest to northeast or north-northeast. The frequent changes in high speed wind during this period causes maximum damage to legume crops which are at blossom stage. This phenomena called *Jhola* in local parlance also affects early sown crops of mustard, jeera and isabgol.

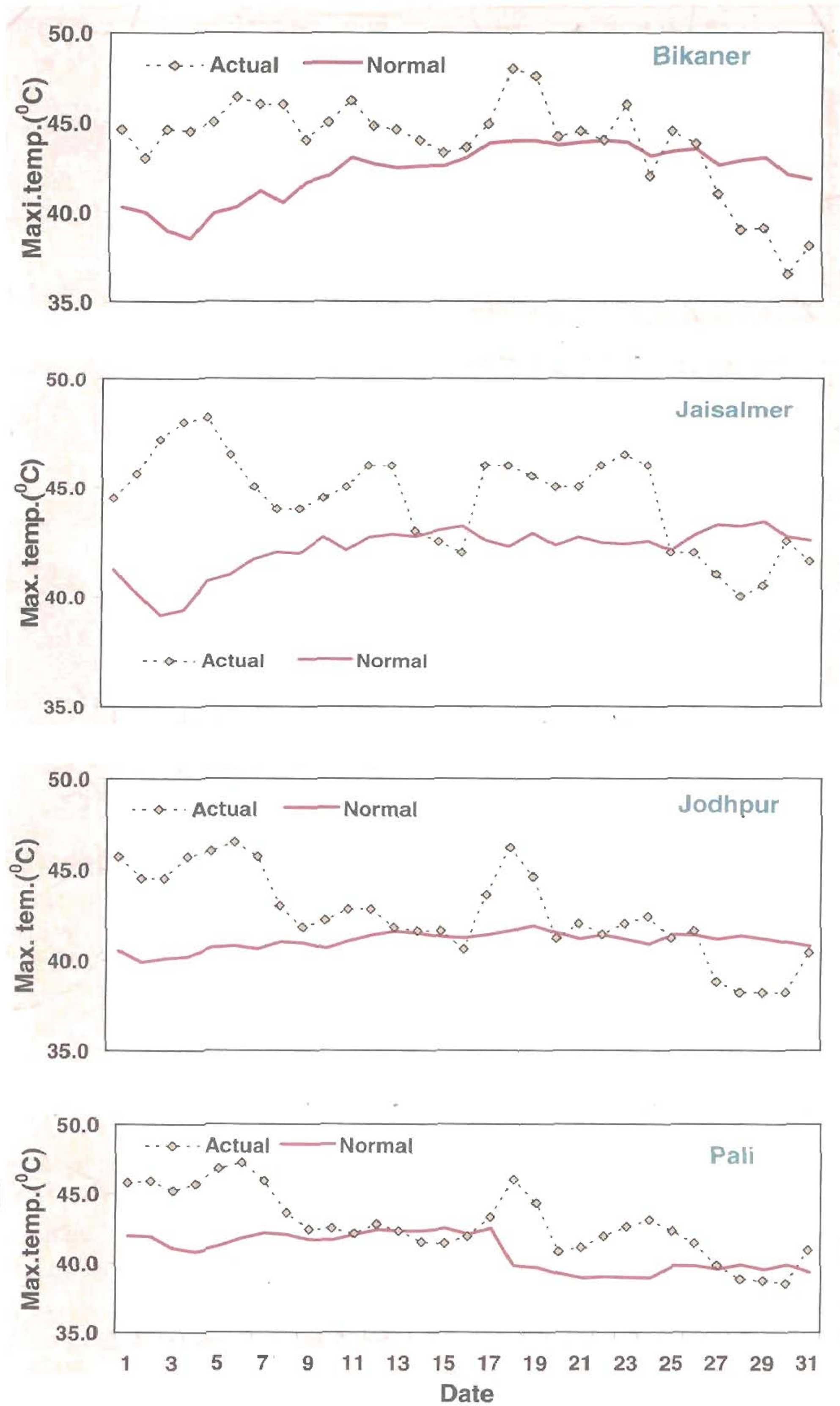

Fig. 14. Maximum air temperature and its normal at heat wave affected areas of arid Rajasthan of May 2002

5.5 IMPACT OF SHELTERBELTS ON HEAT WAVE

Shelterbelts have been found to have considerable affect on crops subjected to heat wave (Table 31). Shelterbelts reduced losses of crops affected by heat wave to the tune of 12 to 16 percent in *kharif* season as compared to losses incurred (30.5%) in crops grown without shelterbelts. The variation in losses in different crops under shelterbelt might be due to difference in plantation density.

Foregoing discussion shows that shelterbelts not only provide defence against strong wind and prevent wind erosion/ sand movement but offer a protection against weather extremes like frost and heat as well as high temperatures.

Table 31. Variation in crop yield ($q\ ha^{-1}$) on farms with and without shelterbelts after heat wave

Season/crop	Farms with shelterbelt			Farms without shelterbelt		
	Normal	Affected	% Variation losses	Normal	Affected	% Variation losses
Kharif (High temperature and high wind velocity)						
Groundnut	23.7	20.8	12.2	8.2*	5.7*	30.5
Bajra	22.0	18.7	15.0	-	-	-
Guar	12.0	10.1	15.8	-	-	-

❑ ❑ ❑

6. Socio-economic Impact of Shelterbelts

6.1 ADOPTION STATUS

The farmers' exposure to the shelterbelt technology was examined in the surveyed villages to assess adoption status (Table 32).

In tube well irrigated villages, out of 175 farmers surveyed, 75% reported that they knew about the technology while only 40% farmers heard about the technology in canal command area. Nearly 100% farmer adopted shelterbelt technology under tube well irrigation. In case of canal command area the per cent of use status was low (38%). The high percentage (62%) of farmers, who used this technology, reported that shelterbelt plantation was yet to establish but they had shown willingness for 100 per cent retention, it was established. This indicated that wherever the shelterbelt established the farmers have retained. The reason for not establishment of shelterbelt in the canal command area is non availability of water throughout the year. Farmers are well aware that without establishment of shelterbelt, drifting sand will cover land within five years if, the present condition continues.

The main reason of adoption of shelterbelt technology in the study area is principally due to beneficial effects in reducing the wind velocity, which normally carries the sand. When the sand particles continuously strike and fall with high speed, the crops are destroyed during the *kharif* season. Farmers are convinced that without

Table 32. Adoption status and rate of adoption of shelterbelt technology in tube well and canal command areas.

Particular	Tube well command area (%)(N=175)*	Canal command area (%) (N=300)*
Heard about		
Yes	72	40
No	28	60
Use Status	N=80	N=100
Adopted	100	38
Not established	-	62
Retention	100	100

* Sample size.

shelterbelt protection, growing of major crops in *kharif* season is not possible. Besides protective benefits from the shelterbelt plantations, farmers also meet out their requirement of wood, fuel and fodder. It is clear that with out shelterbelt, farming activities particularly during *kharif* season is not feasible. Similarly during rabi season, optimum yield could not be obtained on the farmers' field without shelterbelt plantations.

Constrains in adoption : Across the villages surveyed in tube well and canal command areas, the technology of shelterbelt plantation has been perceived highly beneficial. The constraints in non-adoption of the technology are different in the different irrigated situations. In tube well irrigated area of Lathi series the main constraints are:

(i) Poor marketing facilities,

(ii) Non availability of inputs,

(iii) Less experience of land owner (as the land is given to agricultural landless laborers who have no experience of improved farming),

(iv) Poor care by land owner, and

(v) Lack of motivation from the concern agencies.

In canal command area, major constraints are :

(i) Non-availability of water throughout the year,

(ii) Allotment of land to the landless and less experienced farmers,

(iii) Long distance,

(iv) Poor transport,

(v) Poor markets for input and farm produce, and

(vi) Lack of enthusiasm

Shelterbelts have been planted only on farms where owners have settled. Majority of farming is contract farming in which there is less interest of cultivator who is not owner of the land. Due to uncertainty about water availability, many farmers have abandoned the farming activities completely leaving fields idle in canal command area of IGNP stage II.

6.2 EMPLOYMENT GENERATION

Massive afforestation work taken by State Forest Department in last two decades along canals, road and railways has created employment opportunities for both men and women. For raising plantations and their maintenance, skilled as well as unskilled work force has been utilized. Employment of about 2.4 million man-days has been generated under Japan Bank of International Cooperation (JBIC) project during 1990-2002 in Jaisalmer district for execution of various plantation programmes along canals, roads, sand dunes, etc. (Table 33).

Besides, shelterbelt plantation has indirectly helped in generation of additional employment on farmers' field in the form of various agricultural activities. The employment generation, yield of the crop, revenue generation per farm basis is given in Table 34.

It is seen that the additional employment was generated by dense and partial shelterbelt to the extent of 107% and 115% on per farm basis, respectively. The higher employment generated

Table 33. Detail of employment generated by state forest department in Jaisalmer during 1990-2002

Year	Man days generated
1990-91	22807
1991-92	24706
1992-93	435599
1993-94	385463
1994-95	258842
1995-96	236400
1996-97	287925
1997-98	301676
1998-99	144290
1999-2000	78615
2000-2001	100650
2001-2002	119220
Total	2395893

Source: Divisional Forest Office, Jaisalmer

under partial shelterbelt was due to labour intensive crops like cumin and isabgol. In canal system, high value timber species (*D. sissoo*) was planted, which performed very well. From above discussion, it is clear that the shelterbelt technology,. particularly in the study area, has increased crop production, generated additional employment and also reduced per unit cost of production.

6.3 CROPPING PATTERN AND PRODUCTIVITY

With the creation of irrigation facility due to tube wells or IGNP canal, the cropping pattern of the region has changed completely. In irrigated areas, orchards of ber, pomegranate, *Citrus spp.* and *cordia myxa.* have been developed and maintained. Today more than two million ha lands in Thar Desert grow brinjal, chillies, tomatoes and potatoes. Ber especially a fleshy grafted variety is an important source of income. The above advancements are directly related to advent of irrigation, however, indirectly the shelterbelt plantation carried out along field boundary for protection has helped in sustaining changed cropping pattern. In addition, tree-belt plantations along canals to protect the channels from sand deposition have immensely helped in maintaining the flow and volume of water in the channels.

Survey of farmers' field in IGNP command area of Mohangarh in Jaisalmer has revealed a significant change in crop rotation, cropping pattern and productivity due to presence of shelterbelt plantations. More changes in crop rotation and cropping pattern have been noticed

Table 34. Employment, machinery, yield of crops and revenue generation (per farm basis) on farms with and with out shelterbelts

Particular	Farms with dense shelterbelt (18)*	Farms with partial shelterbelt (62)*	Farms without shelterbelt (Control) (80)*
Labour (Man-days farm^{-1}) (farm size 5ha)			
Kharif	215	165	75
Rabi	200	265	125
Total	415	430	200
Production (q farm^{-1})			
Kharif	110	94	32.5
Rabi	120	108	75.0
Total	230	202	107.5
Returns (Rs. farm^{-1})			
Kharif	200000	182000	52000
Rabi	144000	194500	90000
Total	344000	376500	142000
Expenses (Rs. farm^{-1})			
Kharif	63020	55800	44685
Rabi	42130	29875	35070
Total	105150	85675	79755
Net return (Rs. farm^{-1})			
Kharif	136980	126200	7315
Rabi	101870	164625	54930
Total	238850	290825	62245

* Number of actual farmers surveyed

within 30H distance on leeward side of the shelterbelt plantations and varied according to age of the trees. Farmers experienced that 10 years old shelterbelt plantations affect crop up to distance of 25H. The crop like groundnut, cumin, cotton, etc. grow well beneath the belt plantation. Most of the farmers agreed that there are no significant changes in bird menace, however, increased infestation with diseases and pests have been noticed in crops grown in sheltered area. Some farmers also expressed increase in maturity time of crop due to presence of shelterbelt plantations on farm bunds, which can be attributed to availability of moisture for longer period as compared to non-shelterbelt farms.

The major crops grown under shelterbelt are groundnut, guar and pearl millet in *kharif*. However, mustard occupied important place during rabi season, the other crops like cumin, isabgol, gram and barley are also coming up very fast but wheat is grown in limited area (Table 35).

Cost and returns of different crops under farms with and without shelterbelts are as follow.

***Kharif* season** : On an average, cost and returns from groundnut worked out per hectare basis and presented in Table 36 revealed that in both dense and partial shelterbelts, maximum expenditure was incurred on labour and minimum on land preparation. In tube well command the irrigation charges varied depending upon actual consumption. However, under canal irrigation, there are no water charges for growing any crop resulting in low expenditure.

It is inferred that in dense shelterbelts the expenditure on labour increases. The yield also increased in comparison with control and over partial shelterbelt in both irrigation systems. The unit cost of production of groundnut was lowest under canal irrigation with single-row shelterbelt and highest under control. The yield obtained under control was mainly from those farms which were situated in depression. During the month of August, high wind velocity can destroy entire crop fields under control situation.

Table 35. Cropping pattern of farms having different type of shelterbelts under different sources of irrigation

Cropping pattern on farms with shelterbelt		Cropping pattern on farms without shelterbelt (Control)
Tube well irrigation	Canal irrigation	
Groundnut	Groundnut	Groundnut
Pearl millet	Pearl millet	Pearl millet
Mustard	Mustard	Mustard
Wheat	Wheat	-
Cumin	Cumin	-
-	Isabgol	-
-	Barley	-
-	Guar	-

Table 36. Cost and return from Groundnut crop under different type of shelterbelts (Rs ha^{-1})

Particular	Tube Well irrigated		Canal irrigated	Control
	Farms with dense shelterbelt	Farms with partial shelterbelt	Farms with partial shelterbelt	
Cost				
Seed	3500	3200	2500	3000
Land preparation	1455	1295	1450	1085
FYM and Fertilisers	1890	1660	1500	1630
Insecticides/pesticides	430	390	231	0.00
Irrigation charges	2357	2357	-	2357
Labour	2972	2258	1975	1065
Total	12604	11160	7656	8937
Returns				
Seed (main product) (q ha^{-1})	25.00	22.75	22.25	6.50*
Fodder (by product in q ha^{-1})	25.00	22.75	22.25	6.50
Total (Rs. ha^{-1})	40000	36400	35600	10400
Unit cost of production	572.91	603.24	463.98	787.40

*Yield obtained under farm sites situated in depression area.,

***Rabi* season :** The main crop during rabi season is mustard which occupies nearly 70% area and the remaining area is under cumin, isabgol, gram and barley crops. The cost and returns from mustard under different shelterbelt is presented in Table 37.

The mustard production increased by nearly 60% and 37% under dense and partial shelterbelt, respectively due to protection from cold wind.

The cost and returns from crops viz. cumin, isabgol, wheat and gram were also estimated and the same are presented in the Table 38.

The major expenditure was on labour and land preparation. In case of cumin the expenditure on FYM and fertilizers were more as compared to land preparation. The low productivity under canal irrigation with shelterbelt was due to low fertility of soil. The availability of farm yard manure is also main constraints in the area.

Table 37. Cost and return from mustard crop under different type of shelterbelts (Rs. ha^{-1})

Particular	Tube well irrigated		Canal irrigated	Farms without
	Farms with dense shelterbelt	Farms with partial shelterbelt	Farms with partial shelterbelt	shelterbelt (Control)
Cost				
Seed	250	215	220	188
Land preparation	1295	1295	1250	1295
FYM and Fertilizers	845	680	1180	560
Insecticides/pesticides	300	330	275	270
Irrigation charges	2946	2946	-	2946
Labour	2790	2260	2340	1755
Total	8426	7719	5265	7014
Returns				
Seed (main product) (q ha^{-1})	24.00	20.50	21.00	15.00
Total (Rs.ha)	28800	24600	25200	18000
Unit cost of production	351.12	376.74	250.71	467.60

Table 38. Cost and returns from cumin, isabgol, wheat and gram crops under canal irrigation with shelterbelt plantations (Rs. ha^{-1})

Particular	Crops grown under canal irrigation with shelterbelt			
	Cumin	Isabgol	Wheat	Gram
Cost				
Seed	750	150	950	450
Land preparation	1500	1400	1400	1400
FYM and Fertilisers	2250	980	850.00	550
Insecticides/pesticides	750.00	250	125	75
Irrigation charges	-	-	-	-
Labour	2750	2250	1750	1250
Total	8000	5030	5075	3725
Returns				
Seed (main product) (q ha^{-1})	9.5	8.25	31.5	18.20
Total (Rs. ha^{-1})	76000	26400	22050	14560
Unit cost of production	842.10	609.70	161.12	204.67

6.4 FULFILMENT OF BASIC NEEDS

Frequent drought and famine are common phenomena in arid region. Natural grasslands and forests are often subjected to excessive biotic interference in the form of overgrazing and removal of fuel wood. Excessive extraction and uprooting of indigenous trees/bushes to meet ever increasing demand of fuel wood and household timber is a threat to natural vegetation resource of arid region. Some of the species like *Calligonum polygonoides,* which forms main vegetation in sandy desert of Jaisalmer, Barmer and Bikaner districts of Rajasthan, are now facing serious threat of their extinction. Supply of fuel wood and small timber from shelterbelt would certainly reduce pressure and contain such devastating processes. Introduction of multipurpose trees (MPTs) like *Accacia tortilis, Albizzia lebbek, Azadirachta indica, Acacia nilotica* etc. for tree-belts along roads, canals, field boundary of farm land and rangelands supplements local demand of fuel and fodder along with its main objective of reducing wind. Farmers informed that leaves of trees *like Acacia nilotica, Prosopis cineraria, A. tortilis Z. mauritiana A. india* etc. are highly palatable and provide good fodder/browse material for animals. The top feed (leaves and pods) provided by trees is very nutritious fodder for grazing animal (Ahuja, 1977). The role of shelterbelts in providing top feed as alternative source to supplement decreasing fodder productivity in traditionally pastoral economy of arid zone of Jaisalmer has been well recognized by the villagers. As a consequence of improvement in availability of fodder for livestock, there has been a change in migration pattern of nomads. As per District sheep and wool development office, Jaisalmer; migration of sheep to neighboring areas has consideably reduced (Fig. 15).

In the surveyed area, the farmers opined that beside top feed, the shelterbelt plantations have generated various types of product including fuel wood, timber and fruits. The dense shelterbelts of trees (three rows shelterbelt of 15 to 20 years old) have provided fuel wood, fodder and timber while partial (single or double-row belt) having fruit plants like *Cordia myxa* (gunda) under tube well irrigation have provided additional income from

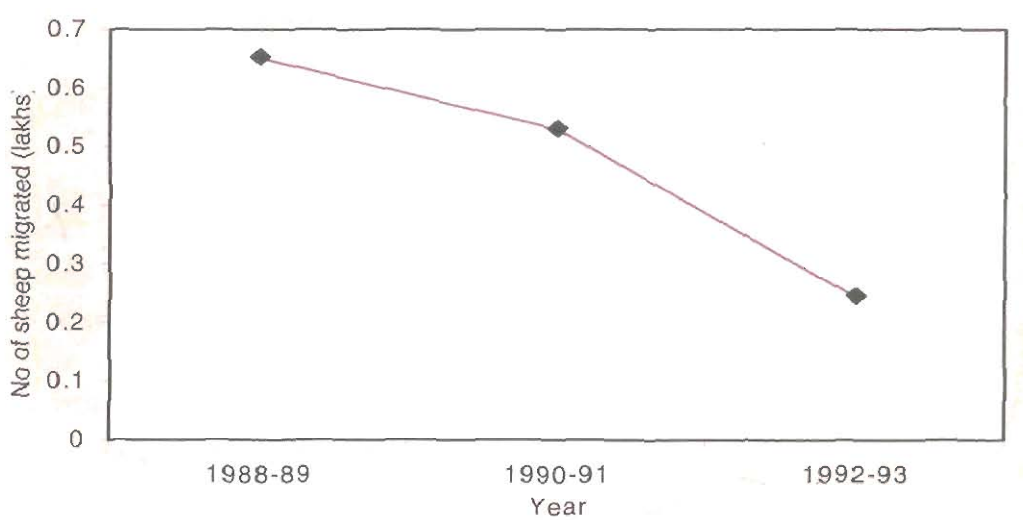

Fig. 15. Migration of sheep from Jaisalmer

fruit yields (Table 39). The D. *sissoo* based shelterbelt under canal irrigation yields timber, high quality wood for furniture and decoration which fetches high price in the market.

The higher returns from timber and fruits are due to production of high quality timber and gunda fruit, which generated more revenue. The pruned material obtained from young plantation partially utilised in home as fuel wood and partially as fencing material. Due to non-availability of market, farmers do not get desired prices for shelterbelt produce. It is assumed that seven to eight years old shelterbelt plantation can provide sufficient quantity of fuel wood and timber to meet some of the needs of local people. As per estimation of Forest Department, Jaisalmer, 1270q fuel wood and 48.5m^3 of timber was produced in five forest ranges of the district during the year 2004. The break up of fuel wood production in different ranges is given in Table 40.

Table 39. The additional income generated from 15-20 years old shelterbelt plantations

Particular	Annual additional income (Rupees per farm of 5ha size)	
	Dense	Partial
Fuel wood	30000	18000
Timber and fruits	7500	7000
Total	37500	25000

Table 40. Production of fuel wood and timber in Jaisalmer district in the year 2004

Forest range	Fuel wood (q)
I	316.6
II	22.5
III	301.1
IV	255.8
V	374.0
Total	1270.0

6.5 COMPOSITION OF LIVESTOCK POPULATION

Traditionally, the study area was recognized as a livestock rearing area where cattle, sheep, goat and camels were dominated and were the major source of livelihood. Earlier the average herd was constituted of nearly 65 cows, 280 sheep and 175 goats. After introduction of the tube well and canal irrigation, the on-farm livestock population has drastically reduced. The farmers shifted their livestock to relatives living in near by villages. The present livestock composition is given in Table 41.

The interesting feature is introduction of buffalo in the herd. The farmers keep some goat to meet out the milk requirement as and when it is required. As the cattle population increased the goat population has declined. In canal command area, plenty of grasses; top feed (pods and leaves of trees) and browse material is available for browsing and grazing of camel, sheep and goats due to shelterbelt plantations along main canal, distributaries and water courses. This has resulted in concentration of more animal population in afforested area in the recent past. The contribution of shelterbelt plantation has increased availability of fodder and has encouraged farmers to keep and maintain stall-fed animals like milch cattle and buffaloes.

Table 41. Average composition of livestock herd of households

Particular	Farms with dense shelterbelt	Farms with partial shelterbelt	Farms without shelterbelt (Control)
Cattle	10	6	3
Buffalo	6	2	-
Goat	15	20	30

6.6 DEVELOPMENT OF ASSETS

The change in social condition depends upon the income from various resources. The asset development has been assessed by construction of pucca house, farm implements and other modern facilities like, vehicle, TV, etc. procured by arid zone farmers. The study revealed that additional income of farmers from dense shelterbelts has changed the assets of farmers in various forms, which resulted in improved living standard over 15-20 years. The improvement in standard of living and changed life style motivated the farmer to send their children for higher education. The assets generated by the farmers in different shelterbelt systems are presented in Table 42. This is also attributed partly to over all development of arid region due to availability of water and increased productivity.

Table 42. Impact of type of shelterbelt plantations on development of assets by farmers

Particular	Farms with dense shelterbelt	Farms with partial shelterbelt	Farms without shelterbelt (Control)
House	Pucca with modern facilities	Pucca with modern facilities	Only Pucca
Transport	Four wheeler, Tractor with implements, motor cycle etc.	Four wheeler, Tractor with implements, motor cycle etc.	Only motor cycle
Children education facilities	Higher technical education at distant places	Higher technical education at distant places	Up to district head quarter
Other facilities	Modern communication like mobile phones, TV with dish	Modern communication like mobile phones, TV with dish	-

6.7 CONTRIBUTION OF SHELTERBELTS IN FARM ECONOMY

Net profit Decomposition model : For decomposition of total net profit of farm (having 5 ha), the regression equations were estimated separately for farms with shelterbelt and without shelterbelt by using 'Ordinary Least squares Method'. Chow's test (1960) applied to find out the equality of regression coefficient, indicated that shift in net profit was due to shelterbelt. Further, non-significant test of homogeneity of regression coefficients also indicated that the shift in high net profit was due to shelterbelt plantations.

The explanatory variables included in regression model explained adequate variations for shelterbelt and non-shelterbelt farms, which were 88.56 and 77.19 per cent, respectively. Further, the 'F' test indicated the value of coefficient of determinant (R^2) were significant at 1 per cent level. This shows that explanatory variables included in the regression model are adequate for forecasting.

The regression coefficient with standard errors and value of R^2 estimated for farms with shelterbelt and without shelterbelts are presented in Table 43. The estimated contribution of technological change and other complementary inputs were worked out with the help of regression coefficients and geometrical mean inputs used. The geometrical means of inputs are shown in Table 44. From the Table 45, it is seen that observed change in net profit per farm was 435 per cent. The technological changes are because of shelterbelt and also due to changes in response of inputs used over non-shelterbelt. Accordingly, the contribution due to shelterbelt were 305.6 and inputs namely like FYM+ (X1), total labour used (X2) and other expenses (X3) were 32.0, 38.8 and 23.0, respectively (Table 45).

The contribution of complementary inputs (change in value) viz. X1, X_2 and X_3 were 7.7, 21.6 and 2.1, respectively. The total estimated change due to shelterbelt was 430.8 per cent (99 % of observed change). The difference between observed change and estimated change might be due to round off the values used in estimation.

Table 43. Regression coefficients with standard errors of farms with shelterbelt and without shelterbelt plantations

Variables	Value of regression coefficients	
	Farms with shelterbelt	Farms without shelterbelt
FYM & Fertilizers (in Rs.)	0.2103 xx	0.1691 xx
	(0.0817)	(0.0611)
Labour (Man-days)	0.2859xx	0.1989 xx
	(0.1013)	(0.0817)
Other Expenses	0.0719 xx	0.0483 x
	(0.0302)	(0.0231)
Intercept	8.9217	3.1994
R^2	0.8856	0.7719
No. of observation	80	80

x Significant at 5 per cent level of significance

xx Significant at 1 per cent level of significance.

Figures in parenthesis indicate standard errors

Table 44. Geometrical means of inputs used per farm with shelterbelt and without shelterbelt

Particulars	Farms with Shelterbelt	Farms without Shelterbelt
FYM & Fertilizers (in Rs.)	15057.56	10571.33
Labour (Mandays)	386.61	181.87
Other Expenses (in Rs.)	22581.97	17083.11

Table 45. Decomposition analysis of change in net profit from shelterbelt

Particulars	Per cent attributes
Observed change	435.0
Technological change (with shelterbelt)	399.4
i) Shelterbelt plantations	305.6
ii) FYM & Fertilizers	32.0
iii) Labour	38.8
iv) Other Expenses	23.0
Complementary inputs (without shelterbelt)	
FYM & Fertilizers	7.7
Labour	21.6
Expenses	2.1
Total Estimated change due to Shelterbelt plantation	430.8

6.8 CONTRIBUTION OF SHELTERBELTS IN EMPLOYMENT GENERATION

Employment decomposition model : To know the additional employment generated by shelterbelt plantation, the data of farmers having shelterbelt and without shelterbelt were pooled with using dummy variable. The results of estimated regression model by using Ordinary least squares method are presented in Table 46. It is revealed that dummy variable is significant at 1 per cent level indicating structural break in net profit of the farm. The value of coefficient of determination of the regression model was 92.17 per cent, which indicated that explanatory variables included in the model are sufficient for forecasting. The 'F' value of R^2 was found to be significant.

Decomposition of labour employment required the estimated values of coefficient of variables and geometrical mean levels of inputs used per farm. Those farmers having shelterbelt plantation used higher levels of inputs in comparison to farmer having no shelterbelts. The observed change in labour due to shelterbelt plantation was 116.50% (Table 47). The decomposition model revealed that technological changes (due to adoption of shelterbelt) contributed nearly 76.5 per cent.

The contribution of complementary inputs due to farm-yard-manure and fertilizers' (X_1) and other expenses were 21.5 and 8.4 per cent, respectively. The total estimated additional employment generated due to shelterbelt was 106.4. It is clear that 75% additional employment generated was due to shelterbelt only and

Table 46. Estimated Net Profit function parameters, standard error and coefficient of determination (per farm)

Variables	Value of regression coefficient
Intercept	2.0715
Dummy (shelterbelt)	0.9579^{**} (0.1759)
FYM & Fertilizers	0.3056^{*} (0.0994)
Labour	0.3957^{*} (0.1083)
Other Expenses	0.1579^{*} (0.0759)
R^2	0.9217
No. of Observation	160

* Significant at 5 per cent level of significance

** Significant at 1 per cent level of significance.

Figures in parenthesis indicate standard errors

Table 47. Decomposition analysis of labour

Particulars	Per cent attributes
Observed change	116.5
Shelterbelt changes	76.5
Complementary inputs changes	
FYM + Fertilizers	21.5
Other expenses	8.4
Total estimated change due to shelterbelt	106.4

remaining 25% was contributed by FYM and fertilizers and other expenditure.The difference in observed change (absolute increase) and estimated changes might be due to round off and also due to estimation procedure.

6.9 ECONOMIC LOSSES

The estimated total command area of Indira Gandhi Nahar Priyojna" phase II is 9.25 lakhs ha which has been allotted on the basis of "One Murba" (equivalent to 5ha) to each farmer.

The area under tube well irrigation is about 20,000 ha. It is assessed that only 5 % and 20% of the total command area of canal and tube wells, respectively, is covered with shelterbelt plantations. This indicates that the large portion of the irrigated land is still uncovered with shelterbelts and the tangible and non-tangible benefits which otherwise, would have been accrued from the sheltered area due to presence of shelterbelt are the net losses to the farmers. The crop-wise estimated losses are presented in the Table 48.

On the basis of the potential productivity, the yearly economic losses from crops (Table 48) due to non-adoption of shelterbelt technology are about Rs. 1142 million. The cumin crop registered losses of nearly Rs. 456 million. Being a high export value crop, more area is likely to put under this crop in near future. Similarly, isabgol, a medicinal crop, has incurred losses to the tune of Rs.76 millions from small area, which may also increase in future.

Presently the average numbers of trees (44 ha^{-1}) under shelterbelt varied from 11 to 80 ha^{-1}. The number of tree requirement is 80 ha^{-1}. Under the canal area the number of trees is therefore, less by 36 ha^{-1}. The total trees are around 54 lacs. The present estimated value of wood from the tree of 15-18 years age is Rs. 3,000/- which itself would cause losses of about Rs. 16,200 million. The total losses therefore from the crops and shelterbelt are around Rs.71,342 millions. Economic returns from shelterbelt plantation all along the main canal and distributaries have helped in generating additional income. The livestock productivity has also increased due to availability of more browse material. The sheep health has improved which is the indicator in price fixation. The value of one sheep has increased from Rs.1000 to Rs.2500 of rearing for two years. Secondly, sheep graziers were forced to migrate every year in search of fodder and water to near by states. Now the process has reverted. The wool production has also increased by 0.5 kg per sheep due to proper

Table 48. Area, productivity and potential yield under shelterbelt plantations in Jaisalmer district

Crop	Area under crop (ha)*	Yield of crop (q ha^{-1})*	Potential yield (q ha^{-1})	Economic losses (Rs. in lakh)
Groundnut	3311	15.65	24.00	442.35
Wheat	5377	27.94	31.50	134.00
Gram	9431	6.33	18.20	895.57
Mustard	30090	9.16	22.00	4636.27
Cumin	12797	5.30	9.75	4555.73
Isabgol	8798	5.56	8.25	757.33
Total	69804	69.94	113.70	11421.25

* Area and Productivity of Jaisalmer during 2003-04 collected from State Agril. Department.

availability of shade, water and feed. The total population of sheep of Jaisalmer district as per "Livestock Census 2003" is around one million. The sheep population around canal shelterbelt considered at 25% i.e. 2.5 lacs. The present practice in the area is to sell out 25% sheep each year. The additional revenue generated by selling of sheep is around Rs. 94 millions. The wool production contributed addirional Rs. 2 million.

The shelterbelt plantation has also generated additional employment on the basis of the crops grown in study area. This would have generated additional 60 lacs man days, if the entire area could be covered with shelterbelt plantations. Similarly, the machinery (tractor and other equipment used) could be used for about 3.3 lacs hours more in land preparation and other farm activities. Additional 1.0 lacs hours can be generated for transportation for carrying crop produce to storage places and also to the market for sale.

The total murba allotted are around 1.85 lacs. The area under crops is only around 45,000 ha, the remaining land (murba) is out of cultivation which may be due to non-availability of canal water and damaged water channels, etc. The net returns from partial shelterbelts are around Rs. 2.91 lacs per murba resultant to net losses to the tune Rs. 49470 million only due to crops. The losses from plantation around the farm field accounts to be Rs.26, 000 million if, the farmers sell the standing 15 years old plants at present or current market price.

Similarly, the area covered under tube well irrigation is 20, 000 ha at present which may further increase up to 25,000 ha. The additional Rs 1455 million can be generated by crop production. The additional income generated due to shelterbelt plantation is estimated to the tune of around Rs.25,000 million apart from existing annual income. The additional employment of 1.5 million man-days can also be generated.

Coming to livestock sector, the entire sheep population can be provided with sufficient grazing material and shelter from heat waves. This will improve the health of sheep and consequently increase the market price. Around Rs.282 million additional annual revenue from sale of sheep can be generated and the additional income from wool production can go up to the tune of around Rs. 6.0 million.

As estimated, State Government spends nearly Rs.20 million during migration of livestock population in search of fodder and water every year. During migration nearly 10% sheep population die due to several reasons. The shelterbelt technology has helped in the decrease of the migration of sheep to other areas. The livestock population can also be supported in shelterbelt area during drought conditions to save such drastic losses through mortality in sheep and goat in particulars.

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7. Summary

Tree-belt plantations, in arid region, were conceived, designed and raised with the primary objectives of providing protection against adverse effects of high velocity of winds. Selection of suitable species and design holds the key for efficacious impacts of tree-belts on various components of arid ecosystem. In past five decades, after independence, massive afforestation work on tree-belt plantation has been done in Indian Thar Desert particularly in eleven district of western Rajasthan. Major thrust has been on shelterbelt plantation along roads, canals and field boundaries of agricultural fields and grasslands. In Jaisalmer district alone about 2023 Rkm along roads and 27812 Rkm canal side, tree-belt have been raised. In addition, about 14245 ha area has been covered under Sand dunes, Rangelands and farmlands.

Impact assessment study have revealed that tree-belt plantations have by and large been effective and fulfilled its primary objective of controlling hazards resulting from high-speed winds. The study revealed that different shelterbelts had varying effects on reduction of wind speed in leeward side of the shelterbelt. The maximum extent of reduction in wind speed on leeward side was observed at distance of 2H, which slowly levels off with increasing distance up to 20H. On an average, irrespective of the species, double row shelterbelts were more effective in reducing wind speed as compared to single row belt; however, the single row belt provided more effective area (up to 20H) in comparison to double row belts (up to 15 H) on leeward side of the shelterbelt. The structure of canopy (density), age height and direction of the shelterbelt etc are major factors, which decide its effectiveness in controlling the wind flow.

For maximizing effectiveness of shelterbelt plantations for providing large sheltered area in leeward side, it is desirable to plant those species which, can grow fast and attain maximum height in short period. Belt of multiple rows apparently provided more resistance due to dense canopy resulting in decrease of sheltered area on the leeward side of the belt because of more turbulence. The height of shelterbelt plantations plays an important role in providing sheltered area in leeward side of a belt. Shelterbelt plantations of lesser heights created a sand deposited ridge at approximate distance of 6 to 8 H. This phenomenon is more encountered at initial stage of belt plantation, when the trees are of lesser height and having comparatively dense canopy. This necessitates planting of shelterbelts at regular interval of 8-10 times of the height of the belt if better results are to be obtained. The turbulence or tunneling effect was more pronounced at both ends of shelterbelt plantations with more height, density and short length. The length of shelterbelt directly controls its turbulence effects on ends. Single row belt having length of 100m or more did not show any sign of turbulence or tunneling effect on ground. It suggest that (considering average

10m height of well grown shelterbelt plantations) length of shelter belt should be 10-12 times of its heights for better efficiency and effectiveness in controlling wind borne hazards. Uninterrupted and uniform shelterbelt plantations appear to be more effective than those with interruption or gaps.

Significant reduction in sand deposition on roads and canals have been noticed thus resulting in savings of millions of rupees which otherwise, used to be spent on de-silting operations. Favorable changes in microclimate of sheltered area on leeward side have been noticed. Reduction in air temperature in sheltered area on leeward side varied with the shelterbelt type and maximum reduction was beneath the shelterbelt. Shelterbelts have improved soil quality in sheltered area of its leeward side. The changes in soil properties were more pronounced up to the distance of 2H and nullified after Distance of 5H. In general the OC decreased with depth of soil in sheltered area of all the shelterbelt. Presence of shelterbelt plantations have resulted in significant changes in cropping pattern, crop rotation and crop productivity in sheltered area as compared to unsheltered area.

Socio economic survey has revealed that adoption status of shelterbelt technology was higher in tube well command area of Lathi series as compared to IGNP command area of Mohangarh. The major constraint faced by farmers in planting of shelterbelt in IGNP area is non-availability of water through out the year. Nevertheless, in general, the farmers of both the areas have opined increase in yield of different crops due to protective role of shelterbelts nullifying damaging effects of hot wind on summer crops (Kharif) and chilling wind on winter crops (rabi). Increase in crop productivity has reduced unit cost of production and provided additional revenue to the farmers, which has resulted in improvement in standard of living. The planting of MPTs (multipurpose tree species) in shelterbelt plantations has provided fodder, fuel and small timber to the farmers. The increase in availability of top feed and foliage as fodder has enhanced live stock productivity. This has also resulted in shift of livestock composition as indicated by increase in the buffalo and slight decrease in the goat/ sheep population. Analyses of farm income have indicated that net profit of the farms with shelterbelts was significantly higher than those with out shelterbelts. Decomposition of total net profit has proved that shelterbelt plantations have contributed 305% out of 435% total technological change indicating thereby about 70% variations in net profit has come from shelterbelt plantations.

Works on shelterbelt plantations has generated employment of about 2.4 million-man days for both men and women with out any gender bias. Decomposition of labour requirement has revealed that labour requirement of farms with shelterbelts has increased by 202% in comparison to those farm which do not have shelterbelts. Out of the total change in labour requirement of farm with shelterbelt, about 76% was due to shelterbelt plantations alone and remaining contributed by other inputs. Due to additional income generated by shelterbelt plantations, the life style of people has changed. Besides creating assets in the form of pucca houses, vehicles, farm machinery, TV, telephone and other electronic gadgets, the people have started sending their children for higher education in distant places. In view of fact that only 20% and 5% of the total command area of tube wells in Lathi series and canals in Mohangarh, respectively is covered under shelterbelt plantations; the beneficial impacts remain limited to small section of the society. Non-adoption of shelterbelt technology is causing losses of millions of rupees to the society in the form of reduced crop yield, poor livestock productivity and other tangible and non-tangible benefits.

Considering huge and irreparable losses due to speedy winds, particularly in hyper arid conditions that prevail in Jaisalmer district of western Rajasthan, from present study it can be concluded that shelterbelt plantations provide relatively cheap and long-term option for reducing wind erosion and associated hazards. The shelterbelt offers range of benefits such as protection to roads, railways and open canals; provide sheltered area for cropping, horticultural and livestock enterprises; and supplementing basic needs of fuel, fodder and timber. Besides, it also improves aesthetic value of the environment. For harnessing maximum benefits of the shelterbelt plantations, careful consideration should be given to the location, species, desired height, length, density and composition of the tree belt. Over all, the basic objective of the shelterbelt should guide the whole farm planning and strategies. The judicious use of shelterbelt technology would not only substantiate potential productivity of natural resources but also help in their sustainable managements in arid ecosystem.

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Annexure I

Socio economic Survey of Shelterbelts Under Different Irrigation Systems

1. Name of the Respondent

   Age

   Farming Experience

2. Family Status

   Number of Children

   Male more than 18 years : Male less than 18 years :

   Female more than 18 years: Female less than 18 years:

3. Number of family engaged in farm activities

   During peak period:

   During lean period:

4. Land :

   Total :

   Irrigated :

Unirrigated :

Type of land :

5. Livestock Composition : Before planting shelterbelt After planting shelterbelt

Cattle :

Buffalo :

Sheep :

Goat :

Others :

6. Types of farm implement:

Tractor

Tractor trolley

Seed drill

Machines for separation of seed and fodder

Others

7. Cropping pattern before planting of shelterbelt.

8. Varietal changes, if any

9. Types of shelterbelt :

   1.No. of Rows:

   2. Variety/types of plants.

10. During last 10 years what has happened to your economic liability (any loan taken for improvement on farm) ?

11. How do you pay back your loan amount ?

12. After how many years of shelterbelt planting you could payback your loan ?

13. After planting of shelterbelt, what type of social changes you have observed ?

14. Any change in your farm as well as living assets ?

15. What types of impact of shelterbelt ? positive/negative

16. If, positive what type of changes you have observed ?

17. If negative, what type of changes you have observed ?

18. What measures you have taken for its expansion on your farm ?

19. Have you noticed any reduction in pest/insect attack on your farm after planting shelterbelt ?

20. Any protection from shelterbelt on crops ?

21. How much protection in terms of crop yield ?

22. Are your all family members working on farm ?

23. How many your family members working on farm ?

24. If not working (partially/fully), what is the reasons ?

25. How much fodder available from your farm activities ?

    Farm

    Shelterbelt

26. How much fuel wood is obtained from shelterbelt ?

27. During the drought year how much fodder you obtained from shelterbelt and also trees in your farm?

28. Is the fodder sufficient for your herd size ?

29. Are you selling out additional fuel wood and also fodder ?

30. Cost of different inputs

Activities	Name of the Crops
Area	
Land Preparation	
Seed	
FYM	
Fertilizers	
N	
P	
K	
Pesticides	
Irrigation Charges	
Hired Labour	
Family Labour	
Other	
Production	
Grain (q)	
Fodder (q)	
Sale	
Home consumption	
Stored for seed	

31. Labour Utilization under different operation (crop wise)

Activities	
Land preparation H F	
Sowing H F	
FYM+Fertilizers H F	
Inter-culture H F	
Irrigation H F	
Harvesting H F	
Threshing H F	
Transportation H F	
Storage H F	
Any other H F	

32. Livestock Activities

Activities	Cow	Buffalo	Goat	Others
Number of animals				
Green Fodder (q)				
Dry Fodder (q)				
Concentration (kg.)				
Medicines (Rs.)				
Labour (Man-days)				
Production				
Milk (Kg.)				
Dung (q)				
Sale of milk (Rs.)				
Sale of dung (Rs.)				

33. Cost and returns from planted species.

Activities	Years								
	Established	2	3	4	5	6	7	8	....
Number seedling used									
Pits									
Irrigation									
FYM									
Fertilizers									
Labour									
Production									
Fodder (q) (Rs.)									
Wood (q) (Rs.)									
Others (q) (Rs.)									

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