Cold Wave of 2002-03
– Impact on Agriculture

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NATURAL RESOURCE MANAGEMENT DIVISION

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Krishi Bhavan, New Delhi - 110 001

December, 2003

Published by

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Printed at: ***Heritage Print Services Pvt. Ltd.***, Hyderabad.
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Foreword

It is well known that weather is a major factor that influences crop growth and productivity. During the *rabi* season in the northern and north-eastern regions of the country, occurrence of cold waves due to passing western disturbances is an annual phenomenon. Under the influence of these synoptic systems, night temperatures may often go below freezing point and day time temperatures become too low, at times less than optimum during the peak winter period.

In 2002-2003 *rabi* season, severe cold wave conditions prevailed for a prolonged period over many parts of northern and eastern India for one to two weeks at a stretch, especially during January. This was a new record in the recent decades. Agricultural crops, horticultural plantations, forest trees and livestock including fisheries were severely affected in Punjab, Haryana, Himachal Pradesh, Bihar and North Eastern States. The damage to fruit plantations was so severe that many farmers uprooted their well-established mango and litchi trees. Quality of produce in some of the fruit species also suffered. However, there are indications that these cold wave conditions proved beneficial in providing the chilling requirements of some of the fruit species thereby improving their quality and also productivity.

It is indeed gratifying to note that the Natural Resource Management Division of the Indian Council of Agricultural Research has compiled information on cold wave impact on agriculture in the form of a bulletin. This will help to plan preventive and ameliorative measures to negate / moderate such effects of cold waves in future.

I appreciate the authors for their timely effort.

(Dr. Mangala Rai)
Secretary, DARE &
Director General, ICAR

Preface

The 2002-2003 *rabi* season will be remembered for its severe cold wave conditions that prevailed for a prolonged period and had a significant impact on agriculture. The most distinguishable feature of the season was the sharp drop in maximum temperatures for a considerable period over an extended area in North India, which was a rare phenomenon. Reduced sunshine hours and limited availability of solar energy also compounded the impact of adverse weather conditions on agriculture. In some of the northern parts of the country day temperature fell lower than 15°C while night temperature was below 0°C. On many occasions the average temperature was less than 5°C for consecutive days. Several crops and orchards in the north and northeastern regions of the country experienced the damaging effect of the cold wave and frost. The cold wave effect was also significant on livestock as well as shelter less human population. Reports that appeared in the mass media about this unique event prompted us to make a comprehensive survey and consolidate an account of the severe cold wave conditions. These conditions were induced by a series of western disturbances that move from J & K and Punjab in the northwest through Himachal Pradesh, Uttar Pradesh, Bihar to north eastern states. There was significant damage to crops, horticulture, forest trees, livestock, fisheries and other livelihood systems in these regions that led to significant economic losses to the farming community.

The input received from Research Centres located in the cold wave affected areas is gratefully acknowledged. Special thanks are due to Dr. B.S. Dhillon, Director, National Bureau of Plant Genetic Resources (NBPGR), New Delhi for going through the manuscript and making useful suggestions, particularly on mechanism of cold tolerance in the plants. Thanks are also due to Professor P.S.N. Sastry, Principal Scientist (Retd.), IARI and Drs. G.G.S.N. Rao, Principal Scientist (Agromet), and Y.G. Prasad, Senior Scientist (Entomology), CRIDA, Hyderabad for their useful input, assistance and editing. Special thanks are due to Mrs. Meera of ICAR and Mrs. Y. Padmini of CRIDA for typing and updating several drafts of this document.

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Contents

Executive Summary

Most appropriate land use systems suited to the local environmental conditions have been evolved and are being updated to derive maximum benefits, livelihood, employment and environmental opportunities in various agro-ecological regions of India. These efficient land use systems are at times adversely influenced by aberrant weather conditions. Besides the variable moisture regime and associated droughts, thermal regime is an important weather phenomenon (though stable under tropical regions) can significantly influence plant survival and productivity. Site-specific short-term fluctuations in lower temperatures, and the associated phenomena of chilling, frost, fogginess and impaired sun shine may sometimes play havoc in an otherwise fairly stable land use or farming system of a region. Except the southern regions of the Indian peninsula (beyond Vindhya ranges) most of the country, particularly the Indo-Gangetic Plains, is vulnerable to freezing and 'cold days' injuries, impacting on productivity of crops, fruit trees, fishery, livestock and human beings. Western disturbances and cold waves that originate around Mediterranean region, pass through Pakistan/Afghanistan, enter into north India and proceed towards the east. In this way they not only bring in occasional rains but also foggy and severe cold wave conditions to the north and northeastern regions of the country. Extreme fluctuations beyond normal variation in temperature due to cosmic events and anthropogenic activities that alter cardinal points of crop growth stages are a major concern in agricultural management, production and resilience. This bulletin aims to bring out the details of these significant weather events and their impact on agriculture through case studies of the cold wave conditions of 2002-03. Sections 1 to 4 define and describe the systems of weather, climate fluctuations, cold waves, freezing, frost, fog, cold days etc. The influence of extended periods of fog, dew and over cast sky conditions on incidence and spread of diseases and temperature limits for crops and trees have been discussed. Sections 5 to 7 elaborate recorded impact of cold wave 2002-03 on agriculture and fishery etc. Section 8 describes farming practices to ward-off adverse effect of such weather conditions on productivity. Section 9 introduces the activities/efforts of value added agromet services for forewarning.

During December 2002-January 2003, daily maximum and minimum temperatures at Adampur (Jullendher), Hoshiarpur, Ludhiana, Chandigarh, Dehradun, Agra, Patna, Pusa (Bihar), Jorhat (Assam) and Shillong (Meghalaya) remained unusually below the normal continuously for 3-4 weeks in January, 2003. Delhi recorded the coldest day in the first fortnight of January 2003 over the past 40 years. Sunshine hours (and associated solar radiation) were also lower than the long-time average over many of the northern stations during January, 2003. As a consequence of such phenomenon, about 600 ha of orchards were severely damaged in the Shiwalik belt of Punjab. The extent of damage varied from 40-100% in mango, 50-80% in litchi with reduced fruit size and poor quality in guava, *ber* and kinnow. Similar damage was also previously reported from this region during December-January in 1996-97 and 2000-01. Plant mortality in mango varieties was highest in Dashehari, followed by Amrapali and least in Langra with 18-48% flowering damage in the *Kandi* area of Jammu, Punjab, Haryana, Chandigarh and Himachal Pradesh. Mortality rate in papaya ranged from 40-83% in the lower Shiwalik region, plains of Uttar Pradesh, Bihar and the north-east. In the Doon Valley of Uttaranchal, plant mortality was nearly 80% in less than 2 year-old plantations, 15% in 2-4 year, 10% in more than 4 year old mango plantations and damage to growing tips in matured trees. Cold wave injury was in the order: mango > papaya > banana > litchi > pomegranate > amla (Indian goose berry). In Barapani of Shillong valley, damage was maximum in Amrapali mango (100%), followed by pine apple (83%), sapota (80%), Assam lemon (64%), *Michaelia champaca* (60%), Jack fruit (58%) and peach (16%). Damage to fruit trees was relatively more in low lying areas where cold air settled and remained for a longer time on the ground. Temperate fruits like apple, peach, plum and cherry gave higher yield due to extended chilling in 2003.

Around Agra region there was 100% damage to brinjal, 80% in tomato and 25% in potato. On the other hand vegetable crops like cauliflower, cabbage, broccoli and root crops such as carrot, sugarbeet, raddish and turnip performed better due to cold wave conditions.

Crop yields in the cold wave year of 2002-03 were lower by 10-40% in wheat, 25-30% in gram, 50-70% in mustard and 60-95% in amla, as compared to previous normal year of 2001-02 in Agra. Early sown winter maize in more than 36,000 hectares was adversely affected by cold wave 2002-03 with 70-80% loss in seed setting in Bihar. Productivity loss due to cold injury in *boro* rice of Assam was 10% and the crop took 10 to 25 days extra to mature as compared to normal year. In the early sown crop, seedling mortality during the vegetative stage was 37%. Grain sterility across farmer fields' varied from 50 to 60 percent. There was a large-scale genetic variation in albinism, seedling mortality, recovery after planting, leaf yellowing, grain sterility and unproductive tillers.

Growth of carp fish in Punjab, Haryana and Bihar was arrested during cold wave periods of December to February 2003 whereas prawn mortality of 5-10% was observed. In Naubatpur block of Patna, mortality in 4 months old fish was 87% in Mrigal, 33% in *rohu,* 7% in *catla,* none in *carp* and 37% in their composite culture.

Proper selection of fruit species or varieties according to site conditions, providing wind breaks or shelter belts, frequent irrigation, smoking, covering young fruit plants with thatches or plastic sheets, air mixing, maintaining maximum depth of water in fish ponds and their aeration are some of the farming manipulations for managing cold wave injury. Value added agromet services for forewarning by IMD, NCMRWF and ICAR (AICRPAM) are also summarized.

Introduction

1. Introduction

An important weather phenomenon that causes significant impact on agricultural production year after year over the northern and northeastern regions of India is the occurrence of "Western Disturbances". The intensity, frequency and the aerial extent of these disturbances significantly influence the quantum of rainfall / snow over these regions during the *rabi* season; lean season flow of rivers and occurrence of cold wave conditions. In the process, they influence overall hydrology, the daily maximum / minimum temperatures, temperature range, bright sunshine hours and humidity. Obviously, these weather conditions induced by the western disturbances have different impacts on agricultural production in various years. The intensity of these short-term variations in the weather systems and their influence on agricultural productivity are associated with long-term impacts of climatic change on agriculture. A good example of this is the severe and prolonged cold wave condition that prevailed over many parts of northern and northeastern parts of India during the winter season of 2002-03, which had considerably affected the survival and productivity of not only the seasonal crops but also the perennials (tree and horticultural). The present study attempts to bring out the impact of weather factors on agricultural productivity in general and during the winter season of 2002-03 in particular. The evaluation is presented in the form of case studies. To make it comprehensive, general background information on climate change, factors influencing agricultural productivity, effect of frost on plants, agromet and forecasting organizations in the country generating value added information on these aspects is also included.

1.1 Factors Influencing Agricultural Productivity

Agricultural productivity of a region is dependent on several biophysical and socio-economic factors. The key biophysical factors are: weather parameters, soil health, water resources, crops/varieties and biotic stresses. The socio-economic factors include level of agronomic management, availability of farm inputs such as labour, fertilizers, chemicals, irrigation, rural infrastructure, institutions and government policies. Amongst all the factors responsible for productivity, weather has the over-riding impact. Weather parameters influence various dynamics of crop growth and development and account for nearly two thirds of variation in agricultural productivity. Therefore, land use planning by matching crop growth with weather forms a basis for successful agriculture in a given region. The need to understand and manage climate and weather systems is critical for achieving sustainable agricultural productivity in the 21st Century.

Climatic Change - Recent Trends

2. Climatic Change - Recent Trends

Climatic changes due to anthropogenic emissions of gases and aerosols are of major concern for negotiations in international conventions and treaties due to their far-reaching geo-political, social and economic implications. Studies report that industrial sector as a whole produces 65% of emissions as compared to 35% by the agriculture sector. In fact crops, trees, bushes, aquatic system and soil act as a sink to sequester (absorb) the industrial emissions, which has been well recognized in the Kyoto Protocol. Rising temperature associated with climate change is expected to melt ice/glaciers, re-distribute water, raise sea level, submerge coastal habitats, islands and dislocate human beings. Spatial redistribution of precipitation, droughts, floods and water balance will change land use, pests, diseases and other ecological parameters. Keeping in view its importance, Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Since its inception IPCC has brought out a series of Assessment Reports (1990, 1995 and 2001). Latest 8th Conference of Parties (COP8) was held at Delhi in 2002 and trading in green house gases is coming up based on the principle of “Polluter should pay”.

To recapitulate the trends in climatic variation, recently observed changes are listed below:

- CO_2 increased from 280 ppm in 1750 AD to 369 ppm in the year 2002.
- Methane increased from 700 ppb in 1750 to 1750 ppb in 2002.
- Nitrous oxide increased from 270 ppb in 1750 to 316 ppb at present.
- The global mean annual temperatures increased between 0.4 to 0.7°C during the last 100 years.
- The 19th Century was the warmest during the last 1000 years
- The decade of 1990 was the warmest since instrumental measurement of temperature started in the1860’s including the seven warmest years globally.
- These long-range climate changes also have an influence on the short-term variations in weather.
- Increased frequency of extreme weather events such as heat and cold waves is the major focus in this publication.
- The recent trends in changes in minimum and maximum temperature and rainfall patterns are moving in different directions in various parts of India (Figures 1,2 and 3). A general fall in maximum temperature, rise in minimum

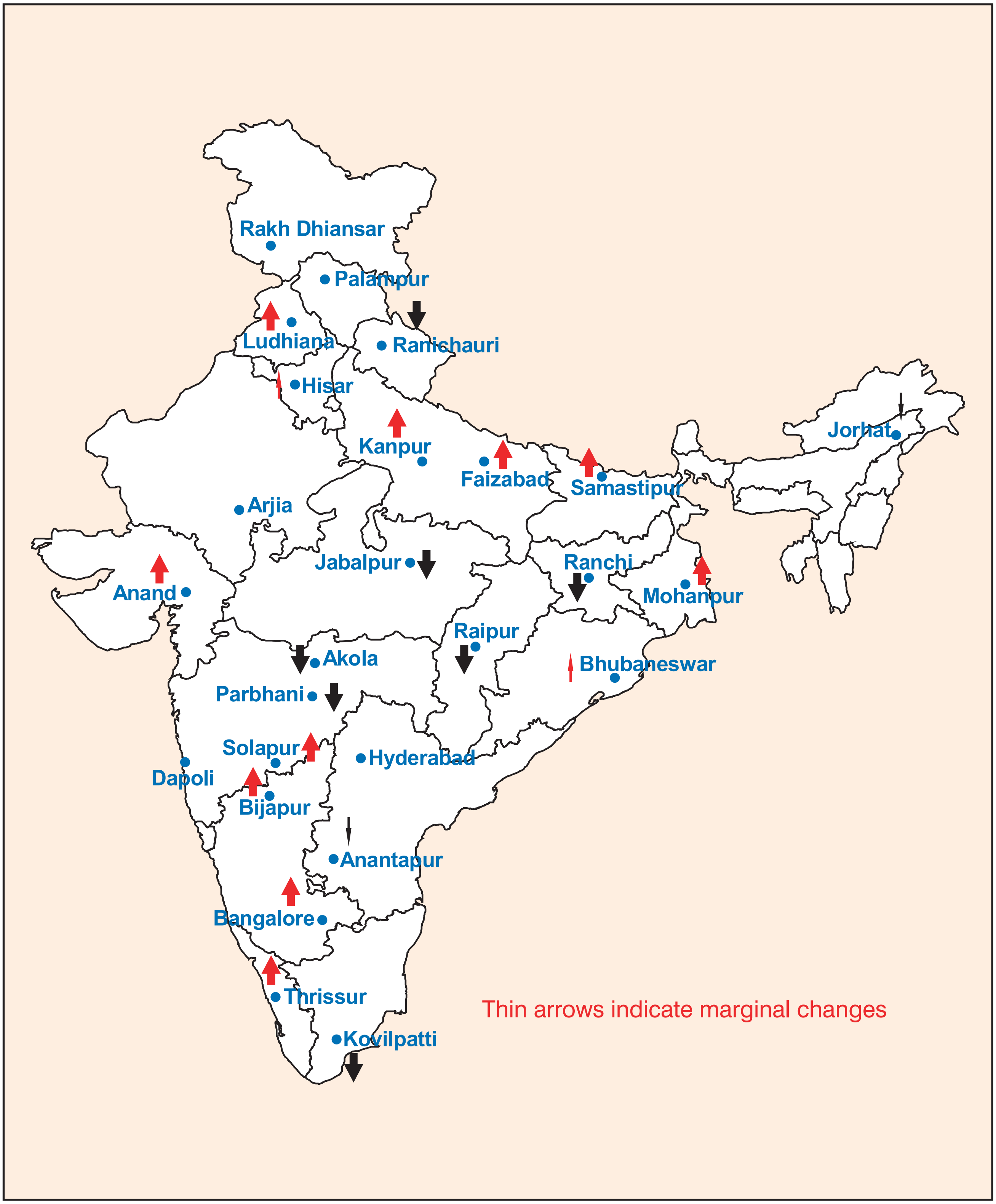


Fig.1 : Trends in Minimum Temperature - *Rabi*

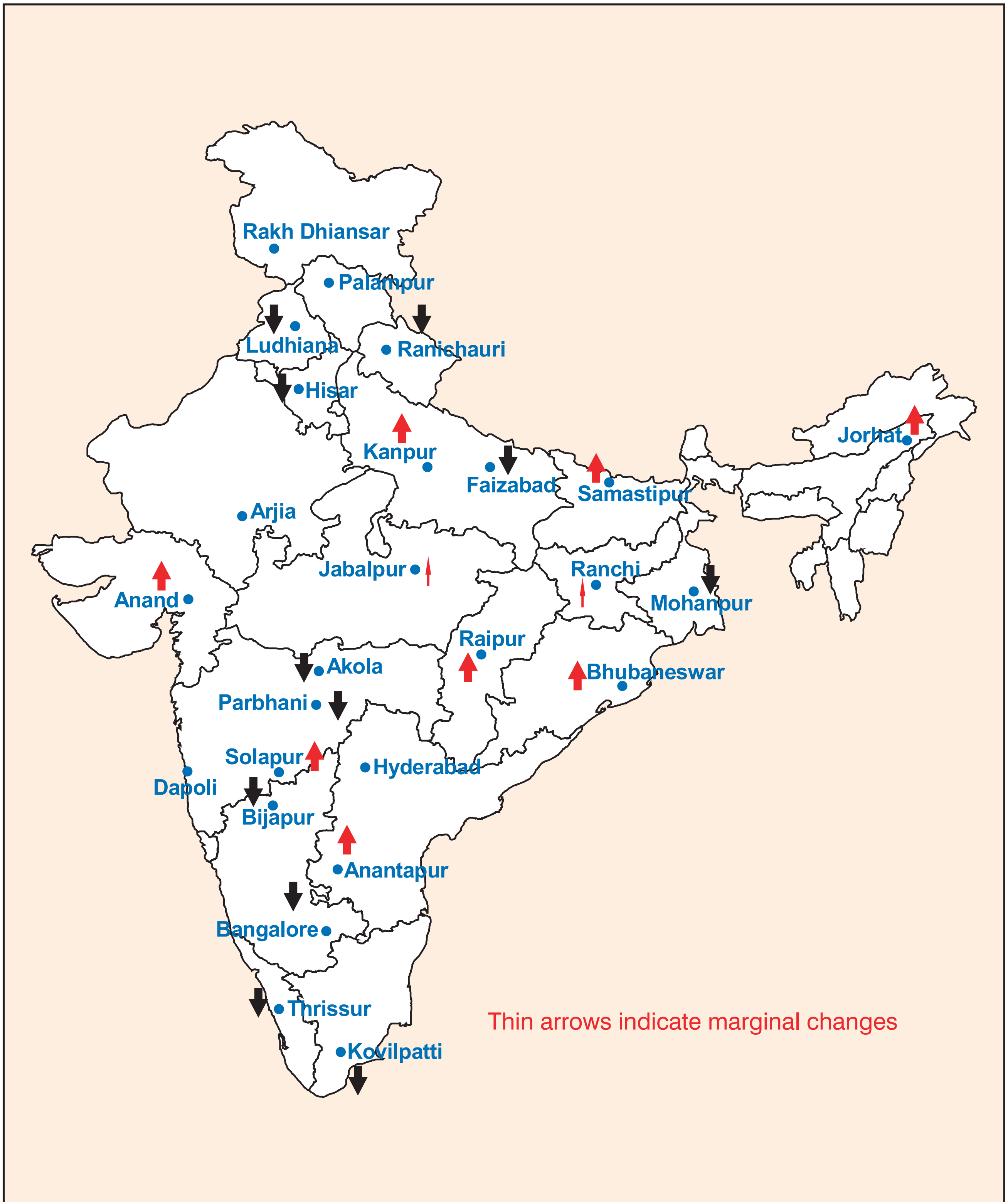


Fig.2 : Trends in Maximum Temperature - *Rabi*

temperature and several other permutations and combinations are becoming perceptible. Cold or temperature tolerance of varieties thus becomes an important issue in different agro-ecologies. Similarly, a shift in rainfall pattern from SW to NE direction during the recent decades is evident (Fig. 3). Similar shifts in rainfall peaks within a growing region are also becoming evident at some places (eg. From September to October at Bangalore).

- In the context of global warming and climate change, variations in the intensity, frequency and impact of western disturbances on the weather fluctuations over the Indian region, and particularly, on agriculture would thus be significant.

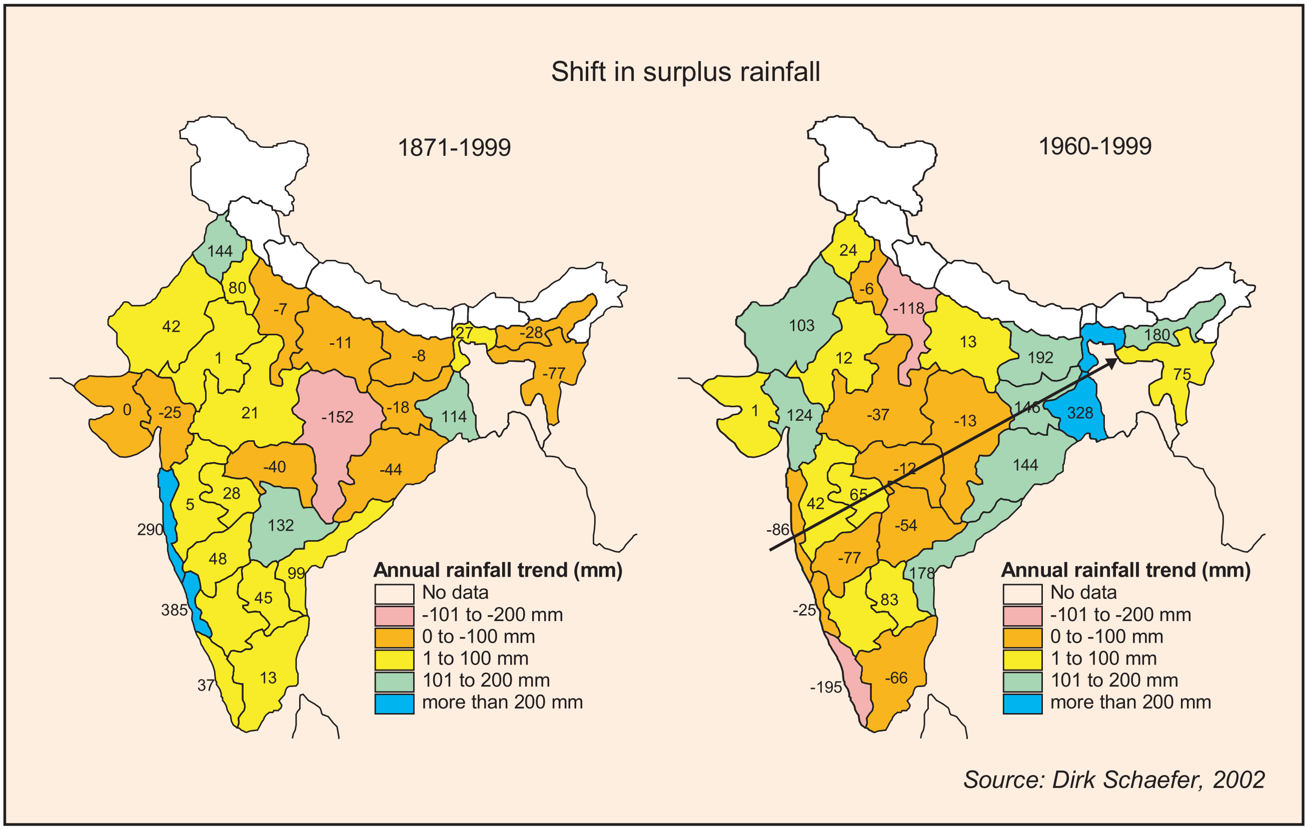


Fig.3 : Trends of annual rainfall in India

3. Western Disturbances and Cold Waves

Western Disturbances and Cold Waves

Western disturbances are occluded (decaying) or weak fronts (extra tropical disturbances) originating around the Mediterranean region, approaching the Indian Sub-Continent from the west (Afghanistan and Pakistan) and passing over the northwestern parts of India during the winter season. As these systems move from west to east they are known as western disturbances. Within the country, during the period October to March (coinciding with the *rabi* crop season), they manifest as weak troughs of low pressure (with cyclonic circulation) extending from the ground to the lower layers of atmosphere upto 4-6 km above the earth's surface. The passage of these disturbances initially causes warm weather followed by rain or snow for a couple of days, and then immediately followed by clear skies and chilly winds (cold wave) or thick fog, and frost on calmer nights. This sequence of weather may last for 5 to 7days at a time with consequent impact on agricultural productivity. The impact becomes manifold when such western disturbances occur in a sequence.

3.1 About Cold Wave

There are separate limits for defining coldness for different regions based on departures of temperature over the normal.

(a) Regions with normal minimum temperature of 10°C and above:

Cold wave conditions are said to prevail when departure of minimum temperature is 5°C to 6°C lower than normal in the region.

Severe cold wave conditions are identified when the minimum temperature departure is 7°C lower than the normal in the region.

(b) Regions with normal minimum temperature less than 10°C:

Cold wave conditions prevail when departure of minimum temperature is 3°C to 4°C lower than normal in the region.

Severe cold wave conditions prevail when the minimum temperature departure is 5°C lower than the normal in the region.

Cold waves occur in the country during the winter months of December to March. Excluding the extreme southern peninsula, the entire country is susceptible to cold waves. Northwestern parts of the country and areas further north, where the minimum temperature in the winter months varies from 10° to less than 0°C are the most probable regions for the occurrence of cold waves. During the eastward or northeastward movement of the western disturbance, cold air in its rear spreads to the south and east. This results in *cold wave* conditions.

3.2 Climate of the Regions Visited by the Western Disturbances

The spatial distribution of minimum temperature during the months of December to March in India is given in Figure 4. It can be seen that the northern states like UP, Rajasthan, Haryana, Punjab and northern parts of MP experience minimum temperatures in the range of 5 to 10°C,

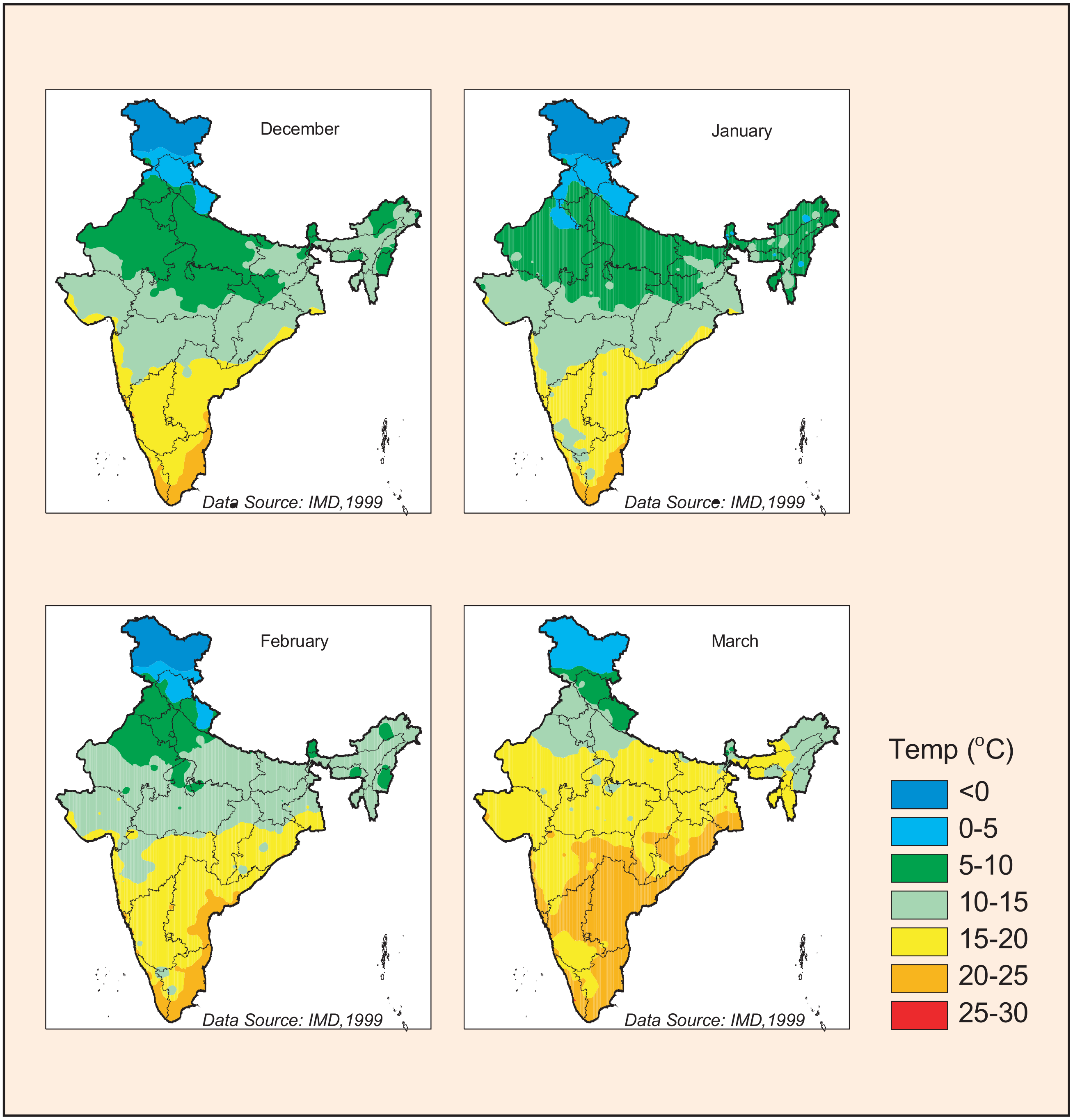


Fig.4 : Spatial variation of normal minimum temperature (normal 1951-80) during December to March

while States like Himachal Pradesh, Uttaranchal and Jammu & Kashmir experience minimum temperatures between 0-5°C. Predicting the cold wave conditions well in advance and devising strategies to moderate/mitigate the adverse impact of such severe cold on agriculture and livestock is an important concern in these regions.

In the plains of north India, foggy conditions prevail during winter for several days or weeks. While the minimum temperature on these days might remain near normal, maximum temperature falls below normal. This situation results in cold condition for a prolonged period. The terminology to represent such situation is "Cold Day". It is reported that when maximum temperature falls below 16°C in plains, it would be declared as a "Cold Day".

3.2.1 Weekly Minimum Temperature Distribution

The average weekly minimum temperatures across the country for the standard weeks number 48 (last week of November) to week 9 (end of February) are presented in Figures 5, 6 and 7. There is a gradual spread in area with minimum temperatures ranging between 5-10°C from 50th week to 52nd week (December 10 to 31). The area under 5-10°C is mostly confined to northern

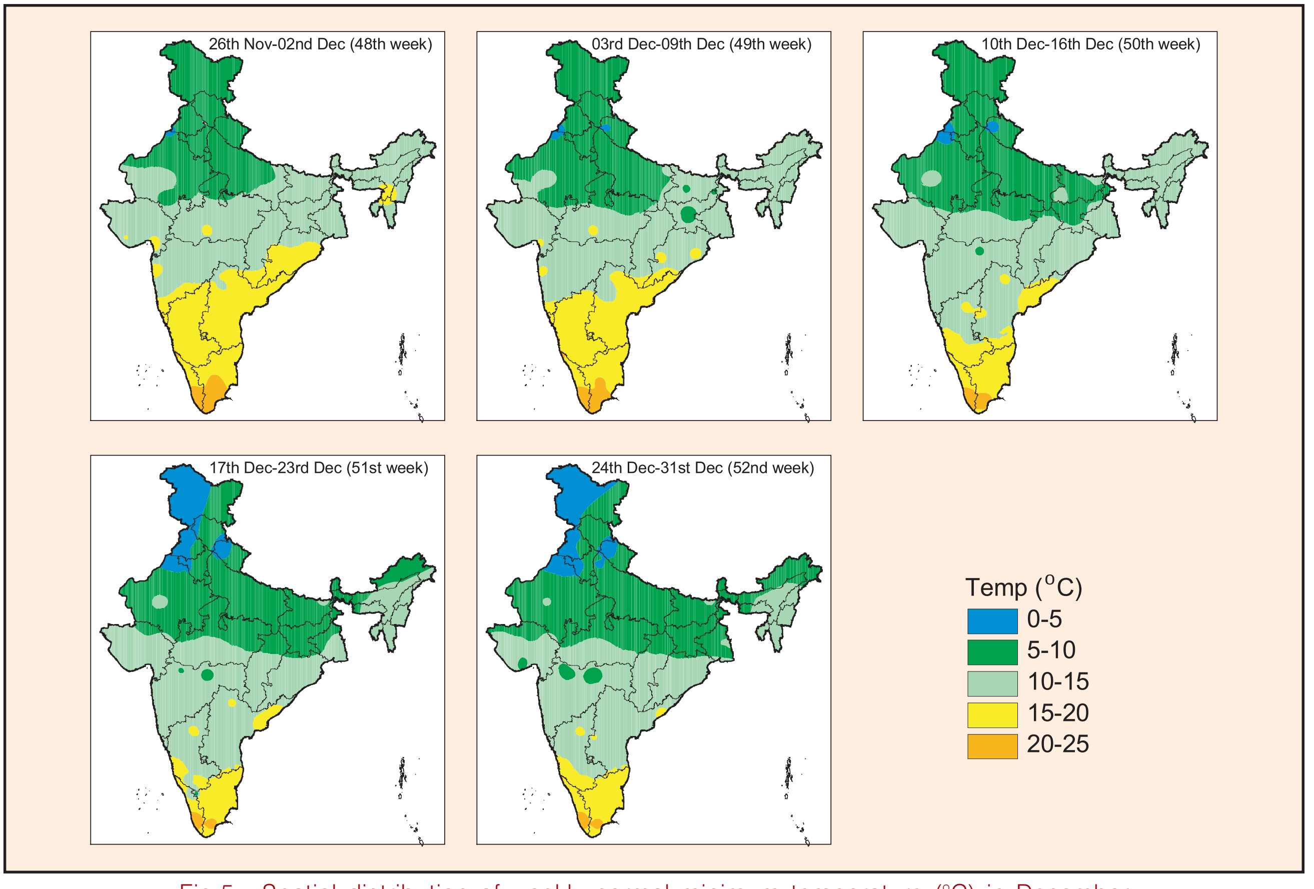


Fig.5 : Spatial distribution of weekly normal minimum temperature (°C) in December

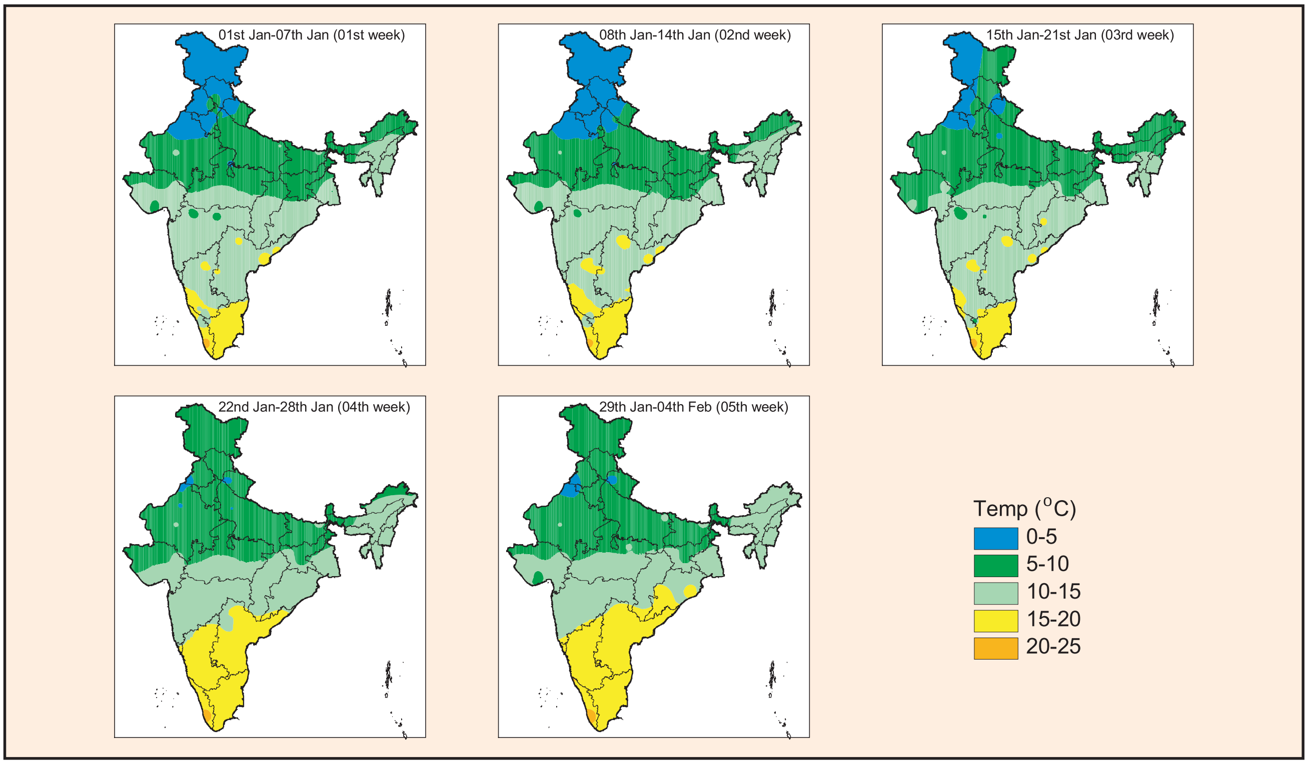


Fig.6 : Spatial distribution of weekly normal minimum temperature (°C) in January

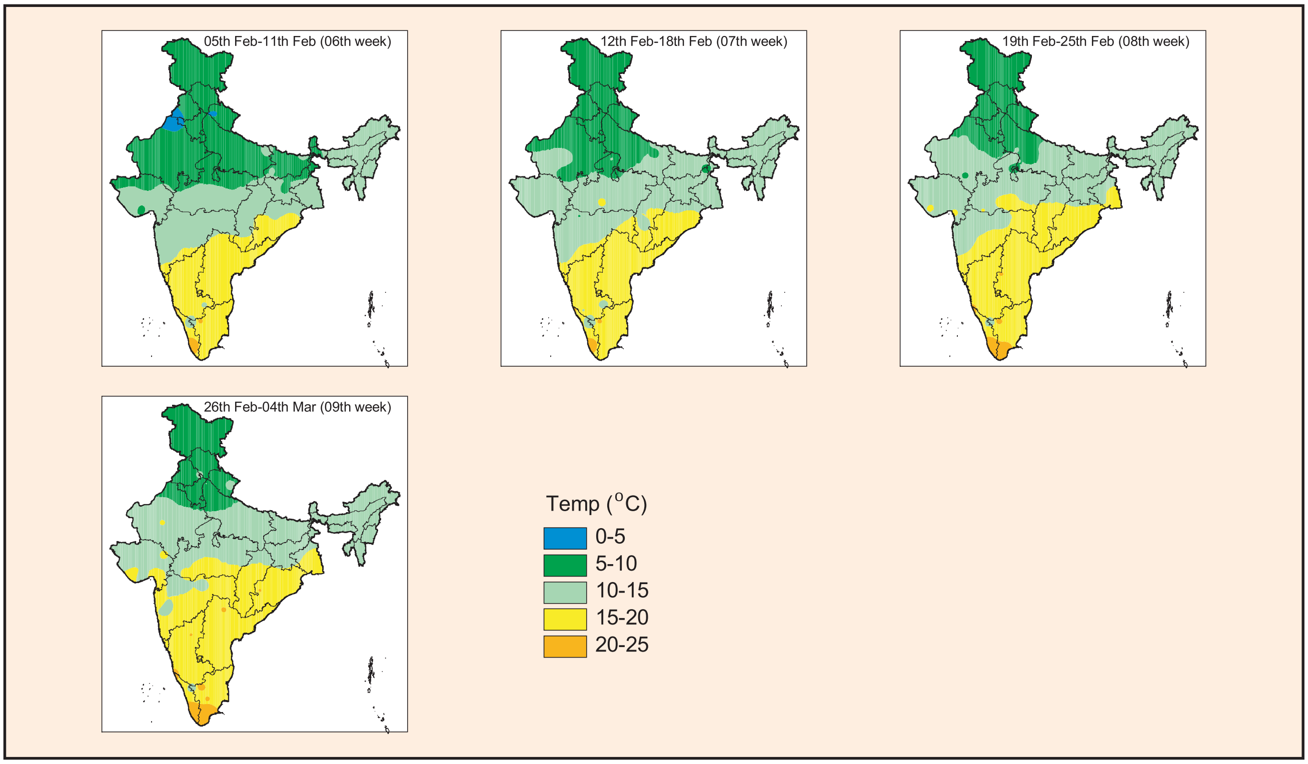


Fig.7 : Spatial distribution of weekly normal minimum temperature (°C) in February

states of Punjab, Haryana, Rajasthan, parts of Gujarat, Madhya Pradesh, Uttar Pradesh, Bihar, Jharkhand and Chhattisgarh. The area under coldest temperature of less than 5°C is maximum during 2nd week (8 Jan – 14 Jan). Then onwards, the area experiencing less than 5°C gradually recedes and by 7th week extremely low temperature area almost disappears from the region. The area under 5-10°C also starts decreasing from 6th week onwards and by 9th week it is restricted to Haryana, Punjab, Himachal Pradesh, Uttaranchal and Jammu and Kashmir States.

3.2.2 Possible Extreme Lowest Temperatures in North and Northeast Indian States

From the extreme values of minimum temperatures recorded during December to March over the years in north and northeast India, spatial distribution maps showing the areas with the lowest minimum temperature ever recorded

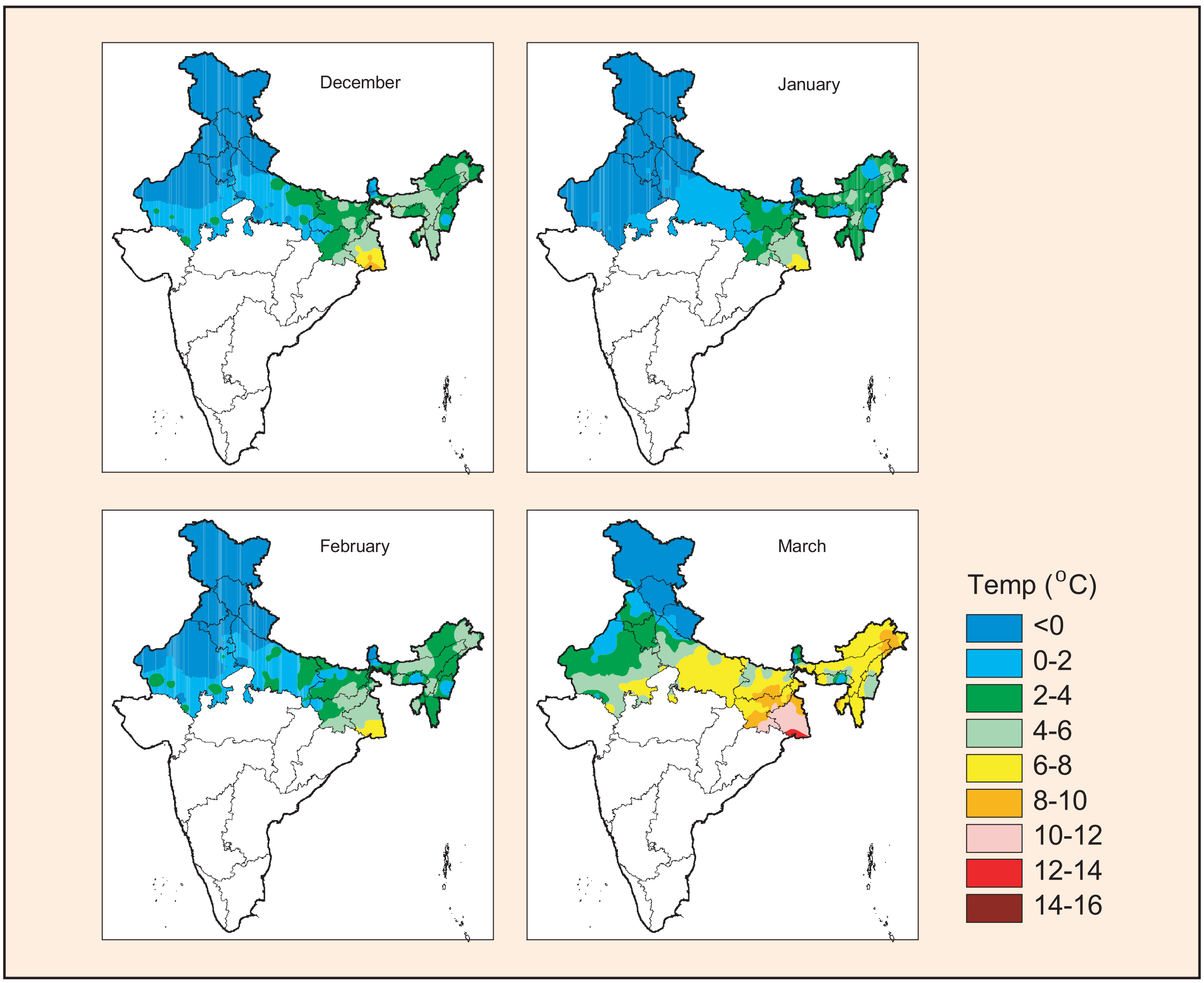


Fig.8 : Possible extreme minimum temperature in North and North East Indian States during winter months

is given in Figure 8. It can be seen that in the states of Jammu and Kashmir, Punjab, Himachal Pradesh, Haryana, Delhi, Uttaranchal, parts of Rajasthan, Uttar Pradesh and isolated parts in the northeastern states, the temperature could go below 0°C from December onwards. In southern parts of these states, mainly Uttar Pradesh and Rajasthan, the temperature can touch between 0 and 2°C. The area under the below freezing point level increases considerably during January indicating greater possibility of recording very low temperatures during this month. The area under 0°C isotherm during February is similar to that in December. During March, the area under low temperatures below zero are confined only to the hilly regions of Jammu & Kashmir, Himachal Pradesh and Uttaranchal.

4. Response of Plants to Low Temperature and Cold Stress

Certain stages of plant growth and development are more sensitive to low temperature than other phases with dormancy generally representing the most tolerant stage. Reproductive organs are comparatively more sensitive to chilling and freezing stress. Likewise, seedlings are more sensitive than adult plants. Both elongation and greening of leaves are affected by cold. Limits of freezing temperatures and plant injury in general are given below:

Light Freeze: -1.7 to 0.1°C – tender plants killed, with little destructive effect on other vegetation.

Moderate Freeze: -3.9 to 2.2°C – wide destructive effect on most vegetation with heavy damage to fruit blossoms, tender and semi-hardy plants.

Severe freeze: -4.4°C and less – severe damage to most plants. At these temperatures, the ground freezes solid, with the depth of the frozen ground dependent on the duration and severity of the freeze, soil moisture, and soil type.

Low temperatures cause two types of injuries to plants. The first is *chilling injury* that occurs between 20 and 0°C. Chilling injury is defined as injury at temperatures low enough to cause damage but not cause freezing of water. This causes a variety of physiological disruptions in germination, growth, flowering, fruit development, yield and storage life. The second type of injury is *freezing injury*, which occurs when the external temperature drops below the freezing point of water. It results from untimely frost or from extremely low temperatures in mid-winter. Freezing injury is attributed to thawing of the bark on cold clear days as a result of solar radiation followed by rapid cooling as the sun sets or is covered by a cloud. Plant protoplasm can survive the lowest temperatures (0°C) if no ice is formed in the tissue. No plant can survive after the formation of ice crystals within the cells. When plants are frozen extracellularly any injury that occurs is likely to be dehydration injury. Among the food crops, rice and maize are sensitive to chilling temperatures. Their growth and development can be adversely affected by temperatures below 10°C resulting in yield loss or crop failure. Chilling during the seedling stage in cotton can reduce plant height, delay flowering and adversely affect yield and lint quality. Other crops that suffer stand loss, delayed maturity and reduced yield as a result of chilling after planting include: soybean, tomato, okra and various cereal crops.

The extent of injury is determined by how low, how fast and for how long the temperature drops. There is more injury to the plants located in depressions in the orchards since cold air settles on the ground and is not replaced easily due to higher density. Unlike freezing injury, chilling injury may be reverse if the chilling period is sufficiently short. Recovery in the post-chilling period is not immediate and depressed rates of plant growth are commonly noted. Different parts of the plant may differ in their sensitivity to low temperatures. This sensitivity may also vary with age. For example in American cotton and soybean, germinating seeds and young seedlings are more sensitive to chilling than mature plants. In rice and sorghum, the flower initiation stage is very sensitive, and low temperatures may disturb the formation of pollen mother cells and can thus cause sterility. Further, leaves and ripening fruits of tropical and sub-tropical fruits such as mango, guava, litchi, citrus etc. are also rapidly damaged by low temperatures. In general, chill injured plants initially have soaked leaves or soft spots on fruits, which necrose or are invaded by secondary pathogens and begin to rot.

4.1 Frost and its Impact on Plants

Frost is defined as the condition that exists when the temperature of the earth's surface and earthbound objects falls below zero degree (freezing). Frost can be classified mainly into two kinds: white (hoar) frost and black frost. White frost is caused by sublimation of the ice crystals on objects such as tree branches and wires etc., when these objects are at a temperature below freezing. On the other hand, black frost occurs when vegetation is frozen because of reduction in air temperature that does not contain sufficient moisture for formation of white frost. Black frost can be further grouped into two categories: radiation frost (short duration) and advection frost (long duration).

Radiation frost occurs on calm clear nights when the terrestrial radiation goes out relatively unimpeded because of absence of cloud cover. Severity of the radiation frost varies considerably with general atmospheric conditions as well as local differences in topography and vegetation. On the other hand, advection frost results from large-scale air mass transportation and is often termed as hard freeze. The characteristics of radiation and advective freeze (Table 1) are depicted below:

4.2 Mechanism of Frost Damage

Different theories and criteria have been advocated to explain the mechanism of how

Table 1. Characteristics of radiation frost and advective freeze

Radiation Frost	Advective Freeze
Calm winds (less than 5 mph)	Winds above 5 mph
Clear skies	Clouds may exit
Cold air mass 30 to 200 ft deep	Cold air mass 500 to 5,000 ft deep
Inversion develops	
Two types: Hoar (white) and black	
Cold air drainage occurs	
Successful frost protection likely	Protection success limited

Source: Katherine B. Perry, 2002, North Carolina State University frosts damage the plants. Plants, which have a tendency to undergo dormancy during winter, can withstand temperatures upto –20°C without injury. However, once growth has commenced, temperatures a few degrees below freezing would be fatal at certain stages of development of the plants particularly at flowering stage. The most accepted theory of injury and death caused by frost is the formation of ice in inter- and intra-cellular spaces of the plant cells. The inter-cellular water freezes first, then the intra-cellular water. The ice within the cells causes more injury through mechanical damage of the protoplasm and plasma membrane. Further, freezing of water in inter-cellular spaces withdraws water from the cell sap and increases dehydration leading to cell death.

4.3 Threshold Temperatures for Agricultural and Horticultural Crops

Plants adapt and adjust to different environmental conditions, but grow well in optimum weather conditions and remain dormant at lower temperatures due to limited metabolic activity while forced maturity occurs at high temperatures. Beyond these limits, plants get damaged and if the exposure to extreme values occurs for a greater period, the damage will be permanent and ultimately the plant dies. Lower limits of temperature for majority of the plants that are grown in Indo-Gangetic belt during winter are around 0˚C. Plants have different tolerance levels for temperatures that vary with species, varieties, age and stage of growth. Table 2 gives information on the threshold temperatures of major crops grown during winter and the perennial plants that are adapted to this region.

Table 2. Temperature limits for agricultural and horticultural crops grown in the northern plains

Crop / Plants	Optimum temperature (˚C)	Limits of lower temperature (˚C)	Higher limits (˚C)
A) Crops			
Wheat	25	3 to 4	30-32
Barley	20	3 to 4.5	38-40
Chickpea	20-25	5	> 30
Mustard	17-22	3	> 32-37
B) Plants			
Mango	24-30	< 4.5 (<1.0 shoots are likely to be killed)	>45
Guava	Warm climate (20-28)	Brief exposure to frost may defoliate completely	>43
Tamarind	Warm climate (30-40)	Young seedlings are susceptible to temperature (< 1.0). Mature trees can withstand brief period of <0.	> 48
Jamum	18-32	Young plants are susceptible to cold	> 44

Optimal soil temperatures, lower and lower lethal thresholds for germination of some vegetables crops are as follows:

Crop	Lower lethal (°C)	Lower threshold (°C)	Optimal range (°C)
Cabbage	0	4	7 to 35
Pea	-1	< 4	4 to 24
Radish	-1	< 4	7 to 35
Tomato	2	<10	15 to 29

4.4 Influence of Fog or Dew on Incidence and Spread of Diseases

Both dew and fog are generally associated with cold weather conditions and are a secondary source of moisture for plant growth especially in semi-arid and arid regions. Fall in temperature leads to increase in relative humidity. When it continues to fall, humidity reaches 100 percent at a particular temperature called saturation point or dew point temperature. Further drop in temperature will cause condensation of the excess water vapor on a surface into minute droplets called dew. Fog can be considered as a cloud on the ground in which visibility diminishes <1 km and the penetration of solar radiation decreases considerably. Fogs are of following 4 types.

i) ***Radiation fog*** : It is produced by earth's radiational cooling. It forms best on cold, clear nights where a relatively thin layer of moist air close to the ground is overlaid by drier air.

ii) ***Advection fog*** : It forms as the result of wind moving moist air from above a warmer surface to a region above a cooler surface.

iii) ***Upslope fog*** : It forms when moist air flows upslope in mountainous regions. With this upward movement the air cools to it's dew point causing condensation and fog formation.

iv) ***Evaporation or mixing fog*** : It is produced by mixing of two unsaturated air masses. If moist air meets and mixes with cooler air resulting in saturation, mixing fog is formed.

Fog or dew promotes surface wetness of leaves, spikes and other parts of plant for a prolonged period, which results in incidence and spread of diseases in most of the crops. Reports on incidence of diseases in different crops in association with cold weather hazards or abnormalities like dew or fog are elaborated as under:

Potato

Infection of early blight of potato is caused by the fungus *Alternaria solani*. Infection may occur within a period of 12 hours at 10°C, 8 hours at 15°C and only 3 hours at warmer temperatures, if moisture is present in the form of dew, fog or rain.

The optimum temperature for tuber infection is 12-16°C and if wet weather occurs at harvest, the quality of tubers decreases due to infections through cuts, bruises etc. Moderate mean air temperatures above 13.6°C, adequate moisture in the form of dew, infrequent rains but of longer periods with RH (80%) and shorter photoperiods in autumn were favourable for the development of early blight disease in potato in the Punjab region. In spring, higher mean air temperature (19.2-31.1°C), frequent rains but shorter total hours of RH (80%), the absence of dew during most of the season, longer photoperiods and prolonged senescence result in low sporulation, restricted size of the lesions and moderate disease intensities.

Late blight severity is positively related with maximum relative humidity, rain, dew, number of cloudy days and negatively correlated with minimum temperature. Normally, blight occurrence is associated with drop in air temperatures and rise in morning relative humidity. Mean RH above 72% persisting for 3-4 days due to rainfall or foggy conditions is favourable for initiation of late blight spots.

Wheat

Optimum conditions for the disease development of black rust (*Puccinia graminis)* are low temperature (16-27°C), relative humidity (> 70%) and excessive dew during late February to mid-March in Punjab.

Mustard

For the development of White rust caused by *Albugo candida*, mean air temperature between 16 and 25°C with an optimum of 20°C is conducive for zoospores to produce germ tubes and penetrate the plant tissues. Heavy dew or fog during periods of extended rainfall and lower temperatures are favourable for zoospore activity.

For peak aphid population mean maximum temperature around 23°C and minimum temperature at 10°C, maximum relative humidity at 85-88%, minimum relative humidity at 30-35%, evaporation 2-3 mm and wind velocity 3-4.5 km/h/day were found to be optimum.

Tomato

The ideal environmental conditions that favour epidemic development of late blight in tomato include warm days (21° to 29°C) and a relative humidity near 100 per cent followed by cool nights (7° to 15°C) with heavy dew, fog or a light drizzly rain that persists through the morning.

Barley

With 5 hours of leaf wetness duration following a day on which maximum temperature > 15°C, the risk of infection of brown rust in barley is reported very high.

Apple

A combination of warm days with temperatures above 16°C and high humidity above 80% created by rain, fog or irrigation favours fire blight development in apples. Prolonged leaf wetness due to late evening or night rains followed by fog or still air is reported to favour the formation of apple scab.

4.5 Genetic and Physiological Basis for Cold Tolerance

Genetic variability has been observed in response to low temperature particularly non-freezing stress. This variability has been used in various crop improvement programs. New cultivars have been developed which give stable performance even when exposed to low temperature stress. Improved varieties in association with appropriate crop production technologies such as sowing date, plant density, proper water and nutrient management, have enabled extension of crop cultivation to the colder regions of the world.

Physiological basis of resistance to freezing injury includes lowering of the freezing points of water in the vacuole and cytoplasm due to the soluble solute content in the cell sap. The protective responses are mediated by plant hormones, proteins and enzymes. Cytokinin levels in plants increase in response to chilling as a tolerance mechanism. Chilling promotes breaking of dormancy in scots pine seedlings, indicating the probable role of cytokinins in the process. There may be accumulation of soluble proteins with a parallel increase in freezing tolerance during winters. There are a number of reports of increase in *rubisco* enzyme content at lower temperatures.

Abscisic acid (ABA) has been related to increased chilling tolerance in a number of species e.g. maize, rice, sunflower, soybean, tomato etc. The protective function of ABA seems to be manifold: stabilization of membranes, protection against oxidative stress, stabilization of water status by increasing the root hydraulic conductivity, closing of stomata, induction of ABA responsive genes and *de novo* protein synthesis and changes of calcium in sub-cellular localization.

Most plants supercool below the freezing point of water within their tissues. Total avoidance of freezing by supercooling can provide protection upto –4°C for tender plants for short periods. In temperate plants, ice first forms in the extracellular spaces and water is then withdrawn from the cell to extracellular sites of freezing by the vapour pressure deficit. Ice does not penetrate the cell and intracellular freezing is avoided.

5. Impact of 2002-2003 Cold Wave on Agriculture – Case Studies

In the northern parts of India, especially Punjab, Haryana and UP region, temperatures in general remain high (Min 28 to 32°C and Max 40 to 45°C) in summer. They start declining from July onwards under the influence of the SW monsoon activity and generally remain in the range of 22 to 25°C (minimum) and 33 to 37°C (maximum). This indicates that temperature remains optimum for plant growth during the *kharif* season. After a brief rise in day temperatures in early October following withdrawal of the monsoon, both day and night temperatures decline from late October. In *rabi* season, especially in the higher latitudes, the prevalence of extreme cold temperatures not only inhibit plant growth but also at times lead to cold injury due to frost as observed during 2002-03 winter season. Occurrence of cold wave/frost during December-January in the north and northeast India is not a rare phenomenon. Such extreme cold wave conditions are often associated with passing western disturbances over the northwest region. It occurs almost every year in one part or the other, but the severity of cold wave of 2002–03 and its impact on crops, horticulture, livestock and fisheries was quite alarming. The first fortnight of January in 2003 was the coldest period recorded in 40 years at Delhi. Also October 2003 remained cooler than usual, which could be an indication for the severe cold wave conditions to follow later in the season.

Past records also suggest that a cold October is generally followed by a colder than average winter. However, the expected severity of cold during December-January 2004 will depend upon the behaviour of western disturbances.

5.1 Weather associated with Cold Wave Conditions during January 2003

In the first three weeks of January 2003, the northern parts of the country experienced severe cold wave conditions due to passage of a series of western disturbances which were mostly dry and have brought down the temperatures considerably. Cold wave, cold day and foggy weather conditions were reported over the northwestern and Gangetic Plains. Intensity of cold wave was such that under the movement of western disturbances in the first three weeks of January, the States of Uttar Pradesh, Bihar, Madhya Pradesh, Jharkhand and Orissa also came under the cold wave spell. Lowest minimum temperatures of -0.6 to -0.2°C at Hoshirapur and 0.6 to 1.0°C at Adampur were recorded in Punjab and a few rain spells occurred over the northwestern region of the country.

The impact of the cold wave conditions on different crops at several locations is described below through case studies.

5.2 Hoshiarpur, Shivalik Foot Hill Zone

The cold wave conditions in Punjab were quite significant during the winter of 2002-03. A perusal of the record of daily maximum and minimum temperatures at Ludhiana (Figure 9 and 10) indicate that the maximum temperature was significantly below normal from 31st December 2002 to 23rd January 2003 (24 days). The departure being of the order of 6 to 8°C, the minimum temperatures were also below normal during 10th to 24th January 2003 (14 days) causing significant cold weather effects on crops.

Frost damage was more severe in Hoshiarpur area. In the beginning of November 2002, the minimum temperature was 12.4°C, which dropped to 9.5°C on 15th November. It continued to fall further and reached a minimum of 2.9°C on 9th December. Thereafter, the minimum temperature rose slowly to 11°C by 16th December and then continued to rise and fall irregularly. The lowest temperature of –0.1°C was recorded at Hoshiarpur on 15th January 2003. The minimum temperature during whole of January varied between 12.6°C and –0.1°C, which was sufficient to cause freeze and chilling damage to the fruit plants. The relative humidity during the months of November-December 2002 was between 30-60 percent. There was no rainfall during this period. Such conditions of low temperature, very low humidity and lack of rainfall are considered conducive for frost damage to crop plants in general, and to fruit plantations in particular.

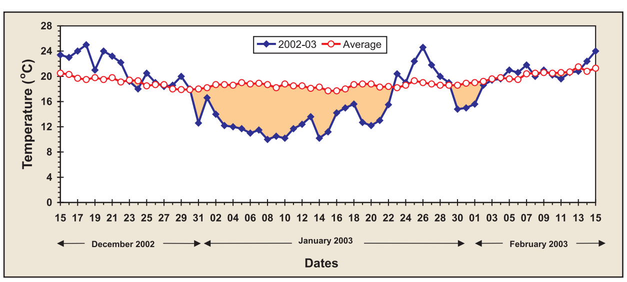


Fig.9 : Daily Maximum temperature of 2002-03 and average at Ludhiana

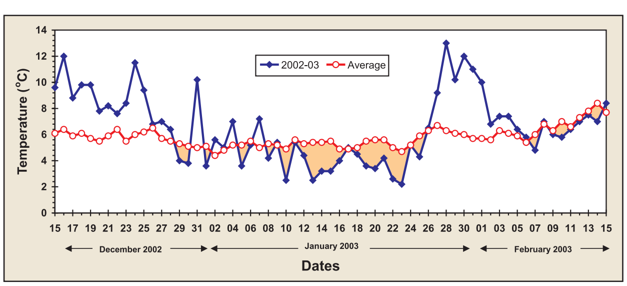


Fig.10 : Daily Minimum temperature of 2002-03 and average at Ludhiana

A survey in the Shivalik Foothill Zone above Una Road, revealed that orchards of mango, litchi, guava, kinnow and ber suffered serious damage because of the low temperature during the months of November-December 2002 and January-February 2003. The extent of damage is apparent from Table 3.

According to media reports losses due to cold wave in mango crop ranged from 40-80% in different varieties. The affected total area reported was around 600 ha. There was a complete loss of fruit yield in all species. The damage to different fruit trees due to frost was as under:

Mango: Depending upon the tree age, the extent of damage was between 40-100%. Shoots dried-up upto 2 meters from the tip. Entire foliage was killed while cracking and stripping of bark was observed. Young plants aged 2-3 years dried-up completely.

Table 3. Effect of cold wave on fruit orchards in selected villages of Hoshiarpur region, Punjab

Name of the farmer and village	Fruit species and age	Area in acres	Yield damage (%)	Damage to plants (%)
Sh. U.S. Chatha Village Mehlawali	Litchi (12 years)	8	100	30-60
Sh. J.S. Lali Bajwa Village Mehlawali	Litchi (15 years)	2	100	30-60
Sh. K.S. Gill Village Kharkan	Mango (15 years) Litchi (12 years)	10 5	100 100	60-80 60-80
Sh. Ranjit Singh Village Kantia	Mango (10 years) Aonla (15 years)	45 10	100 100	80-100 80-100
Mr. Ramji Das Village Dholwaha	Mango (8-10 years)	30	100	40-60
Sh. J.S. Dhaliwal Village Dholwaha	Mango (8-10 years)	60	100	40-60
Mr. Deepak Puri Village Chohal	Mango (30 years)	5	100	100
Sh. Jaspal Singh Village Mehmowal	Mango (10 years)	6	100	60-80
Village Salimpur	Mango (2-3 years)	5	100	100

Litchi: The entire foliage was killed and the shoots dried-up. Folding and rolling of leaves took place. The extent of damage was 30-80 percent.

Guava: In guava orchards dropping, bronzing and hardening of fruits occurred and the shoots were completely defoliated and such shoots dried-up later on. Fruit size was very small and whatever fruits were left on the trees, tasted bitter.

Kinnow: In kinnow orchards defoliation occurred at some locations.

Ber: Fruit maturity was delayed and the fruit size was reduced drastically. Defoliation of the bearing trees also took place.

Similar damage was recorded in horticultural plantations in the *Kandi* region during December 2002-January 2003, occurring for the third time during the last seven years (previously in December 1996-97 and 2000-01).

Inspection of these orchards further revealed that:

i) Frost damage to fruit plants was more in cultivated fields. Plants situated in low-lying areas in the field were more affected due to high accumulation of cold air mass. Similarly, the damage to plants was higher on sandy soils (with low heat capacity) than on heavy soils.

ii) Amongst the horticultural plants mango and amla trees suffered more damage than the guava trees. Also, grafted trees were more affected by frost than seedling mango and amla trees.

iii) The damage in mango orchards interplanted with kinnow was less compared to pure mango orchards.

iv) Frost damage was much less both to orchards and nursery plants.

v) Frost damage was more in younger plants compared to older plants and in weaker plants compared to healthier ones

Other Trees: *Acacia catechu,* a highly priced leguminous tree in the Shiwalik belt of north India (as *Katha* is distilled from its heartwood), suffered widespread damage to growing tips. Adverse effect on neem and tamarind trees was also reported.

5.3 Chandigarh and Adjoining Areas

For most part of the 2002-03 winter (December to February) both the daily maximum and minimum temperatures remained much lower than the long-term average of 1962 to 2002 (Figure 11 and 12).

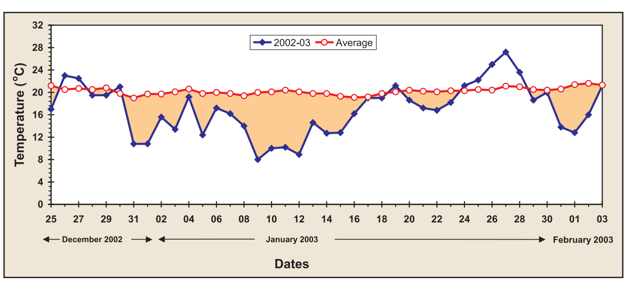


Fig.11 : Daily Maximum temperature of 2002-03 and average at Chandigarh

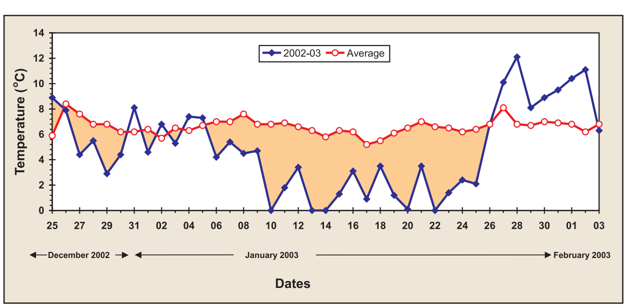


Fig.12 : Daily Minimum temperature of 2002-03 and average at Chandigarh

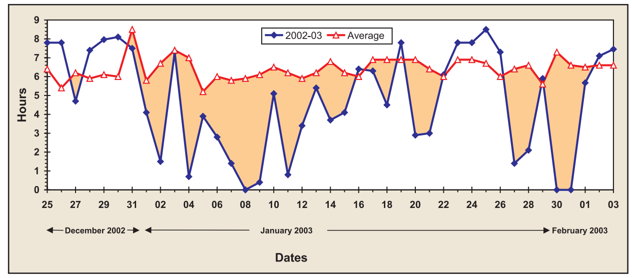


Fig.13 : Bright Sunshine Hours during 2002-03 and average at Chandigarh

Similarly, the daily duration of bright sunshine hours was drastically less compared to the long-term average (Figure 13).

A survey of about 23 private and government gardens, nurseries and project areas was conducted at the end of March, 2003 in Panchkula, Chandigarh and Solan areas of Himachal Pradesh to assess the damage caused by frost on fruit plantation in general and mangoes in particular. The results are summarized as under:

Mango

- Amongst all the cultivars, *Dashehari* with 15-18% mortality was the most affected, followed by *Amrapali* (9-12% mortality) and *Langra* in some cases. The affected plants did not regenerate.
- Younger plantations (1-3 years old) were more vulnerable to frost as compared to the older plantations.
- Mango plantations having windbreaks around the boundaries were less affected.
- In almost all the gardens surveyed, flowering in mango was adversely affected as compared to the previous year and it ranged from 18-48%. Even

flowering per plant was much below the normal range of 22-68%.

- Further, in local seedlings, flowering was much less as compared to grafted plants and ranged from 5-20%.

Other Fruits

- High density and multi-layered fruit plantations were affected little due to frost. In many cases the flowering was normal.
- Among other fruit species, papaya was the most affected and mortality ranged from 40-83%. Other impact of frost includes mis-shapen fruits, small size, poor growth, insipid, hard in texture and fruit drop. Vegetative growth of plants was also hampered.
- Guava plants were also affected showing very poor vegetative growth, tip burning, premature leaf fall, poor fruit development, hard in texture, insipid and less juicy. Fruit drop was the major problem.
- In *Loquat,* fruit development was adversely affected and 45-60% fruits were damaged in the form of aborted fruits, mis-shapen, shrinkled, smaller in size, less pulpy and showing spots on the fruits.

5.4 Dehradun

Frost is a common feature during December-January in the Doon Valley. Thirty years average of maximum and minimum temperatures range from 20.2 to 26.2°C and 4.2 to 4.5°C, respectively (Figures 14 and 15). However, during December, 2002 and January, 2003 extremely low temperatures prevailed. During December 25-31, 2002, minimum temperature for 3 days ranged between 1.2 to 1.5°C. Similarly, in January 2003 there were 9 days having minimum temperature <2°C. Minus 1°C was recorded on January 11,12,13 and 14 (Figure 15). The severe cold wave conditions continued upto January 26, 2003 and the minimum temperature remained below 3°C. This extreme cold wave condition resulted in occurrence of severe frost and reduced bright sunshine hours (Figure 16) and caused extensive damage to fruit plants.

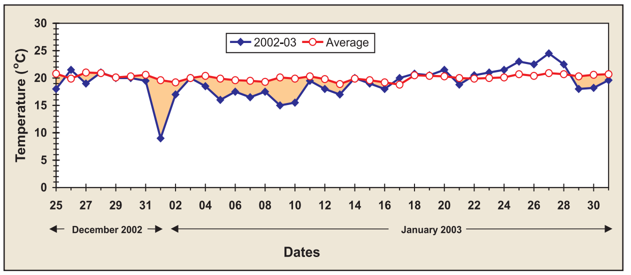


Fig.14 : Daily Maximum temperature of 2002-03 and average at Dehradun

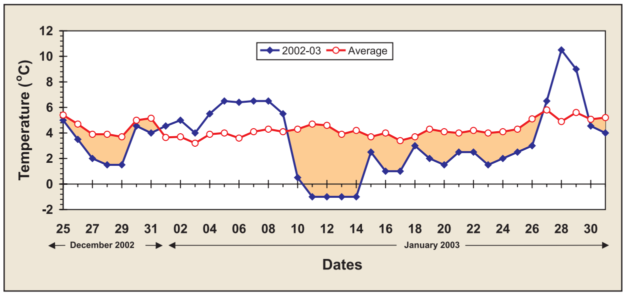


Fig.15 : Daily Minimum temperature of 2002-03 and average at Dehradun

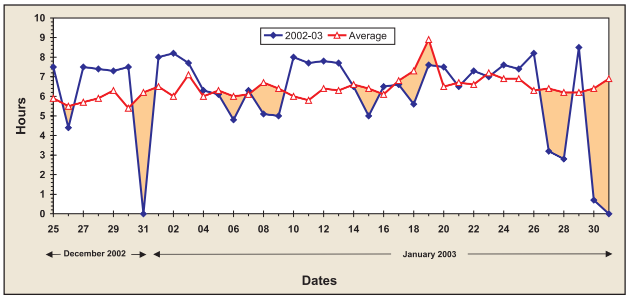


Fig.16 : Bright Sunshine Hours during 2002-03 and average at Chandigarh

A total of 37 orchards of different fruit types were surveyed from 21 villages of Sahaspur, Vikasnagar, Doiwala and Raipur blocks in Dehradun district. The fruit orchards were classified into various categories, based on location, age group and crop combinations. In the Doon valley, mango and mango based agroforestry systems are the most popular (57.8%), followed by litchi (15.6%), guava (11.2%), Kinnow (7.8%), peach (4.4%) and lemon etc. (1%).

The damage due to cold wave on fruit plants was in the order: mango >papaya > banana > litchi > pomegranate > amla. Citrus (kinnow, lime and lemons), guava and peach were the least affected. The damage was maximum in younger plants (Plate 1) upto 2 years age (80.43%), followed by 15.47% in 2-4 years plantations and about 10% in orchards above the age of 4 years (Figure 17).

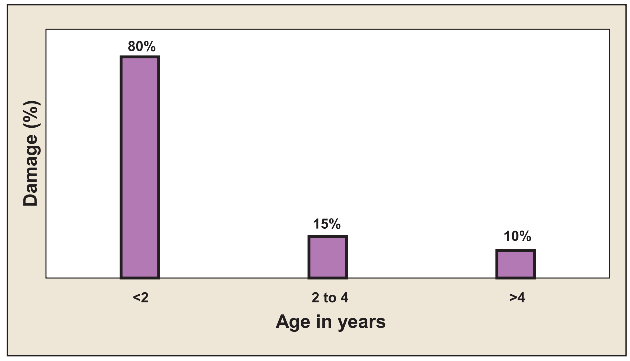


Fig.17 : Effect of mango tree age on cold injury during 2002-2003 in 21 villages of Doon valley, Uttaranchal

5.5 Agra

During 2002-03 winter, maximum temperature was generally less than15°C from December 27, 2002 to January 07, 2003 and again from January 17 to January 24, 2003 (total of 20 days). Likewise, minimum temperature was lower than 5°C for consecutive days in three spells; 2-6 December 2002; 29 December to 11 January 2003 and

Plate 1 : A broad view of the young mango plants damaged by frost at the Research Farm, Selakui. In the background unaffected 3 ha plantation of Kinnow is seen

21-26 January 2003 (total of 25 days) (Figure 18, 19, 20). Further, bright sunshine hours were less than 5 hrs from December 25 to January 21 and this had an adverse impact on agricultural productivity.

The prolonged low temperature, foggy and cloudy weather that prevailed at Agra and nearby

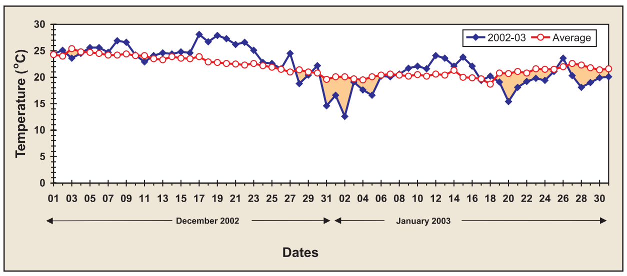


Fig.18 : Daily Maximum temperature of 2002-03 and average at Agra

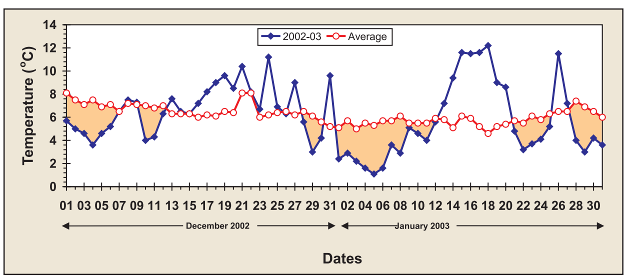


Fig.19 : Daily Minimum temperature of 2002-03 and average at Agra

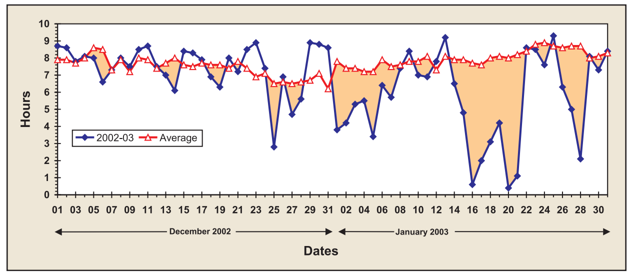


Fig.20 : Daily Bright Sunshine Hours during 2002-03 and average at Agra

places during the winter of 2002-03 had an adverse impact on agricultural productivity over the entire region (Table 4). Yield of mustard was reduced to almost half (Plate 2), that of wheat by 40%

Plate 2 : Mustard suffered during the prolonged winter at Bamrauli Katara

Table 4. Yield loss in major crops during 2002-03 owing to prolonged winter in Agra district (Irrigated conditions)

Crop	Location	Yield during 2002-03 (q/ha)	Crop loss (%) in comparison to 2001-02
Wheat	Bamrauli Katara	25-30	10-20
	Bilauni	32	40
Gram	Bamrauli Katara	8-10	25-30
Mustard	Bamrauli Katara	8-10	50 (70 in case of late sown crop)
Brinjal	Bamrauli Katara	-	Almost total failure
Potato	Bamrauli Katara	200	25
Aonla	Dauki nursery		
	Balwant variety	-	95
	Chakaiya variety	-	60
Neem	Arnauta forest nursery	-	Seriously affected but revived
Imli	Arnauta forest nursery	-	Severely affected

Plate 3 : Wheat sown in valley lands at Bilauni suffered loss due to cold wave conditions

Plate 4 : Brinjal crop totally lost during prolonged winter has revived at Bamrauli Katara

Plate 5 : Neem tree that suffered severe damage due to prolonged winter is seen reviving with fresh up coming leaves

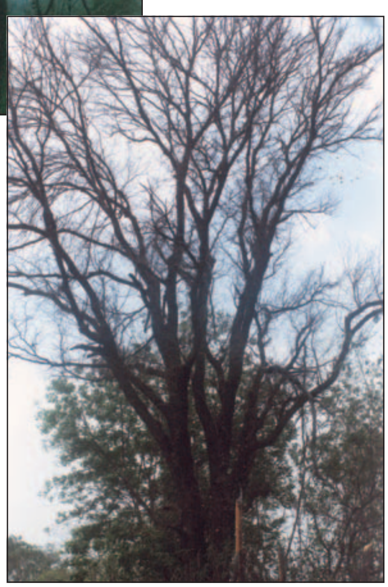


Plate 6 : Acacia nilotica that suffered severe winter is yet to revive

(Plate 3) and potato by 25%. Vegetable crops were also adversely affected (Plate 4). The prolonged cold wave led to delay in ripening of guava and ber fruits. Amongst the forest species, neem (*Azadirachta indica*) and *imli* (*Tamarindus indica*) were the most damaged species (Plate 5 and 6). The loss in Aonla was of the order of 60-95%. Milk production from buffaloes and cows was reportedly reduced by 20-25%. The impact of cold wave was more severe in depressions than in upland fields. Adverse effect of cold wave was negligible where tomato and pigeonpea were grown together in a ratio of 3:1 (Plate 7). In this case, pigeonpea was planted in furrows and regularly irrigated.

Plate 7 : Tomato-Pigeonpea cropping system at Rajpura in Bah Tehsil (3:1)

5.6 Lucknow and Adjoining Areas

Central Institute for Subtropical Horticulture, Lucknow conducted a survey of mango, guava and papaya orchards at Lucknow and adjoining areas to quantify the cold wave impact. The major findings emerged from this survey were:

- In general, *Dashehari* cultivar of mango was most affected. Cultivars *Jauhari, Safeda*, *Chausa* and *Tamuria* suffered maximum in Barabanki, Khushalganj and Sitapur road areas.
- Extremely low temperatures during January 2003 delayed panicle emergence/flowering (flowering emerged in three stages) in mango. It is generally observed that maximum fruiting occurs on panicles, which emerge first. The characteristic *Jhumka* with aborted embryos was noticed in almost all the areas.
- The low temperature during January resulted in reduced population of pollinators and hoppers. Heavy infestation of mango mealy bug was also reported at Barabanki and Lucknow Mal Road areas.
- No detrimental effect of cold wave was noticed on guava.
- Damage to papaya plants and the fruits in Bhata, Bhitora and Rasoolpur areas of Fatehpur district was severe. In Chandipur and Maheshpur areas nearly 50% of the crop was damaged. Similarly, in Kaushambi, Allahabad and Varanasi districts, the damage ranged from 30-40%. The fruit quality was also degraded by the cold wave.

5.7 Hisar

Loss due to cold wave during the months of December 2002 and January 2003 in mustard was reported to be 15 to 25%. In areas where mustard crop was sown purely on residual moisture and grown without supplementary irrigation, the cold wave spell on 14th and 15th January caused loss to the extent of 40%.

Similarly, the loss to vegetables and fruits particularly ber, papaya and guava was 20 to 50 per cent. In vegetable crops like brinjal and tomato the loss was still higher.

5.8 Jodhpur

Normally cold waves occur in western Rajasthan for 10-12 days during January and that too intermittently. However, during 2002-03, the cold wave prevailed continuously for three weeks. Previous records showed that the longest severe cold wave occurred in 1998 for a maximum period of two weeks. The peculiar feature of 2002-03 cold wave was that its occurrence was coupled with dense fog and less sunshine affecting crops through frost injury and reduced levels of photosynthesis.

Daily maximum temperature was below normal from 25 December 2002 to 14 January 2003 (Figure 21). The first spell of cold wave of moderate intensity with minimum temperature falling by 2.5 to 3.0°C from normal, prevailed during December 31, 2002 to January 6, 2003 (Figure 22). The second cold spell occurred around January

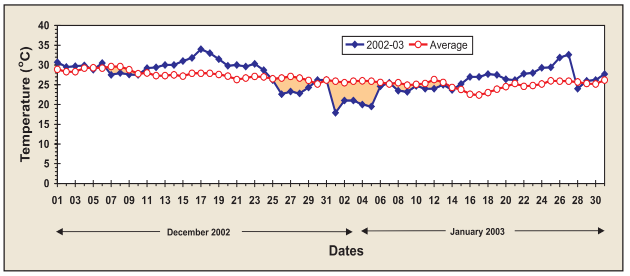


Fig.21 : Daily Maximum temperature of 2002-03 and average at CAZRI, Jodhpur

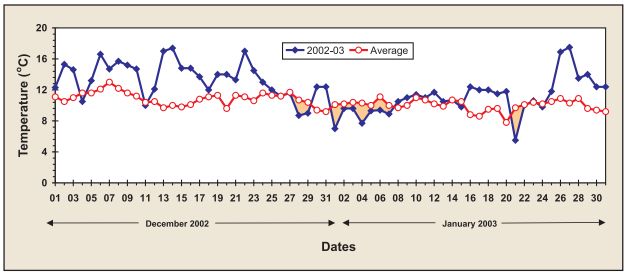


Fig.22 : Daily Minimum temperature of 2002-03 and average CAZRI, Jodhpur

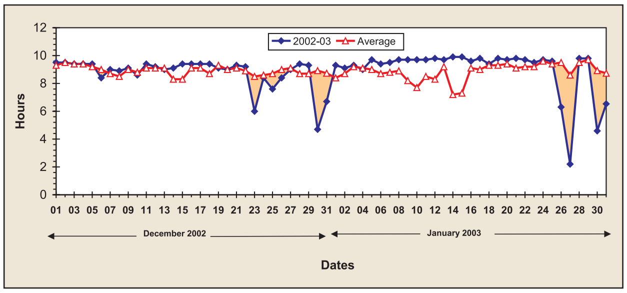


Fig.23 : Daily Bright Sunshine Hours during 2002-03 and average at CAZRI, Jodhpur

20, 2003 with more severity and air temperature falling by 4°C from normal. The sunshine hours were below normal from 23 to 31 December 2002 (Figure 23) except for two days. The lowest sunshine hours were recorded on 27th January 2003.

A survey conducted to study the impact of cold wave on field crops near Jodhpur indicated damage upto 20-30% in tomato and 5-10% in chillies. Cold wave damage to chillies was negligible when it was associated with castor as an inter-crop. Garlic, onion and wheat were unaffected.

5.9 Barapani, Shillong

Impact of cold wave on establishment and performance of fruit trees at ICAR Research Complex for NE Hill Region, Shillong is reported in Table 5.

5.10 Pusa, Bihar

Meteorological data recorded at Pusa, Bihar indicated that very low temperatures prevailed in the month of January, 2003. The mean air temperature during winter months was much below

Table 5. Effect of 2002-03 frost on one-year-old fruit plants at Barapani, Shillong

Fruit Species	No. of saplings planted	No. of saplings survived	Mortality %
Mango (Amrapali)	15	Nil	100
Sapota	20	04	80
Chuckrasia tabularis	36	24	33
Michaelia champaca	50	20	60
Jack fruit	60	25	58
Guava	50	40	20
Peach	50	42	16
Pear	24	16	33
Rose apple	20	07	65
Assam Lemon	100	36	64
Litchi	10	09	10
Pineapple (Kew)	3500	600	83
Citrus sinensis			
Var. Valentia	30	16	47

the normal temperature of around 15°C. The maximum and minimum temperature variations during January 2003 in relation to normal daily temperature for the corresponding period are depicted in Figures 24 and 25. There were reports

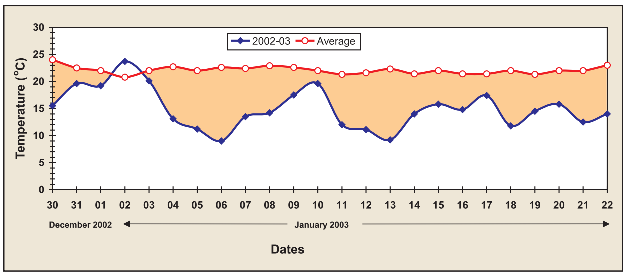


Fig.24 : Daily Maximum temperature of 2002-03 and average at Pusa

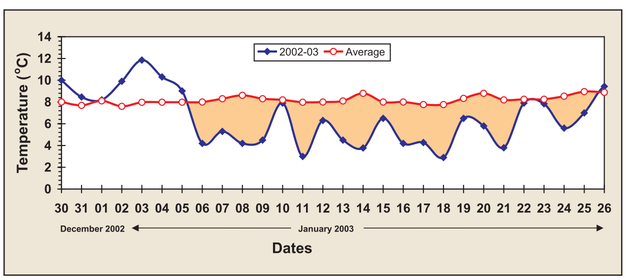


Fig.25 : Daily Minimum temperature of 2002-03 and average at Pusa

that on some individual nights the temperature even dropped to less than 2°C at other locations. Similar measurements of maximum and minimum temperatures at Patna (Figures 26 and 27) indicate a large drop in both maximum and minimum temperatures continuously during the period 8-27 January 2003.

These sharp aberrations in minimum temperature adversely affected the winter maize productivity, which was grown in an area of about 2.2 lakh hectare. Maize being a *thermophilic* species requires temperatures above the threshold limits (average day and night temperatures above 10 and 4.4°C, respectively). It is a known fact that exposure of maize to short photoperiods and cool nights (< 5°C) for more than 3 days during flowering causes severe male sterility. Further, the concentration and activity of floral hormones such as *gibberellins* and *cytokinins,* and other essential enzymes decline sharply under low temperature conditions.

A survey conducted in the winter maize growing area of Bihar to ascertain the causes for no/poor seed setting in some maize hybrids during *rabi* 2002-03 revealed the following facts:

- Late planted (December) maize had shortened internodal length, thick stalk and stunted growth.
- All early planted hybrids (October) flowered during cold spell which resulted in:
  - Poor tassel development
  - Restricted growth of anther lobe & filament
  - Pollen availability and viability was badly affected

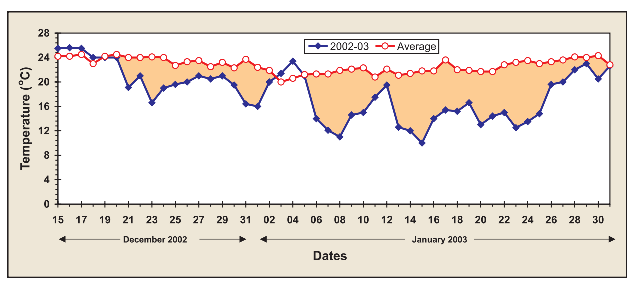


Fig.26 : Daily Maximum temperature of 2002-03 and average at Patna

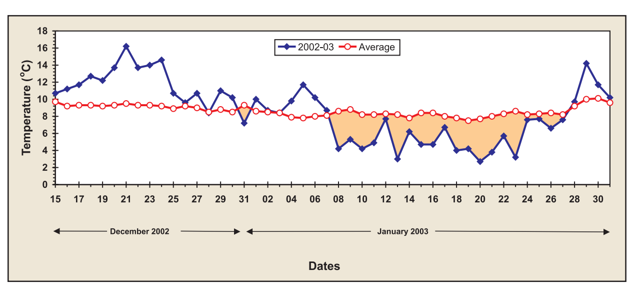


Fig.27 : Daily Minimum temperature of 2002-03 and average at Patna

- Silk emergence was delayed and non-synchronous with pollen availability
- Silk balling and abortion due to excessive cold
- Seed setting was as low as 20-30 percent (70 to 80% less) in early sown winter maize
- Flowering in early planted maize escaped cold and gave 70 to 100% seed setting
- Composites like *Lakshmi* and *Devki* were less affected
- Sheltered sowing near villages and orchards suffered less damage
- Pigeonpea and mustard were also damaged

5.11 Jorhat, Assam

During the *boro* season from October to April in 2002-03, unlike the previous years, *boro* rice in Assam experienced a long spell of 'Cold Stress". In rice below 20°C night temperatures play an adverse role on plant productivity. It can be seen that average night temperatures remained below 20°C consecutively for 183 days since November 2002 (Figure 28). Similarly, the mean daily temperature was below 20°C for 10 weeks (Figure 29). Lowest night temperature recorded was 7.5°C, which continued for 11 days. The lowest daily average temperature reported was 12.5°C.

The normal sowing/planting time for *boro* rice in Assam is from October to December. The

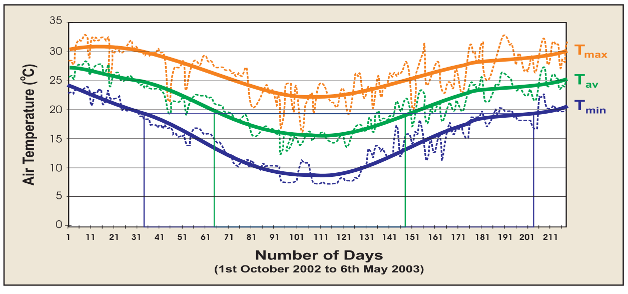


Fig.28 : Trends of daily temperature variations in boro season, 2002-03

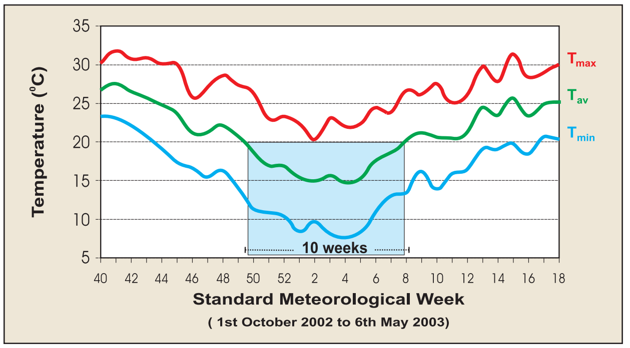


Fig.29 : Diurnal variations of weekly temperatures in boro season, 2002-03

low night temperatures affected the *boro* rice crop markedly. The effect of cold temperatures greatly varied with the variety used and time of sowing/planting. Late sown crop (December sown) in different localities of Central Brahmaputra Valley Zone of Assam suffered very poor germination and exhibited higher proportion of albinism (Plate 8). Effect of blast was also visible on this crop.

Plate 8 : Effects of cold injury in *boro* rice nursery bed

Top : Failure of germination (48.5 to 60.4%), and

Bottom : Albinism (On-Station: 13.6% On-Farm: 37.9%)

In case of normal sown/planted crop average seedling mortality during the vegetative stage was 37.1% in the On Farm Research locations, 26.2% in farmers' fields and 20.9% (Figure 30) at the Research Station at Shillongani and Nagaon (Table 6,7,8). Yellowing at a later stage was also noticed in some varieties that were otherwise promising (Plate 9).

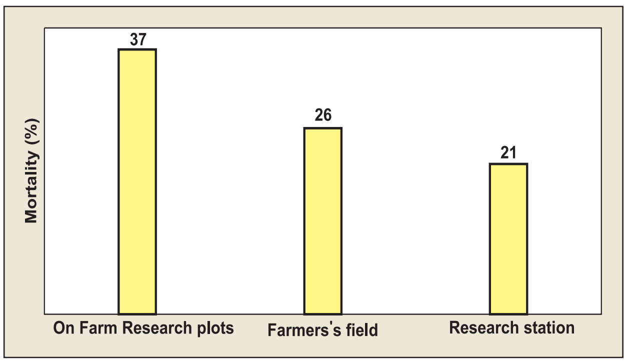
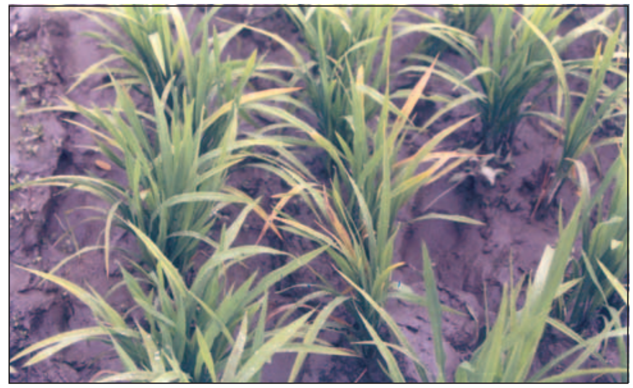


Fig.30 : Seedling mortality of normal planted boro rice during vegetative stage during the cold wave period of 2002-2003 at Jorhat, Assam



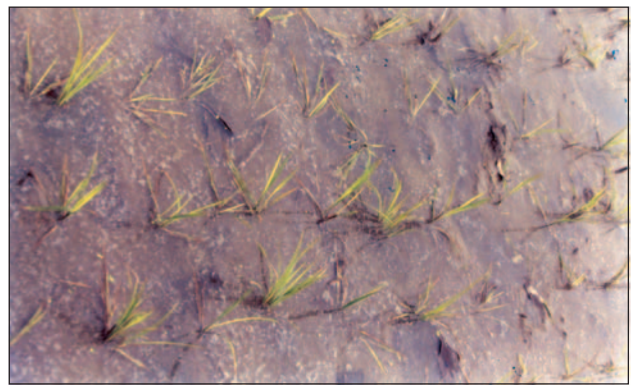


Plate 9 : Cold stress during vegetative stages of growth in *boro* rice

Top : Failure of seedling establishment (at 22 DAT), and Bottom : Start of leaf yellowing (at 35 DAT)

Table 6. Cold injury in 'on-farm' research experiments during *boro* season in Assam, 2002-03

On-farm location	Seedling stage		Vegetative stage		Reproductive stage	
	Albinism (%)	Seedling mortality (%)	Crop recovery after planting (%)	Leaf yellowing (1-9 score)*	Grain sterility (%)	Unproductive tillers (%)
Shillongani	35.5.	50.8	66.9	8	51.3	18.8
Tokowbari	30.2	33.3	70.2	5	48.9	14.2
Bhakatgaon	31.0	25.4	66.4	5	48.9	18.7
Raha	16.8	29.7	75.8	5	40.2	14.9
Tezpur	18.2	20.7	82.2	4	68.4	12.8
Kaliabor	20.4	42.2	76.5	8	52.1	16.4
Kawoimari	37.9	45.6	60.6	6	61.2	19.0
Morigaon	18.9	40.0	70.8	6	52.6	20.0
Juria	26.8	46.2	65.5	7	60.0	16.9
Average	**26.2**	**37.1**	**70.5**	**6**	**53.7**	**16.8**

* 1=Normal, 9 = Severely yellow

Table 7. Cold injury in experiments on 'farmer's fields' during boro season in Assam, 2002-2003

Farmer's field	Seedling stage		Vegetative stage		Reproductive stage	
	Albinism (%)	Seedling mortality (%)	Crop recovery after planting (%)	Leaf yellowing (1-9 score)*	Grain sterility (%)	Unproductive tillers (%)
Shillongani	29.0	45.2	56.0	7	58.9	16.7
Tokowbari	20.0	30.1	73.3	5	44.8	17.7
Bhakatgaon	22.0	29.8	78.5	5	45.0	13.8
Hojai	26.0	28.8	-	5	98.0	13.7
Thekeraguri	-	26.4	82.2	4	61.1	19.8
Nanoi – I	31.0	22.0	70.0	5	100.0	25.7
Nanoi – II	35.0	20.0	64.6	5	100.0	20.0
Kaliabor	24.0	16.9	78.7	7	46.9	15.5
Kampur	-	20.2	70.6	-	52.8	20.1
Morigaon	27.0	23.7	76.5	6	58.0	14.3
Jagi	22.0	25.4	61.2	6	60.7	18.8
Average	**26.2**	**26.2**	**71.1**	**5.5**	**66.0**	**17.8**

*1=Normal, 9 = Severely yellow

Table 8. Cold injury in 'on station' experiments in Assam (*boro* rice, 2002-2003)

On Station experimental sites	Seedling stage		Vegetative stage		Reproductive stage	
	Albinism (%)	Seedling mortality (%)	Crop recovery after planting (%)	Leaf yellowing (1-9 score)*	Grain sterility (%)	Unproductive tillers (%)
Shillongani – I	13.6	26.5	82.3	6	30.8	15.0
Shillongani – II	10.2	20.2	85.1	5	31.0	16.4
Shillongani – III	10.0	16.5	88.2	4	26.4	14.4
Tokowbari – I	11.5	21.4	80.3	7	42.6	13.2
Tokowbari – II	19.2	20.0	80.5	6	26.5	13.7
Average	**17.9**	**20.9**	**80.3**	**5.6**	**31.5**	**14.5**

* Leaf yellowing score 1 = Normal 9 = Severe

Grain sterility between 54 to 66 percent was observed during the reproductive stage (Plate 10) in the farmers' managed plots, while it was 31.5% in the experimental plots at Shillongani (Figure 31). The unproductive tiller percentage was 15±2% in all the fields monitored. The expected loss in productivity of recommended varieties was nearly 10% compared to normal years. The proportion of chaffy grain was also

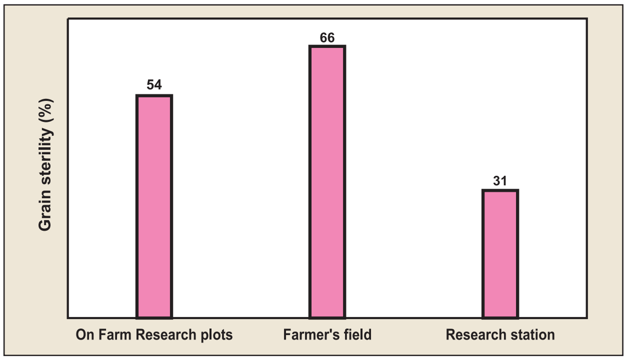


Fig.31 : Grain sterility of normal planted boro rice during productive stage in the cold wave year 2002-03 at Jorhat, Assam

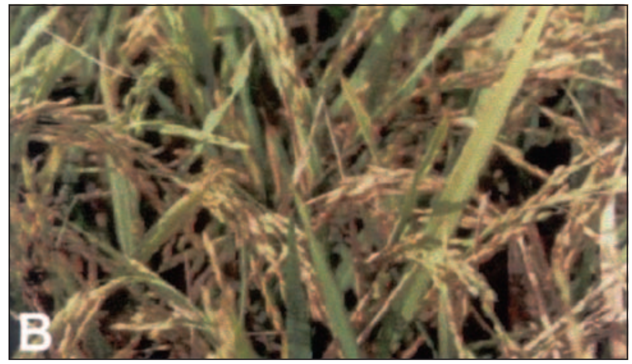


Plate 10 : Cold damaged during reproductive stage of *boro* rice; Left : Panicle with non-functional anthers, and Right : Sterile spikelets (42.7%) and Immature grains (22.0%)

more. Besides, the maturity duration for most of the crops was extended by 10 to 25 days. A significant varietal variability (Plate 11 and 12) in *boro* rice for tolerance to cold wave was also observed (Table 9). To avert the effect of cold stress in the nursery bed, low cost *Poly tunnel* was found quite effective for quick raising of seedlings (Plate 13).

Plate 11 : Promising boro rice crosses (F6 generation) in pipeline; Left : 'Mahsuri x V41' - an early maturing-medium tall, and Right : 'V108 x Pusa 5' - an medium maturing-tall

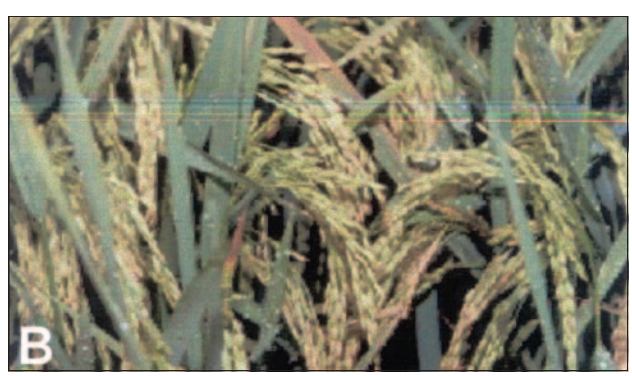


Plate 12 : Promising boro rice crosses (F6 gerneration) in pipelline; Left : 'Joymati x V108' - an early maturing - semi dwarf, and Right : '510BR x JYM' - a High yielding - cold tolerant cross

Table 9. Variability in tolerance of some promising *boro* rice varieties to cold wave at RARS, Shillongani during 2002-2003

Boro rice varieties	Seedling stage		Vegetative stage		Reproductive stage	
	Albinism (%)	Seedling mortality (%)	Crop recovery after planting (%)	Leaf yellowing (1-9 score)*	Grain sterility (%)	Unproductive tillers (%)
Dhanalaxmi	10.5	16.0	88.0	4	35.6	20.0
Saroj	9.4	10.1	87.3	4	29.0	26.4
Prabhat	10.5	11.4	80.3	3	32.6	14.2
Gautam	19.0	25.4	37.7	8	45.6	44.4
Joymati	9.0	16.8	86.0	5	29.9	12.0
Bishnuprashad	15.6	19.0	85.2	5	17.5	15.3
Mahsuri	11.1	11.6	90.0	5	18.6	15.0
Satabdi	10.7	12.2	85.0	4	14.2	15.6
Jagilee boro	18.9	21.9	80.1	3	20.2	38.1
PSB RC 2	12.3	20.1	80.6	5	14.1	12.2
Average	**12.7**	**16.3**	**80.0**	**4.6**	**25.7**	**21.3**

* Leaf yellowing score 1 = Normal 9 = Severe

Plate 13 : 'Poly-tunneling' to avert cold-stress in boro rice seed bed; Left : Low cost frame from jute sticks, bamboo etc., and Right : Raising rice seedlings under polythene cover

5.12 Effect of Frost on Fruit Trees (1994-95 Experience)

The fruit species planted at Bichhian experimental farm of Central Soil Salinity Research Institute, Karnal experienced unusual frost conditions during the nights between December 30, 1994 and January 2, 1995. Young shoots bearing leaves in almost all the species of more than 2 years age dried-up till the ground level. The frost effect was so severe that even 6 to 8 years old plantations of many forest species in the adjacent area dried-up till the ground level. Though most of the fruit species recovered in the following spring season, their growth was significantly reduced.

It took nearly one year for the plants to regain the same growth as recorded before the onset of frost. The damage was maximum in case of sapota, *karaunda*, pomegranate, *amla* and *imli* and minimum in *ber* and date palm (Table 10). Almost all plants of *Imli, jamun* and guava recovered in the following months of March-April. Recovery was only 96, 92 and 88 percent in case of pomegranate, guava and *karaunda*, respectively. Sapota which otherwise was growing very satisfactorily did not recover at all and almost all plants of 2 years age died. A general view of fruit plantations of *jamun*, guava, tamarind and *amla* before and after the frost is shown in Plate 14, 15, 16 and 17.

Table 10. Relative tolerance of fruit trees to frost at Bichhian farm, Kurukshetra (1995)

Fruit species	Plants damaged (%)	Plants recovered (%)
Pomegranate	94	90
Sapota	100	4
Imli	92	92
Karaunda	100	88
Ber	6	6
Date palm	0	0
Jamun	72	72
Guava	78	76
Amla	92	84

Similar experiences of frost damage to mango plantations was recorded in the Nurpur area of Himachal Pradesh during severe cold winters, wherein not only the younger plants were extensively damaged but also fully matured trees dried-up at some places.

Plate 14 : A view of jamun plantations at Bichhian farm before frost (above) and after the frost (below)

Plate 15 : About 5 years old guava plantations at Bichhian farm before frost (above) and after the frost (below)

Plate 16 : Nearly five years old tamarind plantations (above) before frost and (below) after frost

Plate 17 : Nearly five years old amla plantations before frost (above) and after frost (below) in a highly alkali soil

5.13 Benefits of Cold Wave

Temperate fruit trees, viz., apple, plums, peaches are extensively grown in the parts of Jammu & Kashmir, Himachal Pradesh and Uttaranchal and in some parts of northeastern states. Income generated by exports of these fruits throughout the country significantly contributes to the economy of this region. As these plants are basically grown in temperate climates, extended periods of cold season meets the chilling requirements adequately and helps in better flowering and more quality fruits in the subsequent season. This is what has been witnessed during 2003. Farmers have reaped a bumper harvest of apple in Himachal Pradesh, which is the highest producer of apple in the country. The increase in production in apple in this State during 2002-03 over 2001-02 was of the order of 93%. Though, wheat crop also grows well under cold periods during vegetative phase, subsequent increase in night temperatures above the optimal values during reproductive stages has diminished the positive influence on productivity.

6. Effect on Livestock

Studies on the effect of daily variations in temperature on livestock under Indian conditions are limited. However, some experiments at the National Dairy Research Institute (NDRI), Karnal reported the favourable limits for maximum milk production in crossbreds such as Karan Fries and Karan Swiss to be between 7°C and 25°C. Similarly, for Bareilly area the optimum limit reported is 7-27°C. The minimum temperature during cold wave of 2002-03 remained <7°C for a considerable period at many places in north India, thus affecting milk production adversely. Agra centre reported about 20-25 percent reduction in the milk production of buffaloes and cows.

It is reported that cold stress results in some hormonal and adaptive changes in livestock, which affect the animal's level and efficiency of production. Some of the effects are:

- An increased energy requirement for maintenance as a result of increased resting metabolic rate.
- Reduced digestive efficiency due to increased rate of passage of digesta.
- Cold stimulates appetite, which may be slightly beneficial for production but the same may reduce utilization efficiency of dietary energy.
- Most studies in cattle have indicated that environmental factors over-ride genetic factors for determining the fertility patterns in buffaloes. The optimum breeding season for buffaloes under north Indian conditions is between October to February. Extreme variations in temperature as experienced during December, 2002 and January, 2003 may affect the fertility rate in cattle.
- Cold environment increases the whole body glucose turnover and glucose oxidation thus resulting in less production of ketones.

7. Effect on Fisheries

7.1 Punjab and Haryana

7.1.1 Carp

Carp culture in Punjab is of recent origin. However, in a short period of nearly two decades, the state has earned the distinction of producing highest per hectare average fish yield of 5.1 ton despite extreme winter conditions that prevailed in the region for about 40-45 days during 2002-03. Presently, about 7327 ha area is under fish farming with a total production of nearly 65799 tons.

Extreme climatic conditions particularly in winter months when air temperature drops to 2-4°C and water temperature is between 10-15°C, adversely affected the growth of Indian major carps. The effect on overall health of stocked fishes may be more when such conditions prevail for a longer duration as observed during winter of 2002-03. The extreme cold temperatures persisted from mid-December to last week of January 2003. It is reported that significant decline in feed intake takes place below 14-18°C among Indian major carps resulting into malnutrition. This condition was more pronounced during 2002-03 with prolonged periods of low water temperature. The weight of advance fingerlings (50-60g) stocked in the month of December, 2002 in one experimental pond remained almost same until end of February, 2003. Although the much lowered winter temperatures had an adverse effect on the growth of fish, mass mortality was not reported from any site. This was confirmed by the Punjab State Fisheries Department and a number of fish farmers.

7.1.2 Prawn

Under the demonstration programme of prawn farming in Punjab and Haryana, about 5-10% mortality was observed from the ponds. At Sangrur in Punjab, during the 1st week of December 2002, when minimum water temperature ranged between 14-17°C, about 150 prawns died. However, after laboratory examination of water and the prawn specimens, it was confirmed that the mortality was probably due to low oxygen and high nutrient load in the pond.

Prawn pond situated at Salam Khera was sampled in the last week of October 2002 and the average prawn body weight recorded was 51.96 g at water temperature of 26°C. On 8th December, 2002 the pond was finally harvested and average body weight increase was 40.0g from October–December, 2002. The average temperature of water during this period ranged between 26-14°C. Fall in temperature below 18°C was noticed from second week of November 2002. Further, mortality of 2-10 numbers per day was also observed. It is presumed that low water temperature, which brings down normal metabolic activities of prawn and produces stress, might be a major factor for stray mortality and reduction in weight.

7.1.3 Disease Incidence

In acute cold conditions, when water temperature was around10-12°C in the month of December, 2002 and January 2003, bacterial septicemia and fungal infections were reported from some ponds in different districts of Punjab and Haryana. Stray incidence of fish/prawn mortality (3-5%) took place in about a dozen of fishponds during these months. This may probably be due to emaciated growth because of low feed intake during extreme winter months.

7.2 Bihar

Reports on the effect of severe cold wave conditions during January 14 to 26th 2003 on fish reared in shallow ponds were received from Bhelura and Rampur (Naubatpur block, Patna). The fish reared by the farmers (Anil Sharma) in a pond of 32 m x 8m x1.5m, suddenly started dying from January 20th under the serious spell of the cold wave. Out of 2508 fry stocked on 3rd August, 2002, a total of 918 fish died on this date (36.6% mortality), when the night temperatures fell to 3.6°C along with overcast sky conditions. With the water in the pond being only 50 cm deep, these weather conditions resulted in low dissolved oxygen level and prolonged cold temperatures (more so at the bottom). Mostly bottom feeders like mrigal were seriously affected (677 died out of 776 stocked, 87%) while column feeders like *rohu* were less affected (204 died out of 616 stocked, 33%). However, surface feeders like catla and grass carp were hardly affected (7% mortality in catla) (Figure 32). As depth of the water in fishpond was

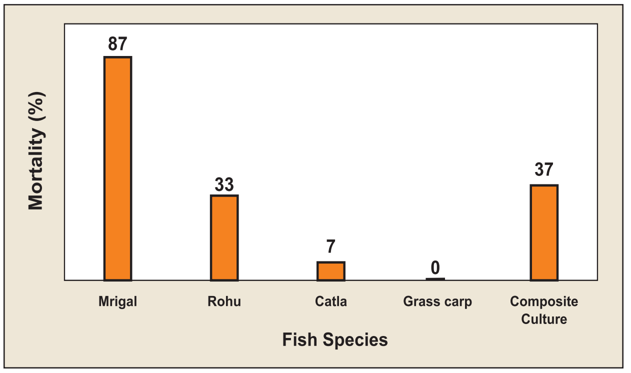


Fig.32 : Relative mortality of fishes on 20th January, 2003, due to cold wave at village Bhelura Rampur (Naubatpur block, Patna)

less than 50 cm, rapid lowering of temperature in a shallow depth reduces dissolved oxygen level, which is detrimental to the survival. It was necessary to maintain more than 100 cm depth of water. Foggy or cloudiness and lack of solar radiation or photosynthesis by aquatic vegetation also raised carbon dioxide levels and depleted oxygen levels in the water bodies. Intermittent aeration of water would probably help to alleviate respiratory stress to the fishes.

8. Impact on People

There have been sporadic reports of death toll in shelterless or pavement dwellers during the coldest weather in centuries that swept from Afghanistan to Bangladesh *via* north India. It was reported that the worst hit states due to cold wave were Uttar Pradesh and Bihar. About 900 deaths were reported in the entire northern region comprising of Jammu and Kashmir, Punjab, Haryana, Rajasthan, Himachal Pradesh, Jharkhand, Bihar and North Eastern States. Nearly 600 deaths alone were reported in Uttar Pradesh (world view update). During the cold wave period, human activity was mainly confined to indoors. The cost of charcoal and fire woods increased sharply, forcing the people to cut down roadside trees to keep themselves warm. The rail, road and air traffic was very badly affected and delayed considerably due to associated thick fog and poor visibility.

9. Infrastructure to Moderate Cold Wave Impact

Protection of crops from frost injury necessarily follows frost forecasting for preparedness in preventing/mitigating adverse effect of the frost occurrence. Various frost protection methods have been studied and a summary of their effectiveness is given in Table 11.

9.1 Practices to Moderate Impact on Standing Crops

Value added agromet initiatives are in progress to manage cold wave impacts. Some of the practices/ techniques are listed below.

- Application of light frequent irrigations during December and January wherever it is possible. High specific heat of water maintains relatively warm temperature in the system to avoid cold injury.
- Increasing radiation absorption and providing warmer thermal regime through covering of nursery and young fruit plants during winter by plastic or by making thatches (*jhuggies)* of straw or *sarkanda* grass etc. and keeping them open from the south-eastern side for direct sunlight entry (Plate 18).

Table 11. Characteristics of frost/freeze protection methods

	Advantages	Disadvantages	Comments
Site selection	Preventive measure – choose location with good cold air drainage		Best method of frost protection; visualize airflow and/or monitor minimum temperatures.
Heaters	Radiant heat helpful in freeze; installation costs lower than irrigation; allows delay; no risk if rate not adequate	Fuel oil expensive	Free-standing or pipeline; free-standing heaters need no power source.
Irrigation	Operational cost lower than heaters; can be used for other cultural purposes such as drought prevention	Installation costs relatively high; risk damage to crop if rate inadequate; ice build up may render braches brittle and prone, for breaking; over-watering	Plant part protected by heat of fusion; fixed-rate design delivers more protection than generally necessary; irrigation must continue until melting begins; backup power source essential.
Wind machines	Can cover 10-acre area if flat and round; installation cost similar to heaters		Mixes warm air near top of inversion down to crop height; may be used with heaters; may use helicopters.
Fog	Blocks outgoing radiant heat and slows cooling		Uses greenhouse effect to trap heat in crop canopy and limit radiation cooling.

Source: Katherine B. Perry, 2002, North Carolina State University

Plate 18 : Protecting young seedlings against cold by covering with straw thatching

- Thermal insulation by the application of locally available organic mulches will reduce the cooling rate of soil surface and keeps the soil warm.
- Air mixing by running fans in orchards will help in breaking inversion layers and allows free mixing of cold air with warm air.
- Provision of heat through heaters/fire between the rows and creating a air blanket of smoke particularly in orchards by collecting and burning dried weeds/wood etc., (Plate 19) shall trap the outgoing long wave radiation and the fall in

Plate 19 : Protecting crop (mango) orchards against frost through smoke by burning semi-dry biomass

temperature is reduced to a great extent (green house effect).

- Sprinkler irrigation to release latent heat of fusion by releasing heat into the surrounding air through condensation of water droplets.
- Cultivation of cold/frost resistant plants/crops/ varieties in frost prone areas should be popularized to minimize crop loss.
- Application of growth regulators and chemicals to enhance resistance to cold stress may also prove helpful.
- Planting of wind breaks/shelter belts around orchards in cold wave prone areas. This will reduce the wind speeds and the wind chill affect in the leeward side besides minimizing the sensible heat losses from the protected crop (Plate 20).

Plate 20 : Shelter belts provide protection to agricultural crops against cold winds

- Mixed cropping of vegetables, viz., tomato, brinjal with tall crop like mustard / pigeonpea will provide necessary shelter against cold winds.
- Other agronomic practices such as raising nursery under partial shade of trees or in between trees

rows, multi-storey/mixed plantations and pruning of undesirable twigs/branches for *in-situ* use as mulch. Providing plant cover shade will also give considerable protection (green house affect).

9.2 Practices to Rejuvenate Frost Damaged Orchards

- The package of practices for rejuvenating frost-damaged plants includes:
- Prune the affected parts of the plants at the end of February or early March. While doing so, also cut a few centimeters of the living tissue of the limb/branch being pruned. Apply Bordeaux paste to the cut ends which are more than 2.5 cm in diameter.
- Spray these plants with Bordeaux mixture (2:2:250) or copper oxychloride @ 1.5 kg/550 litres of water after pruning so as to block infection of the wound.
- Give irrigation to the frost affected plants soon after pruning, if it is available.
- Apply nitrogenous fertilizer before irrigation to encourage new growth on the affected plants based on soil test results.
- Remove water sprouts from the main trunk of trees to encourage the fresh growth from the top.
- Application of P and K to soil to activate better rooting and sap flow in the plants.
- Application of farmyard manure also helps in improving nutrient management besides improving soil thermal regime.

10. Agrometeorological Efforts for Forecasting of Cold Wave Conditions

In the country, study of frost and cold waves had received the attention of agrometeorologists since the early 1940s. Frost warnings are included in the weather outlook bulletins. With recent developments in the organization and institutional set-up dealing with agrometeorology in the country and services to agriculture, it is envisaged to streamline the early warning system for frost and foggy conditions with reference to cold waves. Both research and organizational set-up in the country is geared up for this. A brief history of the development of agromet institutions and forecasting activities is given below for reference.

10.1 Agrometeorology in India

Agrometeorology is the scientific study of influence of weather on crops, animals, fisheries and other living species. Several agricultural activities from seedbed preparation to harvest, storage, marketing and transport are influenced by weather. In the year 1966, Austin Bourke, a renowned scientist expressed the scope of agrometeorology at a Symposium on agrometeorological methods organized by UNESCO at Reading, U.K. as follows: "The task of the agrometeorologist is to apply every relevant meteorological skill to helping the farmer to make the most efficient use of his physical environment, with the prime aim of improving agricultural production, both in quantity and quality….". This sufficiently explains the scope of agrometeorology.

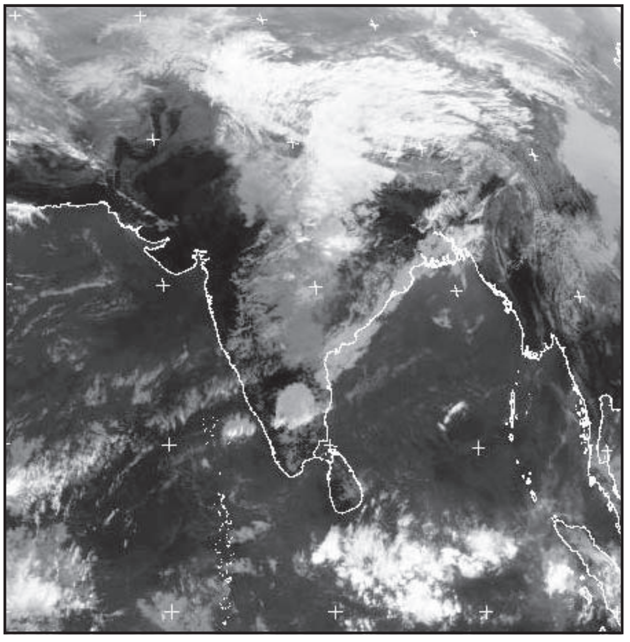
Activities in the discipline of agrometeorology in India started with the setting up of a 'Division of Agrometeorology" in the Indian Meteorological Services in the year 1932, under the pioneering guidance of Dr. L.A. Ramdas, considered as the Father of Agrometeorology in India. As a part of these activities, agrometeorological observatories were set-up and crops were raised in adjacent areas and weather parameters were recorded. Between 1945-48, in collaboration with the then Imperial Council for Agriculture Research, Indian Central Cotton Committee and Indian Central Sugarcane Committee, a crop-weather scheme was started at selected research stations all over the country, which functioned till 1970. These developments led to the formulation of statistical crop-weather models and development of crop-weather calendars depicting crop conditions in relation to both current and normal weather. At the same time, "Farmer Weather Bulletins" and "Weather Outlook" for 48 hours were initiated for broadcast through the All India Radio every day.

During the year 1952, climatic classification of the country was initiated at the Andhra University, Visakhapatnam by Prof. V.P. Subrahmanyam through climatic water balance approach. This approach has given rise to development of several useful indices such as the moisture adequacy index and moisture availability index, which have become tools to monitor drought stress in crops using threshold values appropriate to the crop and its growth stage. The above climatic classification has laid a good foundation for the agroclimatic characterization and subsequently to agro ecological zoning at regional and *taluk* level by other organizations like the IMD, NBSS&LUP, CAZRI, NARP project under ICAR, and Planning Commission with several improvements.

Agrometeorological research units were started under ICAR in the mid-sixties at CAZRI, Jodhpur and IARI, New Delhi. Post-graduate teaching in agricultural meteorology was also initiated at IARI. The National Commission on Agriculture in its report (1976) laid considerable stress on expansion of research and teaching in agrometeorology. The All-India Coordinated Research Project on Agrometeorology (AICRPAM) was started in 1983 with CRIDA, Hyderabad as the headquarters. Expanded in two phases, twenty-five centres located at SAUs in different agroclimatic regions are in operation under this project. Climatic Characterization, Crop-Weather Interactions, Crop-Weather Modeling, and Weather Effects on Pests and Diseases are being taken up as critical themes for study. Several crop weather models for yield estimation and pest/ disease incidence in crops were developed and these are being utilized in providing in-season forecasts by the SAUs. Strengthening these efforts to enhance the value of the medium and long-range climatic forecasts can help in efficient management of climate sensitive sectors such as agriculture and water resources with potentially very significant implications for the economic upliftment of the resource poor farmers.

10.2 National Weather Forecasting Mechanism

Timely and accurate information on seasonal climatic conditions helps the farmer to adjust land allocation between appropriate crops for reaping better benefits. Also, the farmer can be advised on the crop variety selection (regular or drought resistant/short duration) and the land management strategies based on whether the coming season's rainfall, temperatures and relative humidity etc., will be normal or otherwise. For



Satellite picture depicting cold wave conditions over northern India management of day-to-day agricultural operations, the farmer needs continuous feeding of information on the change in weather conditions from sowing to harvest and post harvest period. Farmers especially would like to have advance information on likely adverse weather so as to adopt need-based and efficient management strategies. In any current crop season, this needs day-to-day monitoring of crop and weather conditions viz., observation, on-line communication, immediate analysis and value addition.

10.2.1 Long-range weather forecast

Presently the India Meteorological Department (IMD) is providing long range forecasting of the SW-monsoon season for the entire country and for the broad homogeneous regions of India viz., northwest India, northeast India and Peninsula. The applicability of the long range forecast at sub regional level at present is weak. Some international attempts are being made to improve the quality and relevance of forecasts including statistical transformations of dynamic climate model outputs. These techniques when perfected can provide considerable opportunities for the use of long-range (seasonal) climatic forecasts to improve management of climatic risk.

10.2.2 Short and Medium Range Weather Forecast

At present, short range forecast (weather outlook for next 48 hours) is being issued by nineteen IMD Regional Centres. These centres are also issuing agro-advisories in consultation with the State Departments of Agriculture. Medium range forecast (presently for next 3-5 days) is being issued by National Centre for Medium Range Weather Forecasting (NCMRWF) using (i) Direct Model Output (DMO) of the Numerical Weather Prediction (NWP) Model (T-80), (ii) statistical interpretation of the NWP model output, and (iii) prevailing synoptic situation. The meteorological parameters covered under this forecast include: rainfall, temperature, humidity, cloud cover, wind speed and wind direction. In an attempt to link this information to crop conditions, the NCMRWF initiated Agrometeorological Field Units (AMFU) in cooperation with ICAR and SAUs. The aim is to cover all the 127-agroclimatic (NARP) zones of the country. Presently, about 83 centres are in operation across various ICAR institutes and SAUs. The Agromet centres of the AICRP on Agrometeorology (AICRPAM) located at the 25 SAUs are functioning as nodal centres of these AMFUs at their respective places. Currently these AMFUs are working on experimental basis providing agro-advisories to the farming community in the nearby locality using local expertise, based on medium range weather forecast received from NCMRWF twice a week. This service, earlier started on a trial basis has created sufficient awareness among the farming community regarding advantages of using weather-based agro-advisories. A Databank Facility in Agrometeorology has been created at CRIDA with support from DST and ICAR. This had been made use of by AICRPAM at CRIDA to launch a Website on "crop weather outlook' to provide value added agromet information and agro-advisories for use by the farming community for need-based efficient management of their agricultural production system.

10.3 Forecasting for Frost

In the light of the case studies cited above, it is needless to emphasize the forecast value of frost warnings. With medium range weather forecasts and weather-based agro-advisories place in the country, frost forecasting on a regional basis is possible.

- In the development of frost forecasting techniques, predicting when the temperature falls to a critical value is important for starting active frost protection methods. In addition, the duration of temperature below the critical value is important for assessing potential damage. Starting at the proper temperature is important because it avoids losses resulting from starting too late and it saves energy by reducing the operation time of the various methods.

- There are several methods of predicting the occurrence of frost. Many involve an empirical relationship to the dew point temperature (T_d.). For instance, in Victoria (Australia) frost is reckoned possible if T_d is less than 6°C, and probable if it is below 0°C. In the latter case, if in addition the wind is southerly, and pressure is rising (so that air is subsiding, making the sky clear and the air aloft dry, and therefore, transparent to terrestrial long wave radiation), frost is certain. It should be noted that the value of T_d is preferably that measured late in the previous day.

- The dew point temperature is defined as the temperature at which the air becomes saturated with water vapor when the air is cooled by removing sensible heat. The dew points measured during night time are often a good first guess for the next morning's minimum temperature. Consequently, it is extremely important for freeze protection of crops.

- Another example is the criterion used by National Weather Service (Table 12) for frost / freeze forecast.

There is scope and need to evolve an action plan for implementation after issue of early warnings on cold wave particularly with reference to individual crop species, fruit tree plantations and animal husbandry to mitigate the adverse effect in a more systematic manner than that followed at present.

Table 12. Definition of frost/freeze warnings issued by National Weather Service, USA

Warning	Wind Speed	Air Temperature
Frost	Below 16 kmph	Below 0°C
Frost/Freeze	Below 16 kmph	Below 0°C
Freeze	Above 16 kmph	Below 0°C

Source: Katharine B. Perry, 2002, North Caroline State University

About The Authors

Jagir Singh Samra: Jagir Singh Samra was born in village Dinewal in 1947, graduated in 1968, completed his M.Sc. in 1970 and Ph.D. in 1974 both from IARI. He had an excellent academic carrier throughout. He was initiated in ICAR in 1974 as Junior Soil Chemist in the Central Mango Research Institute (Lucknow) of the IIHR, Bangalore. He did pioneering work on tree crop nutrition. He served as Sr. Research Officer at Forest Research Institute and College, Dehradun from 1978-82 by selection through UPSC. Upstream research was carried out in the field of soil vegetation relationships. He repatriated after doing excellent research in the field of forestry and joined at CSSRI, Karnal in 1982. He became **Alexander Von Humboldt fellow** in Federal Republic of Germany by undergoing stringent competitive process. He specialized in modelling spatial and temporal variability for improving mapping, inventorization and precision of field experimentation.

He joined as Officer-In-charge at Chandigarh Regional Station of Central Soil & Water Conservation Research and Training Institute, Dehradun in 1990. He pioneered participatory process in resource conservation through watershed management. In recognition of his significant contribution in the area of research and management, he was selected Director, CSWCR & TI, Dehradun in 1994. People's participation in watershed management through process of their empowerment by creating village level institutions was carried further at different locations of India. He also promoted vigorously consultancies, contract research, resource generation, incentives and other organizational as well as management reforms. He is also member of several national level committees, NGOs and international organizations for promoting community partnership for realizing resource conservation. He joined as Deputy Director General (Natural Resource Management) ICAR, New Delhi, on 4th August, 2000. He has more than 170 publications of research papers, book chapters, bulletins and books to his credit. His publications cover a vast range of international and national journal of repute. He has four national awards to his credit and rendered 13 international and national consultancies.

Gurbachan Singh: Gurbachan Singh was born on September 16, 1954 in village Bhaini Maraj district Sangrur, Punjab. He completed his B.Sc. (Agri.), M.Sc. and Ph.D. in agronomy from PAU, Ludhiana in 1975, 1978 and 1988, respectively. After successfully competing the ARS examination in 1978 he joined as Scientist-S1 at CSSRI, Karnal where he worked for nearly 20 years and did commendable research on reclamation and management of salt-affected soils. The bio-amelioration technology for reclamation of sodic soils developed by Dr. Singh has gained wider applicability in the field and is acknowledged in journal **SCIENCE.** Based upon this pioneering research work he was awarded **Hari Om Ashram Trust Award in 1989, Dr. K.A. Shankarnarayan Memorial Award (1992-93), Tenth Sukumar Basu Memorial Award (1995-96) and the Rafi Ahmed Kidwai Award (1997-1998).**

Dr. Singh joined as Principal Scientist at National Research Centre for Agroforestry, Jhansi in August 1998 and then elevated to the position of Head, Crop Production Division, IGFRI, Jhansi in February 2000 by selection through ASRB and continued till November 2001. At present, Dr. Singh is working as Assistant Director General (Agronomy) at ICAR headquarters in New Delhi and facilitating research on cropping systems, dryland, weed management, desertification, climate change and agrometeorology. He has more than 150 publications to his credit including 25 in International Journals. He is fellow of the National Academy of Agricultural Sciences and scientific advisor to the International Foundation for Science (IFS), Sweden.

Yezzu Sri Ramakrishna: Ramakrishna was born on June 15, 1946 at Yelamanchili in Visakhapatnam District of Andhra Pradesh. He completed his B.Sc., M.Sc. (Tech), Meteorology & Oceanography and Ph.D. in Agricultural Meteorology from Andhra University, Waltair in 1963, 1966 and 1984, respectively and also did P.G. Diploma in Applied Statistics in 1967 from the same University. He has joined CAZRI, Jodhpur in 1971 where he worked for 23 years in different positions (Climatologist, Head, Division of Wind Power and Solar Energy Utilization; Head, Division of Resource Management). In 1994, he joined as Project Coordinator (Agrometeorology) at CRIDA, Hyderabad. At present, he is working as Director, CRIDA since June 2003.

He is a recognized as a research guide in various Universities and has guided few students for their Ph.D. Degrees. He has published more than 107 research papers in reputed National and International journals and written many chapters in various books. As a Principal Investigator, he has handled many research projects funded by various agencies, viz., DST, NATP and reviewed the progress of work of a multi-national (ACIAR) project. He has contributed significantly in the field of Drought climatology, System analysis approach for crop planning, Crop growth modeling, climate change and agriculture. A model to estimate the food production at National level was developed.

He was awarded ICAR Gold Medal during 1986 for Team Work for the year 1983-84. He was also felicitated for outstanding contributions in Agrometeorology by CLUMA during 2003 by Professional Society on 'Land use/Land Cover Management'.