Hailstorms: Causes, Damage and Post-hail Management in Agriculture

National Institute of Abiotic Stress Management

Malegaon, Baramati - 413 115, Pune

भाकृअनुप
ICAR

राअप्रस
NIASM

NIASM Technical Bulletin - 5

Hailstorms:
Causes, Damage and Post-hail Management in Agriculture

National Institute of Abiotic Stress Management
(Indian Council of Agricultural Research)
Malegaon, Baramati - 413 115, Pune, Maharashtra, India

June 2014

Published by
Director
National Institute of Abiotic Stress Management
Malegaon, Baramati, 413 115, Pune, Maharashtra

Edited and Compiled by
S. K. Bal
Sunayan Saha
Babasaheb B. Fand
N. P. Singh
Jagadish Rane
P. S. Minhas

Technical Assistance
Sunil Potekar

Citation
Bal, S. K., Saha, S., Fand, B. B., Singh, N. P., Rane, J. and Minhas, P. S. 2014. Hailstorms: Causes, Damage and Post-hail Management in Agriculture. Technical Bulletin No. 5, National Institute of Abiotic Stress Management, Malegaon, Baramati. 413 115.Pune, Maharashtra (India). p. 44.

Contact details
Director
National Institute of Abiotic Stress Management
Malegaon, Baramati, 413 115, Pune, Maharashtra
Tel.: 02112-254057, 254058
Fax: 02112-254056
Web: www.niam.res.in

Printed at :
Flamingo Business Systems
19, Laxminagar Commercial Complex No. 1
Shahu College Road, Pune 411 009
020-24214636, Email : flamingo.b.s@gmail.com, srgupta.tej@gmail.com

Preface

The increased incidences of extreme weather events have been causing widespread damage and loss to agricultural sector especially during the past decade. Recent trails of hailstorm events in India during Feb-Mar, 2014 that affected a large part of the country as well as interior parts of peninsula took everyone by surprise as the phenomenon, direction, locale and the coverage was hitherto unnoticed. The central India (Maharashtra and Madhya Pradesh) was the worst hit. This necessitated the need for strong institutional arrangements and techniques to combat hailstorm losses but the actions required were not documented so far. Keeping this in view, the available information has been compiled on formation of hailstorms, its characteristics and damage potential, climatology, forecasting and control mechanisms. The state of affairs with regard to forecasting by radar technology, vulnerability zonation tools have been included. Causes of recent unseasonal hailstorm events particularly in Maharashtra have been discussed and the consequent damage complemented with photographic evidences. The management techniques for recovery of different field and fruit crops have been recommended. The crop specific management strategies should help in formulating the plans and strategies for minimising the impacts of such vagaries if these happen in future.

We take this opportunity to gratefully acknowledge the contribution made by NIASM-scientists involved with the post hailstorm survey and field experimentation. Various photographs and data obtained by them are duly acknowledged. We also acknowledge the various publications and media sources from which valuable materials were drawn for this bulletin.

Authors

डॉ. अलोक कुमार सिक्का
उप महानिदेशक (प्रा सं प्र)

Dr. Alok K. Sikka
Deputy Director General (NRM)

भारतीय कृषि अनुसंधान परिषद
कृषि अनुसंधान भवन–II, पूसा, नई दिल्ली 110 012

INDIAN COUNCIL OF AGRICULTURAL RESEARCH
KRISHI ANUSANDHAN BHAVAN-II, PUSA, NEW DELHI - 110 012

Ph. : 91-11-25848364 (O), 24121571 (R)
Fax : 91-11-25848366
E-mail : aksikka@icar.org.in; aloksikka@yahoo.co.in

Foreword

Indian agriculture continues to be vulnerable to weather vagaries despite self-sufficiency in food grain production. Climate change and increased extreme weather events in recent decades as well as uncertainty in prediction of those events further add to the woes of the farmers causing widespread losses of agricultural output. Thus, it is of paramount importance to predict our climate better and adopt climate smart management practices for ensuring food security. Research initiatives on various aspects of crop management in the event of unfavourable extreme weather events or post- disaster crop management have necessitated the need of effective and fool proof contingency plans specifically for droughts and waterlogging situations. Amongst weather hazards, hailstorms cause a great damage to standing crops even though these occur for a very short duration. Nevertheless, little information exists on the management of various aspects of these hails. The recent occurrence of unusually widespread and untimely hailstorms that affected crops in a number of states in India and particularly Maharashtra triggered an imperative need of a comprehensive document covering all aspects of hail. The present document is an attempt in this direction that includes information on the mechanisms behind hail formation, current status of hail forecasting technologies, hail vulnerable areas of the world, frequency of hail occurrence, climate change scenarios of hailstorm occurrence, extent of damage in the state of Maharashtra and appropriate pre- and post- hail management practices. Apart from the crop specific management recommendations, this bulletin also presents results from some of the original research on post hail management interventions and crop recovery experiments initiated at the NIASM, Baramati.

I appreciate the initiative of NIASM, Baramati for this timely document and hope this will be useful for researchers, farmers, extension specialists, policy makers and other stakeholders for formulating strategies for minimising the impacts of such vagaries in future.

June, 2014

(Alok K. Sikka)

Contents

1. Introduction

Agricultural production in India is becoming increasingly vulnerable to climate variability and change characterized by altered frequency, timing and magnitude of precipitation and temperature. High rates of snow and glacial melting, frequent floods and droughts, heat waves, hailstorms, heavy frost and increased incidences of the pests and diseases cause widespread damage and losses to agricultural sector in India. Hail is a solid, frozen form of precipitation that causes extensive damage to properties and growing crops. Hot, humid afternoon hours during the summer are the most congenial for development of hailstorms. These usually form over a relatively small area and pass over within a very short period, however, causes havoc even from a few minute spell.

Though hailstorm can occur in any part of the world, temperate zones are the most vulnerable. Among the countries, hail related losses are most prevalent in USA (Hughes and Wood, 1993). The damage with hails is determined by the size ranges and the number of hailstones that fall per unit area during a hail fall, wind force during the event and the property of the target. The extent of crop-hail damages also varies depending on the stage of occurrence of hail during the crop growing season. Even a short episode of hail can cause severe injury to crops, fruit trees, both downgrading the quality and causing subsequent losses due to diseases like blight, mould, canker and fruit rots. The hailstorms in a region often follow a definite pattern. However, the recent events in the country have surprised farmers and fruit growers when hail moved in from unexpected directions. Widespread unseasonal rainy spells accompanied by hail occurred in several states during February-March, 2014. It caused a large scale destruction of crops in Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra, Punjab, Gujarat, Uttarakhand, Haryana, Andhra Pradesh and Karnataka with central India (Maharashtra and Madhya Pradesh) being the worst hit. The country did not witness such a severe weather aberration since a long time (source: The Indian Express, 20 March, 2014).

Hail being a very short term and localized phenomena, its prediction well in advance to inform all stakeholders for adequate preventive measures is a major challenge for even the most technologically advanced and hail affected countries like as US. India, being situated in the tropical and subtropical region, the frequency of hail eventsis less than mid-latitude and temperate countries. However, with climate change, the instances of severe weather aberrations are increasing the demand for strong institutional arrangements to combat such challenges. While occurrence, losses and post disaster management have been discussed extensively for the other climatic hazards such as excess rainfall, drought and flood, little attention has been given to hailstorm. The following sections elaborate on various aspects of hails for better hail preparedness and post-hail management measures.

2. Hailstorm

2.1 The science behind

Thunderstorm is a meso-scale system with space scale of few kilometers to a couple of 100 kilometers and time scale of less than an hour to several hours. It produces heavy rain showers, lightning, thunder, hail-storms, dust-storms, surface wind squalls, down-bursts and tornadoes. Hail is often associated with thunderstorm activity and changing weather fronts. This is formed in huge cumulonimbus clouds, commonly known as thunderheads (Fig. 2.1). Hailstorms are the result of four atmospheric factorswhich are characterised as:

i. Strong convective instability creating strong updrafts

ii. Abundant moisture at low levels feeding into the updrafts

iii. Strong wind shear aloft, usually veering with height, enhancing updrafts

iv. Some dynamical mechanisms that can assist the release of instability such as air flow over mountain ridges

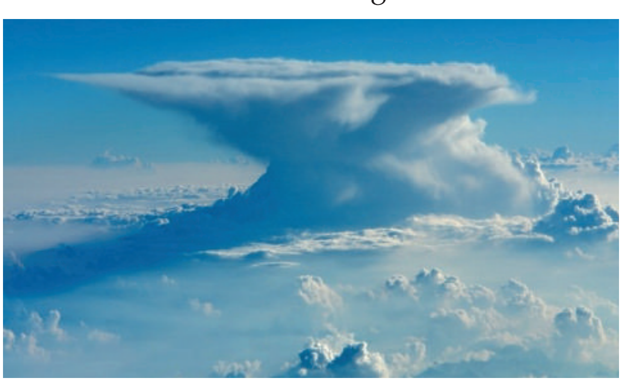


Fig. 2.1. Anvil shaped thunderstorm cloud (cumulonimbus) formed over south-central Kansas, USA during June, 2004.

The typical mechanism of hail formation in a thunderstorm is described in Fig. 2.2. When the ground is heated during the day by the sun, the air close to it gets heated as well. Hot air, being less dense and lighter than cold air, rises and cools. As it cools, its capacity for holding moisture decreases. When the rising, warm air has cooled so much that it cannot retain all of its moisture, water vapour condenses, forming puffy-looking clouds. The condensing moisture releases heat of its own into the surrounding air, causing the air to rise faster and give up even more moisture.

Cumulonimbus clouds contain vast amounts of energy in the form of updrafts and downdrafts. These vertical winds can reach speeds over 175 km/hr. Hail grows in the storm cloud's main updraft, where most of the cloud is in the form of "super-cooled" water. This is water that remains liquid although its temperature is at or below 0°C (32°F). A super-cooled water droplet needs something on which to freeze, or it remains liquid. Ice crystals, frozen raindrops, dust, and salt from the ocean are also present in the cloud. On collision, super-cooled water will freeze onto any of these hosts, creating new hailstones or enlarging those that already exist. The faster the updraft on these balls of ice, the bigger they can grow.

Cross sections of hailstones often reveal layers, much like those of an onion. These layers are caused by the different rates of accumulation and freezing of super-cooled water, as the hailstone forms. When there is a very high amount of super-cooled liquid in the air through which the hailstone falls, water accumulates faster than it can freeze, so a coat of liquid forms. This becomes a layer of clear ice when it does freeze. When a hailstone falls through air with less amount of liquid, the liquid freezes on

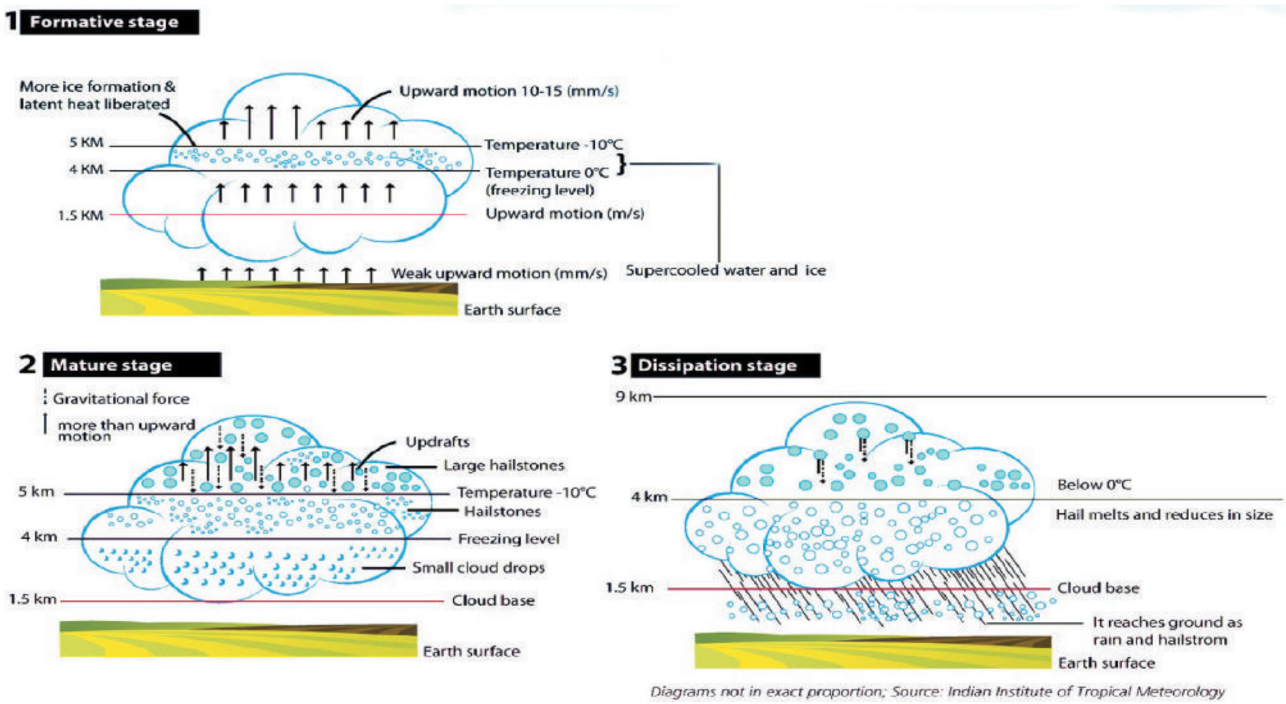


Fig. 2.2. A sequence showing the development of hail inside a thunderstorm, then its descent and arrival at the ground (Source: IITM, Pune)

contact with the hailstone forming small air bubbles in the opaque layers. The more super-cooled water a hailstone makes contact with, the larger and heavier the stone is likely to become. The growth of hailstones sufficiently large to reach the ground requires very strong updrafts, forces creating taller than usual thunderstorms (Brandes et al., 1997). Strong updrafts support the hailstones aloft and allow hailstones to grow, often to 1 inch diameter or larger. If the falling hailstones enter another strong updraft, they can get carried aloft again in the moist air and grow even larger. This repetitive growth process is reflected in the structure of hailstones that often shows layers of ice around their embryo. When the hailstone becomes so heavy that the updraft can no longer support it or when there is dominance of downdraft over the updraft, it falls from the sky (Fig. 2.3). The development of hailstones typically occurs 5 to 7 km/hr above the earth's surface. Most of the hails come from thunderstorms, however, only about 60 percent

Fig. 2.3. Hailshafts descending from the base of a thunderstorm
(Source: National Geographic Magazine (left); http://stormeyes.org/latest/tag/downburs (right))

of all thunderstorms ever generate hailstones aloft (Changnon, 2001).

As a thunderstorm moves along, it may deposit its hail in a long narrow band (often several kilometers wide and about 10 kilometers long) known as a hail-streak or hail-swath. If the storm should remain almost stationary for a period of time, substantial accumulation of hail is possible. Its size and shape depend on how fast the storm is moving and how strong the updrafts are inside the storm. A typical hail-streak is about 1.5 km wide and 8 km in length. However, these may vary from a few acres to large belts, about 16 km wide and 160 km long. Most storms that produce hail generate one or two hail-streaks during their lifetime. Some organized lines of thunderstorms produce many hail-streaks with hail covering hundreds of square kms as the storms move across the terrain. Infrequently a thunderstorm becomes a well-organized giant and lasts for three or more hours. These "supercell storms" generate very large hail-streaks.

The volume of hail reaching the ground falls at a speed of about 40 m/sec, and is usually less than 10 per cent of the volume of rain produced by a thunderstorm (Gokhale, 1975). Hail produced by many thunderstorms never reaches the ground because it melts into raindrops as it descends into warmer air near the ground. That is why thunderstorms in warmer climate zones seldom produce hail at the ground. On the other hand, hailstorm damages are more common and severe in the mid latitude and temperate nations owing to higher frequency and intensity. Among the nations in the world, USA has been reported as the worst hail affected. Table 2.1 provides information on the various types of meteorological condition under which hailstorms are produced in USA.

Table 2.1. Causes of hail storm in USA

Meteorological conditions	Per cent share
Squall lines and low pressure centres at the intersections of warm and cold fronts	41
Cold fronts	21
Warm fronts	14
Stationary fronts	12
Unstable air mass	12

2.2 Hail characteristics and damage potential

The damages accrued with hails are determined by its characteristics that include the size and number of hailstones that fall per unit area and the strength of winds during a hail fall. The association between intensity and the damage depends greatly on the target such as crop, livestock or property. Some delicate-leaf crops such as tea and tobacco suffer damage from small hailstones, whereas other crops such as maize may not be damaged unless hailstones are of size more than 2 cm. The extent of crop-hail damages also varies with stage of a given crop. A specific type of hailstorm may not cause much damage during vegetable phase growing season but the same storm can be very destructive during flowering and seed/fruit development.

Hailstones range in size from pellets to golf balls or even larger. These are seldom perfectly circular, mostly of oblate shape and some have knobs of ice radiating outwards and usually have layered structure inside (Fig. 2.4). Unusual shapes such as pyramids and discs (Fig. 2.5) and size variations arise out of the different atmospheric conditions in which they were formed.

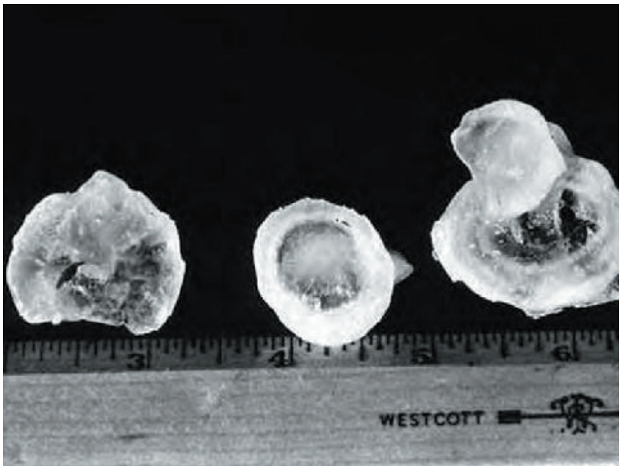


Fig. 2.4. Layered structures of hailstones (inside view after cutting in halves (Source: Illinois State Water Survey, USA)

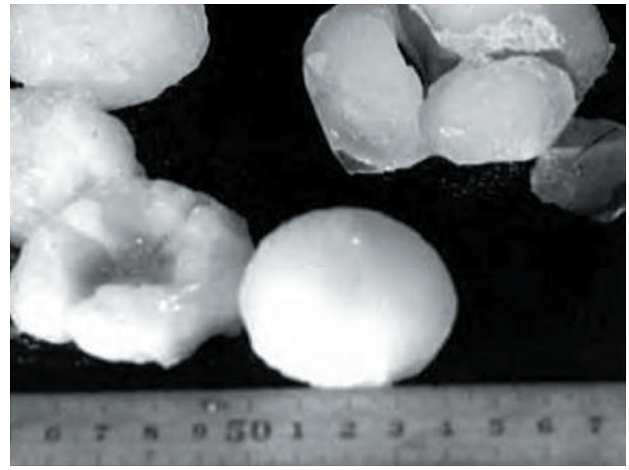


Fig. 2.5. Hailstones of different shapes (Source: Illinois State Water Survey, USA)

Hail mass is often the most critical factor causing crop damage. Studies have concluded that most property damage begins when hailstone diameters are 20 mm or greater. The larger the stones, typically the greater the property damage (Morrison, 1997). However, different crops are damaged in varying ways by hail. Tea, soybeans, and tobacco leaves are delicate and subject to serious damage even when 6.4 mm diameter hailstones fall. Windblown hailstones of 13 mm diameter or larger cause serious damage to corn stalks and wheat stems. Fruit crops, such as apples and peaches, can be easily bruised by small- to moderate-sized hail and can loose great value because of reduced quality. Semi-quantitative estimates of the severity of damages by hails of different sizes borne out of hailstorms of different intensities are given in a table 2.2 and fig. 2.6.

Table 2.2. Hailstorm intensity scale (Source: www.noaa.gov and www.torro.org)

Size code	Typical hail diameter (mm)	Equivalent shape	Intensity category	Typical damage impacts
H0	< 8.4	Pea	Hard hail	No damage
H1	8.4 to 15.2	Marble	Potentially damaging	Slight damage to plants, crops
H2	15.2 to 20.3	Coin or grape	Potentially damaging	Significant damage to fruit, crops, vegetation
H3	20.3 to 30.5	Nickel to quarter	Severe	Severe damage to fruit and crops, damage to glass and plastic structures, paint and wood scored
H4	30.5 to 40.6	Golf ball	Severe	Widespread glass damage, vehicle bodywork damage
H5	40.6 to 50.8	Tennis ball	Destructive	Wholesale destruction of glass, damage to tiled roofs, significant risk of injuries
H6	50.8 to 61.0	Baseball	Destructive	Aircraft bodywork dented, brick walls pitted
H7	61.0 to 76.2	Grapefruit	Very destructive	Severe roof damage, risk of serious injuries
H8	76.2 to 88.9	Softball	Very destructive	Severe damage to aircraft bodywork
H9	88.9 to 101.6	Softball	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open
H10	>101.6	Softball and up	Super hailstorms	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open

Fig. 2.6. Hail stones produced under varying intensities of hailstorm

2.3 Hail climatology

Information on two basic characteristics of hailstorm, viz., frequency and intensity is most important for risk assessment and vulnerability mapping point of view. Frequency is defined by the number of days with hail or number of hailstorm events at a point or over an area, for a month, season or year. The intensity of hail is typically determined by the sizes and number of hailstones that fall at a given time (described in the previous section) and the associated wind speed.

Hailstorms occur in many parts of the world; however, there frequency and intensity are more in temperate and mid-latitude regions. Finding information about the climatic aspects of hail has been difficult, not because there are major unknowns about the hail climate, but because much of what is known is widely distributed amongst diverse sources published over the past 100 years or so. Thus, hail information is hard to locate for those seeking a comprehensive description of the hail climatology for the country. Some publications have addressed the issue of hail climate in nations including USA, China, France, Italy, Canada, Russia, Argentina, South Africa, and Finland (Zhang et al., 2008; Touvinen et al., 2009; Dessens, 1986; Gokhale, 1975; Morgan, 1973). However, such a comprehensive account is not available in India.

2.3.1 Hail frequency in India

Thunderstorms with associated showers of rain and hail are the commonly observed weather phenomena in India, generally during the pre- and post- monsoon months. The frequency of hailstorms is small in winter, but increases generally February onwards and peaks in the months of March and April as the season advances to summer. Notwithstanding the sporadic incidences, hailstorms are practically absent from the whole country during the monsoon season (Fig.2.7). With respect to the diurnal frequency, it has been observed that in conformity with the other regions of the world, peak no. of hailstorms events happened to occur in late afternoon and early evening hours (Fig. 2.8).

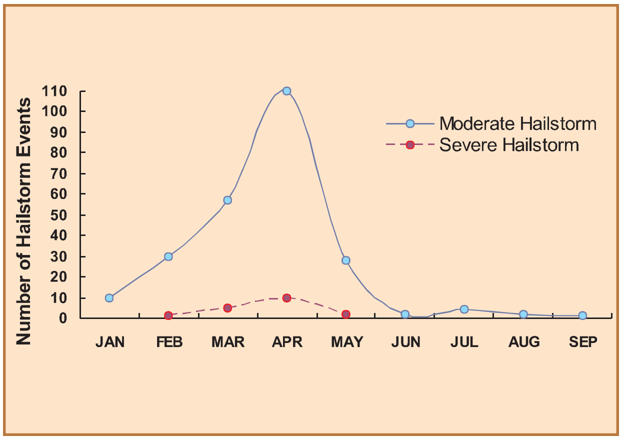


Fig. 2.7. Monthly distribution of moderate and severe hailstorms in India (Reproduced from: Chowdhury and Banerjee, 1983)

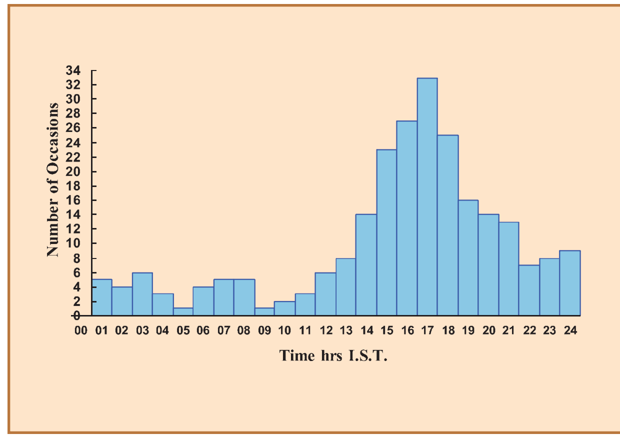


Fig. 2.8. Diurnal variation of hailstorm frequency (Reproduced from: Chowdhury and Banerjee, 1983)

Spatial assessment of hailstorms in India revealed that violent thunderstorms accompanying hail are comparatively more frequent in northern India than the other parts. Fig. 2.9 shows contour lines of the total number of hail occurrences in India that were recorded between hundred years period. The average number of days with hail is about 6-7 per year over Himachal Pradesh and its neighbourhood, but it decreases sharply to 1 in 2 per years over the adjoining plains. Over Bengal, Bihar, Uttar Pradesh and in central Indian states of Madhya Pradesh and Maharashtra hailstorm occurs on an average once a year. In the interior parts of southern peninsula, only one hail event may be expected once in five years. Hailstorms are comparatively rare over the coastal tracts of the Peninsula.

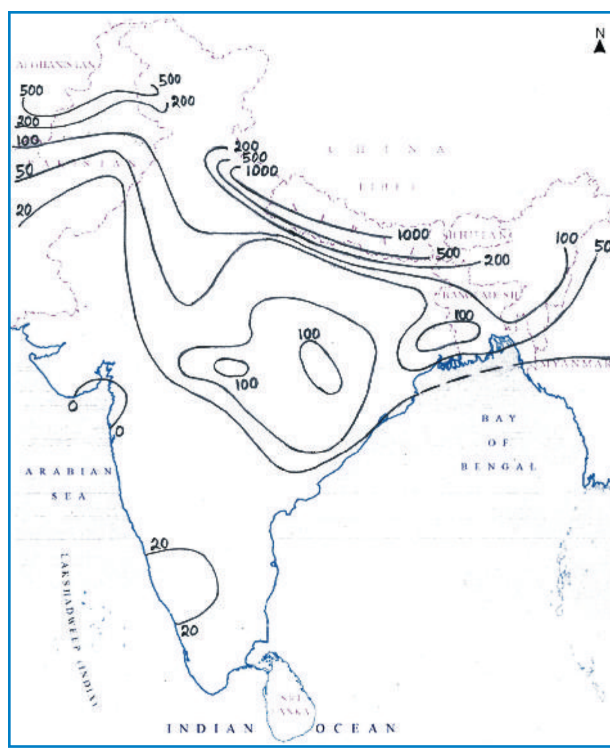


Fig. 2.9. Hail occurrences in India over a 100 year period (Reproduced from:Ramanamurthy, 1983)

2.3.2 Severe hailstorm events of the World

The chronological sequence of some of the severe hailstorm events that happened across continents in the recent recorded history is presented in table 2.3.

Table 2.3. Severe hailstorms in the world during the recent recorded history (source: http:// en.wikipedia.org/wiki/List_of_costly_or_deadly_hailstorms)

Date	Location	Incident
09 Aug 1843	Midlands and East Anglia, Central and Southern England	One of Britain's worst ever hailstorms, possibly a super cell, caused massive destruction as hailstones reached up to 1.5 metres deep in places. The overall damage was so great that a new insurance company, The General Hail Insurance Company was formed to help cope with future hailstorms.
30 Apr 1888	Uttar Pradesh, India	One of the deadliest hailstorms of all time killed at least 230 people, and over 1600 sheep and goats. The hailstones were reportedly as big as oranges, and in some places were as high as 60 centimetres.
01 Feb 1936	Transvaal, South Africa	Devastating hails of the size of coconuts killed 26 people and several cattle.
01 Jan 1947	Sydney, Australia	1947 Sydney hailstorm
17 Nov 1949	Pretoria, South Africa	Hailstones of about 7 cm diameter damaged windows / roofs on all buildings and damaged hundreds of cars.
02 Sep 1960	California, USA	Golfball to baseball sized hail occurred in parts of southern California, Boulevard and in Riverside County.
30 Jul 1979	Colorado, USA	A violent forty-minute hailstorm bombed Fort Collins with hail up to grapefruit size. Two thousand homes and 2500 automobiles were severely damaged, and about 25 people were injured.
12 Jul 1984	Munich,Germany	Tennis ball sized hail fell on Munich and surrounding areas. It was the greatest loss event in the history of the German insurance industry: 2,00,000 cars were damaged and reported severe losses in monetary terms.
18 Jan 1985	Queensland, Australia	Alate afternoon supercell thunderstorm swept in from the west dropping hailstones as large as 6 cm over parts of the Brisbane city. A wind gust of over 180 km/h was recorded at Brisbane airport. This rate as the 5th most costly insured event in Australia since 1968.
01 Nov 1985	Transvaal, South Africa	Major hailstorm struck central Pretoria and surrounding areas. Damage estimated at 400 million of south African currency
14 Apr 1986	Gopalganj, Bangladesh	At least 92 people were killed in Gopalganj by some of the heaviest hailstones ever recorded, which were the size of grapefruits and weighed around one kilogram each.
11 Jul 1990	Colorado, USA	Softball-sized hail destroyed roofs and cars in Denver, causing damages costing about 1.1 billion US dollar.
07 Sep 1991	Alberta, Canada	A single hailstorm damage costing about 342 million US dollar. Thirteen additional hailstorms occurred between 1981 and 1998 causing an estimated 600 million US dollar in damage in the Calgary area alone.

Date	Location	Incident
19 Jun 1992	Kansas, USA	Two batches of severe thunderstorms, occurring within 6 hours of each other, dumped hailstones up to about 10-12 cm in diameter across Sedgwick, including the city of Wichita and surrounding counties in south-central Kansas. Over 10,000 homes were damaged. Estimated property damage totalled 500 million US dollar with crop damage at 100 million US dollar.
05 May 1995	Dallas,Texas, USA	The 1995 Mayfest Storm produced 1.1 billion insured losses, and total storm damage was reported at around $ 2 billion. The storms produced hail about the size of softballs.
14 Apr 1999	New South Wales, Australia	20,000 properties and 40,000 vehicles were damaged during the storm with more than 25 aircraft damaged at Sydney airport. At $ 1.5 billion, it was the costliest hailstorm to hit an Australian populated city. Largest stone measured was 9.5 cm.
29 Mar 2000	Texas, USA	Softball sized hailstone was reported in Lake Worth.
18 May 2000	Chicago, Illinois, USA	Golfball-, baseball-, and softball-sized hails were reported. Hail was about 7-8 cm deep in many areas.
10 Apr 2001	Missouri, USA	The costliest hailstorm (damage estimated at more than $ 2.0 billion) in US history struck the I-70 corridor of eastern Kansas, across Missouri, into south-western Illinois.
19 Jul 2002	Henan, China	25 dead and hundreds injured.
22 Jun 2003	Nebraska, USA	Hailstone as large as about 18 cm in diameter was recorded.
20& 21 Apr 2006	Texas, USA	Hail of sizes up to 10 cm resulted in 10,000 auto claims, 7,000 homeowner and commercial property claims ranging between $ 100–160 million insured losses.
28 Jun 2006 29 Jun 2006	Baden-württemberg Germany	Super-cell thunderstorms, severe damage by grape fruit sized hail stones, causing € 150 million damage and more than 100 injuries
9 Dec 2007	New South Wales, Australia	Super cell thunderstorms caused immense damage in the North and Western Suburbs of Sydney. Hail stones were of golf ball sizes.
20 Jul 2009	Colorado, USA	A hailstorm in Denver caused $ 770 million (USD) damage.
06 & 07 Mar 2010	Melbourne, Australia	2010 Victorian storms: Heavy rain and large hail across much of Victoria lead to flash flooding in central Melbourne, roofs collapsing at Southern Cross Station and Docklands. 40,000 insurance claims for over $ 500 million were lodged.
22 Mar 2010	Perth, Australia	The hailstorm that struck after a long dry spell lasted only a few minutes but caused havoc damages to house and properties
10 & 16 May 2010	Oklahoma, USA	Two major hailstorms separated by less than a week caused damage to large portions of the Oklahoma City metropolitan area causing damages totalling around $ 1 billion.
12 Jul 2010	Calgary, Alberta, Canada	Hails of about 4 cm or more (dia) recorded. Total insurable damages of about $ 400 million, excluding agricultural crop damage.
23 Jul 2010	Vivian, USA	The largest hailstone of all time, measuring 20 centimetres in diameter- larger than a bowling ball - and weighing about 0.9 kg was recorded

Date	Location	Incident
28 Apr 2012	St. Louis, Missouri, USA	Series of hailstorms amount to second costliest in US history at estimated $ 1.6 billion in insured losses.
13 Jun 2012	Dallas&Fort Worth, Texas, USA	Baseball to Softball-sized hails recorded; total damages estimated approximately at $ 900 million.
28 Jul 2013	Southern Germany	A super cell dropped hailstones with a diameter of up to 8 centimetres. Around 70 people were injured by large rain amounts, downbursts, lightning strikes and the hail. Reported as the second most expensive hailstorm in the history of Germany after the Munich hailstorm of 12th July 1984.

2.3.3 Climate change and hail events

In the last decade, there has been an increase in the phenomenon of Arctic air being pushed down leading to unusual regional climate anomalies across the Northern Hemisphere. In 2010, Pakistan witnessed record floods while Russia suffered intense heat waves and forest fires. The year 2012 witnessed record surface melting of the Greenland Ice Sheet, wettest summer ever in England and heat waves in the US and Russia. In 2010 and 2011, there were some enigmatically cold winter spells on both sides of the Atlantic and in eastern Asia. December of 2010 was the coldest December since 1890 in central England records, says German oceanographer and climatologist Stefan Rahmstorf, in his research paper 'A decade of weather extremes'. There are plenty of such evidences of significant weather anomalies in the recent past decades.

So what all the changes in weather conditions can be attributed to? Is this natural variability in climate, or climate change? Fifth assessment report (AR5) of Inter-governmental Panel on Climate Change (IPCC, 2013) puts all arguments and counter arguments to rest and reaffirms these manifestation as climate change. There are indications that a warming climate would favour an increase in the intensity and frequency of extreme events and we are already witnessing some of these such as heat waves and precipitation extremes. Tough road lies ahead for India, says the IPCC report. It warns the country of severe food crisis due to extreme weather events, and estimates countrywide agricultural loss. This will severely affect the income of 10 per cent of the population with increasing weather extremities.

Hails or thunderstorms are extreme forms of weather events and deserve special attention in view of climate change. However, these are not well monitored in many parts of the world because the density of surface meteorological observing stations is too sparse to measure all such events. Moreover, homogeneity of existing reporting and data quality in many instances are questionable (Doswell et al., 2009). AR5 of IPCC (IPCC, 2013) highlighted some studies with regard to trends of hailstorm occurrence over the years in different parts of the world. Brooks and Dotzek (2008) found significant variability but no clear trend in the past 50 years in severe thunderstorms in a region east of the Rocky Mountains in the USA. Cao (2008) found an increasing frequency of severe hail events in Ontario, Canada during the period 1979-2002 and Kunz et al. (2009) found that hail days significantly increased during the period 1974-2003 in southwest Germany. Hailpad studies from Italy (Eccel et al., 2012) and France (Berthet et al., 2011) suggest slight increases in larger hail sizes and a correlation between the fraction of precipitation falling as hail with average summer temperature while in Argentina between 1960 and 2008 the annual number of hail events was found to be increasing in some regions and decreasing in others (Mezher et al., 2012). In China between 1961 and 2005, the number of hail days has been found to generally decrease, with the highest occurrence between 1960 and 1980 but with a sharp drop since the mid-1980s. However, there is a little consistency in hail size changes in different regions of China since 1980 (Xie et al., 2008, 2010). Remote sensing offers a potential alterative to surface-based meteorological networks for detecting changes in small scale severe weather phenomena such as proxy measurements of lightning from satellites (Zipser et al., 2006) but there remains little convincing evidence that changes in severe thunderstorms or hail have occurred since the middle of the 20th century (Brooks, 2012). In summary, there is low confidence in observed trends so far in small-scale severe weather phenomena such as hail and thunderstorms because of historical data inhomogeneities and inadequacies in monitoring systems. But long-term climate projection studies are suggestive mostly for a trend towards occurrences of more severe thunderstorms in all parts of the world.

2.4 Hail forecasting

Protection against violent hailstorms is possible only when we are capable to forecast those well in advance. However, it is difficult to forestall a hailstorm, since its occurrence is sporadic and confined to very limited areas in a thunderstorm. While hail formationcontinues to elude scientists, sophisticated radar has been developed that can detect the presence of hail before it falls to the ground. Eventually, warnings may be issued as about 15 minutes before hail strikes, thus allowing pilots to avoid threatening air space, people to seek shelter, and property to be protected.

2.4.1 RADAR technology in hail forecasting

Efforts to detect and measure hail have been underway for many years. Forecasters use radar technology for detection of hail and have met with various degrees of success depending on conditions. Radar is an acronym that stands for RAdio Detection And Ranging. A weather radar consists of a parabolic dish (it looks like a satellite dish) encased in a protective dome and mounted on a tower of up to five stories tall (Fig. 2.10). The radar itself does not delineate between rain and snow but use of algorithms do, based on atmospheric conditions. The exclusive conglomerate of weather radar data base plots the expected movement of significant storms over the next hour, and also gives access to storm details like hail and rotation.

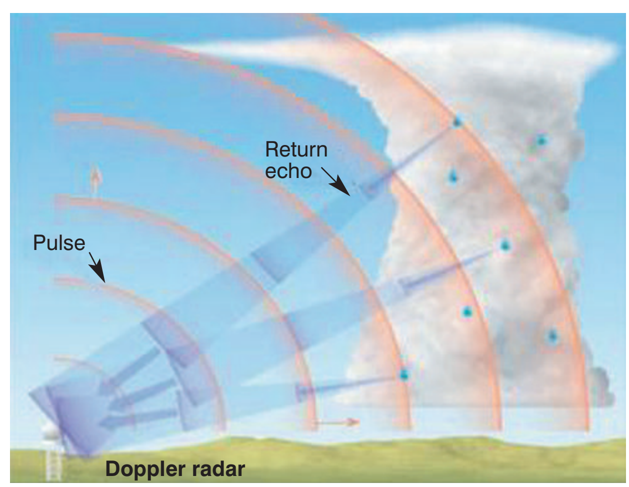


Fig. 2.10. A microwave pulse is sent out from the radar transmitter. The pulse strikes raindrops / hailstones and a fraction of its energy is reflected back to the radar unit.

Early attempts using single wavelength radars were not successful as conventional radar could provide only rough subjective guidelines for identifying or inferring hail, turbulence, tornadoes, etc. The dual-wavelength Doppler-radars were designed during 1970s for research studies and subsequently put to operational use under the national hail projects in USA (Mueller and Morgan, 1972; Changnon, 1973). Dual wavelength radar (DWR) makes simultaneous use of two different wavelengths, hence offer better scope compared to single wavelength radars for detecting hail and distinguish it from rain showers. This technique has been successfully applied in the USSR. Usually a single antenna with dual primary feeds for the two wavelengths can be used for the purpose. During the 1990s new NWS radars were tried to detect hailstones aloft, but failed in most hail cases (Edwards and Thompson, 1998). Later, polarimetric radars were tested to detect hail aloft (Kennedy et al., 2001). Donovan and Jungbluth (2007) tried detecting large hail aloft using radar reflectivity and echo dimensions with some success. A study using differential reflectivity radar values found that it could detect hail quite well (Depue et al., 2007). Pradhan et al. (2012) studied hailstorm occurrence over Kolkata on 06 May, 2007 at 1002 UTC using DWR. The size of hails was about 2 cm and the hailstorm lasted for 10 minutes. Authors found some typical signature of the system in the DWR observations as a very long "Anvil" ahead of the main cloud and extended up to a distance of 100 km towards east of Kolkata (Fig. 2.11). Vertical extent of the cloud was only 8 km and the RADAR reflectivity was lying in the range of 53.3 dBz to 56.7 dBz. A similar RADAR imprint of Sydney hailstorm has been shown in figure 2.12.

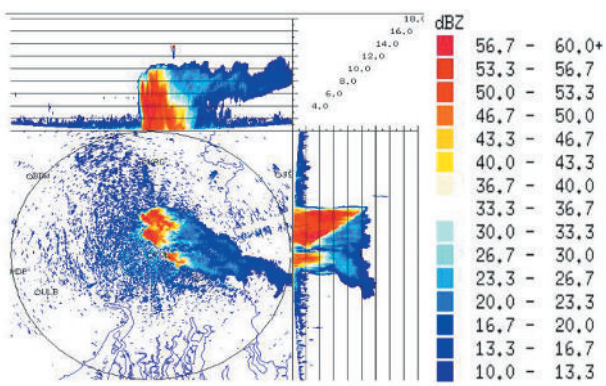


Fig. 2.11. Hailstorm occurrence over Kolkata on 06 May, 2007 at 1002 UTC (Radar Image)

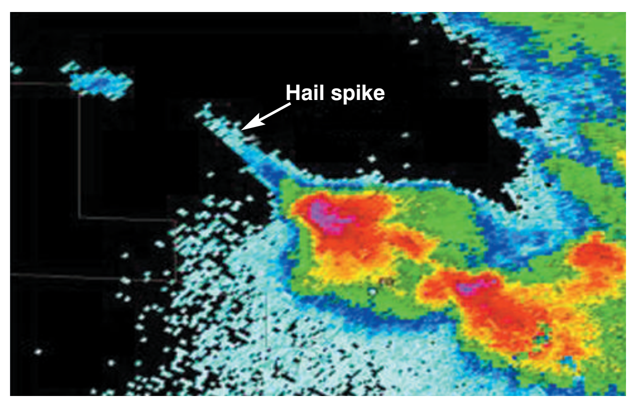


Fig. 2.12. Imprint of Sydney hailstorm (14 April 1999)

2.4.2 Probability mapping

Occurrence of hail may be predicted based on probability maps (Fig. 2.13). These probability maps are prepared from a long-term (say, 30-year or more) observed data on actual hail events. The procedure to create the maps is as follows: Reports for each day are put onto a designated grid (for example 80 km x 80 km). If one or more reports occur in a grid box, that box is assigned the value "1" for the day. If no reports occur, it's a zero.The raw frequency for each day

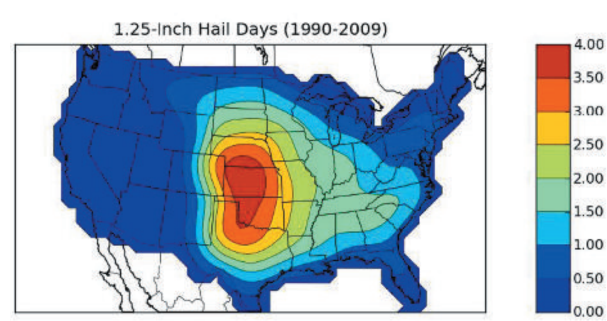


Fig. 2.13. A Hail Probability Map *(Source: Storm Prediction Centre Oklahoma Climatological Survey, USA)*

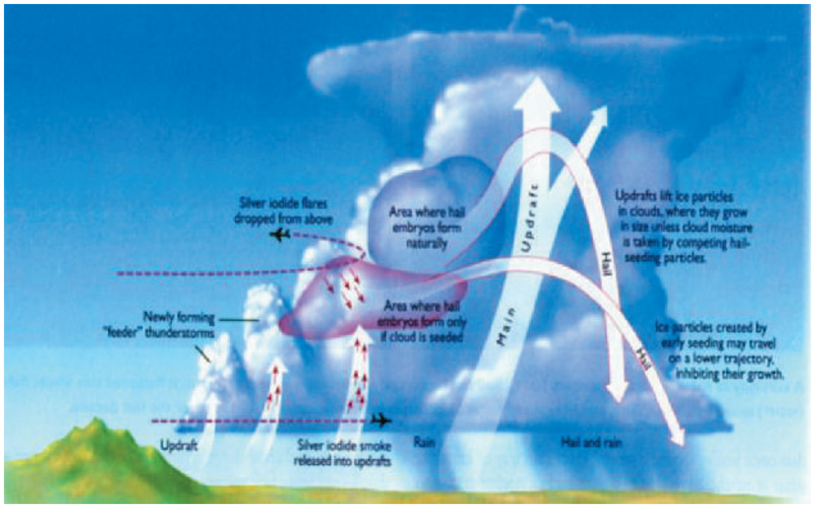


Fig. 2.14. A Conceptual model of hail formation and suppression (Krauss, 1981; ARC, 1986)

at each grid location is found for the period (number of "1" values divided by number of years) to get a raw annual cycle. The raw annual cycle at each point is smoothed in time, using a Gaussian filter with a standard deviation of specified period (e.g. 15 days).The smoothed time series are then smoothed in space with a 2-D Gaussian filter with a standard deviation of certain period (e.g. 120 km in each direction).

2.5 Hail control mechanisms

Artificial hail control is an important measure in disaster prevention and mitigation. With the development of atmospheric science and related science and techniques, the ability of hail cloud identification and subsequent hail suppression technique has been improving continuously.

2.5.1 Cloud seeding

The cloud seeding hypothesis for hail suppression is based on the cloud microphysical concept (Fig. 2.14). There are two ways in which seeding is postulated to reduce hail severity. The mostly common pursued is the "beneficial competition" approach. Beneficial competition assumes a deficiency of natural ice nuclei in the environment and that the injection of silver iodide (AgI) will result in the production of a significant number of artificial ice nuclei. The natural and artificial ice crystals compete for the available super-cooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If sufficient nuclei are introduced into the new growth region of the storm, then the hailstones will be small enough to melt completely before reaching the ground. Another approach, premature rainout, involves seeding of cloud elements at an early stage, so that particles which might otherwise become hail embryos fall out of the cloud as rain from lower levels rather than ascend to the higher levels where hail formation takes place.

Cloud seeding operations alter the microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a deficiency of natural ice nuclei. Cloud seeding does not attempt to compete directly with the energy and dynamics of the storm. Any alteration of the storm dynamics occurs as a consequence of the increased ice crystal concentration and initiation of riming and precipitation sized ice particles earlier in the cloud's lifetime.This process of seeding of condensation nuclei into the system on or before the start of hail formation process can be done using either specialized aircrafts (Fig. 2.15) or anti-hail rockets (Fig. 2.16).

Fig. 2.15. Cloud seeding aircraft

Fig. 2.16. Anti hail rocket

2.5.2 Creating shock waves

The creation of shock waves can prevent the formation and growth of hail by melting altogether. Shock waves are produced using hail guns/cannons (Fig. 2.17). The super-cooled water situated on the external layer of hailstone is transformed from liquid state to solid state. Therefore the hail nuclei are not able to melt anymore andremain at a small size which thus minimise the damage when they hit the ground. In early 1900s', hail cannon's shockwaves were generated by gun powder, which was both dangerous and took a longer time to reload and large number of cannons were needed to be deployed. Nowadays,acetylene or butane gas is used to generate hail disruptive shockwaves this allows the emission of a more powerful shockwaves with higher continues to 1 frequency. Shockwaves generally are not affective against already formed hailstone, so its timely start-up is the most important requirement. A hail cannon operation must be initiated 20 minutes before hail storm formation on storm arrival. The efficiency of the cannon decreases in proportion to start-up delay. If the anti-hail device is activated when the storm is directly above the device, its efficiency will be very low. Therefore it is usually recommended combining their use with storm tracking devices like Doppler radar. Though these devices are quite effective, but still improvement in their efficiency are warranted.

Fig. 2.17. Anti-hail cannon

It is be reiterated that hail control mechanisms cannot eliminate hail completely but the cloud seeding can be beneficial. The hail swaths are more severe either before the time of seeding, or outside the areas of heavy seeding. Seeded storms have lesser maximum reflectivity compared with non-seeded storms. Also, storm tops on average, begin to decline after seeding commences. Since maximum reflectivity and storm top height are correlated with maximum hail size, cloud seeding helps in reducing the size. However the methods of hail suppression that appears to have some beneficial effects none can be recommended with absolute confidence.

2.5.3 Preventive measures

Protective screens termed as anti-hail nets above the crop can be appropriately utilised especially for high value crops (Fig. 2.18). The hail climatology, microclimatic effects of the cover, its durability properties and installation cost are useful in evaluation of the merit of such screens. These anti-hail nets are not effective against strong hail storms.

Tree shelterbelts can markedly reduce hail damage in their immediate vicinity since hails are usually associated with strong winds (Fig. 2.19). The trees have three effects. Some hail is intercepted directly by the trees protecting crops immediately downwind. The trees also create a change in the air flow so that the area in the lee of them is particularly sheltered with hail deflected laterally. Wind speeds will also be less in the lee of the shelter so the total hail kinetic energy, which results both from the vertical fall speed of the hail and the wind speed will be less.

Fig. 2.18. Anti-hail nets

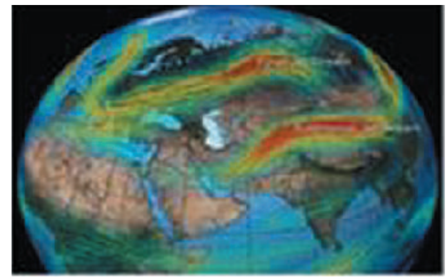
Fig. 2.19. Shelterbelts

3. Trails of recent hail storms in India

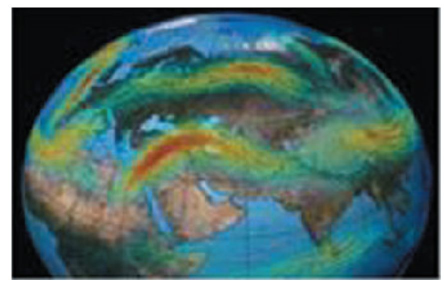
Various parts of the country have recently experienced widespread unseasonal rain and hailstorms. The freak weather event battered eight states namely Punjab, Haryana, Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh - for an unprecedented 20 days, during February 24 to March 14, has left millions of farmers in a state of shock. It occurred when farmers were getting ready to harvest *rabi* crops such as wheat, pulses, potato, sugarcane, maize, groundnut and mustard and horticultural crops like grapes, papaya, mango, banana, onion and other vegetables. According to the estimates, 4.65 million ha of standing crops were ravaged in the worst-hit Maharashtra and Madhya Pradesh alone.

3.1 Causes of the unseasonal hailstorm events

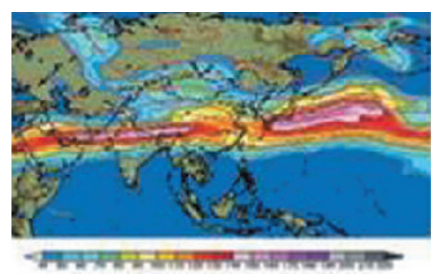
Indian Institute of Tropical Meteorology (IITM), Pune has attributed this year's (2014) unseasonal rain and widespread hailstorm during February-March to the shifting of polar jet stream from its regular trajectory. It has been observed that due to the melting of Arctic ice, polar jetis shifting southwards, triggering extreme weather events all across the globe. This year, it has pushed down the cold westerlies in India that usually flow over 30 degree latitude to 15 degree latitude, causing unprecedented hailstorms and rainfall. Movement of the polar jet stream has been illustrated in the figure 3.1.



(a) Normal polar and subtropical jet streams



(b) Meandering polar jet streams after the polar vortex collapses



(c) Shift of jet streams southward affects wind patterns across the globe

Fig. 3.1. Movement of polar jet stream (Source: NASA, Stormsurf, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences)

There were incursions of two opposing systems within the country - easterlies bringing in warm moisture-laden winds from the Bay of Bengal and western disturbances bringing in cold, dry winds from Afghanistan through north India. The dynamic instability coupled with the sudden conflict of the easterlies and westerlies and availability of moisture has caused this hailstorm phenomenon. The extended hailstorms in the non-conventional areas were resulted due to collision of winds from Bay of Bengal and Arabian Sea over Central India (Fig. 3.2). Madhya Pradesh, Maharashtra (barring coastal districts) and also parts of interior peninsula such as north of Andhra Pradesh had witnessed such events during the aforesaid period. Clouds measuring up to 22 km in height and sub-freezing temperatures have been observed during these events. According to IMD, although a hailstorm in parts of Marathwada and Vidarbha after winter especially in early February is not unusual, it displayed higher intensity this time.

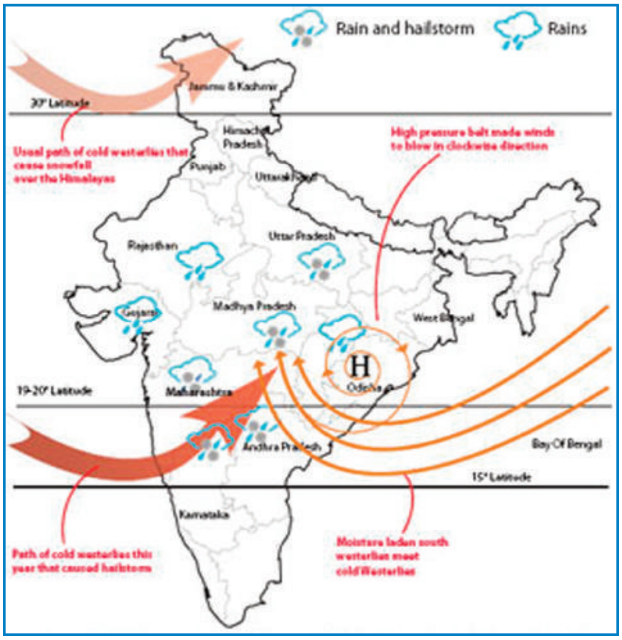


Fig. 3.2. Polar fear- the causes of Feb-Mar, 2014 widespread hailstorm in north and central states and some peninsular parts of India (Source: NASA, Stormsurf, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences)

3.2 Are the recent hail events a symptom of climate change?

Most Indian climatologists opine that the unprecedented and untimely weather events were yet another sequence in the chain of freak weather events India has been witnessing in the last few decades. But many shy away from attributing it to climate change. As per Climate Change Centre, IITM, Pune it is premature to attribute it to climate change. More samples are required for the attribution. Temperatures are rising in the world everywhere and every year, so it is a symptom of climate change. But the current event is an isolated one and has not been witnessed in the last 25-30 years. So it is difficult to link it to climate change. It may be a part of natural variability of weather conditions. It is well established that there has been an increase in extreme weather events. Only 20 per cent of these are due to natural causes; 80 per cent are human-induced changes. The sheer magnitude of the event merits it a climate change tag. It occurred due to unnatural and drastic fluctuations in temperatures, which are symptomatic of climate change. Extreme and unprecedented weather events have to be accepted as climate change phenomenon regardless of their frequency (Down to Earth, 2014). However, such argument needs to be supported by more scientific evidences and a detailed analysis of past and recent events is the need of the hour.

3.3 Hail observations and monitoring

India Meteorological Department (IMD) is the nodal agency that keeps a record on hail occurrences in the country. While the rainfall excess can be forecasted, such information can note be given for hailstorm because of the sporadic and localized nature of the phenomena and lack of adequate radar network along with the limitations in the present radar technologies. Apart from the inherent limitations in radar technology in detecting likely presence of hail, since the radars are usually not operated for 24 hours in IMD and even when operated, heights of only selected echoes, usually the tallest, are recorded. Tornadoes also occur occasionally but have rarely been observed by radars in India. As the life of a tornado or that of a hailstorm is very short and there extent is very narrow it is often difficult to spot them on conventional radars.

Recently, IMD has operationalized its location-specific nowcasting weather services across the country. This service, through Earth System Science Organization (ESSO) and IMD, covers 117 urban centres. The service is currently on experimental basis and would nowcast severe weather conditions like thunderstorms, heavy rainfall and depressions over land three to six hours beforehand, using data from Doppler weather radars. Origin, development or movement of severe weather phenomena are regularly monitored through all available observing systems, such as automatic weather stations, automatic rain gauges and Doppler weather radars. The High Performance Computing (HPC) system at the ESSO-National Centre for Medium Range Weather Forecasting (NCMRWF) and ESSO-IMD has provided the opportunity to assimilate satellite radiance data into the global or regional forecast systems which has helped in enhancing the spatial resolution of the global forecast systems from about 50 km grid scale to about 22 km grid scale. In order to capture the characteristics of the severe weather in real time, 14 Doppler weather radars will be installed across the whole country. Despite the logistical challenges, it has been decided to set up and enhance gradually its observational network for monitoring abnormal weather patterns and upgrading its forecasting capabilities, so that advance warning can be provided to National Disaster Management Authority (NDMA), Ministry of Home Affairs, and Ministry of Agriculture to tackle the impacts of the adverse and extreme weather phenomena (Source: http://ndmindia.nic.in/ NPDM-101209.pdf).

3.4 Hailstorm occurrences in Maharashtra and the recent events

Maharashtra occupies the western and central part of the country and has a long coastline stretching nearly 720 kilometres along the Arabian Sea. Same has a tropical monsoon climate. The hot scorching summer beginning March onwards contributes to the rainy monsoon from June to September. The South-Western sea-clouds yield over 400 cm rainfall on the Sahyadri crests and Konkan, declining northwards with the districts Solapur and Ahmednagar lying in the heart of scarcity zone.

Maharashtra falls under semi-arid tropical (SAT) region, except few districts of Konkan region along Western Ghats which falls under sub-humid tropics. The frequency of hailstorm occurrence in Maharashtra is very low, as this is a feature most common to temperate areas. Although, the hailstone showers of size less than 1-1.5 mm have often been experienced in Vidarbha and Marathwada region at an interval of every 3-4 years, they were of very low intensity and short duration, hardly 2-3 minutes. Historically, no references are available for hailstorm occurrences causing widespread damage on large areas, though reports exist for spurt of hailstones of considerably bigger sizes. During 1908-09, hailstone of coconut size was recorded at Kondhwa in Pune. Further, during 1986, the hailstones of cricket ball size showered in Pune district (Daily Agrowon, March 07, 2014).

Surprisingly in 2014, almost 28 out of 35 districts in Maharashtra were severely affected by unseasonal rains and heavy hailstorm causing widespread damage to the agriculture. According to the elders, in most of the affected villages, this is the first life time experience of heavy damage from hailstorm in Maharashtra during last 60 years. Usually, hailstorm activity occurs during the months of April and May. But this time it has occurred during February-March which is a severe weather aberration.

4. Hail damage to agriculture in Maharashtra

According to information from various sources including the Commissioner of Agriculture, Maharashtra, hailstorms have damaged various agri-horticultural crops on approximately 16 lakh ha area in Vidarbha, Marathwada and Western Maharashtra regions (Figs. 4.1, 4.2 and Table 4.1).

Fig. 4.1. The districts of Maharashtra affected by hailstorm (Blue shade) [Source: http://epaper3.esakal.com/ 11Mar2014/ Normal/PuneCity/index.htm]

Fig. 4.2. Farmers are anguished as officials assess crop damage in Nagpur

Table 4.1. Type of damages recorded in agricultural crops and animal husbandry sectors

Crop/Animal	Type of damage
Field crops	
Cotton	Plant stem lodging and breakage, deterioration of fibre quality
Sorghum	Lodging, ear head broken, grain shattering and secondary infection
Wheat	Lodging and ear head damage, secondary infection
Maize	Defoliation, lodging, stem bruises
Chickpea	Pod shedding
Horticultural crops	
Grapes	Scars in bunches, berry drop, defoliation
Pomegranate	Defoliation, fruit and flower drop, fruit cracking, stem bruises
Sweet lime	Immature fruit dropping, lesions on fruits, secondary infection
Guava	Lesions on fruits
Papaya	Petiole breaking and defoliation, fruit scars and drop
Mango	Flower bud and immature fruit drop
Fig	Stem bruises, fruit lesions, flowers fell off, leaves shattering

Crop/Animal	Type of damage
Vegetable crops	
Water melon	Lesions on fruits, drying of leaves and rotting of fruits
Garlic	Terminal end of leaves burning, lesions on leaves
Tomato	Lesions on fruits
Brinjal	Lesions on fruits and leaves
Drum stick	Lesions on drum stick, bruises on stems, breakage of twigs
Lucerne	Lesions on leaves and secondary fungal infection
Fishes and animals	
Fisheries	Migration, damage to fishing structures and irrational impact due to microalgae and pathogens
Poultry	Mortality and fungal infections
Animals	Mortality and injury

Among the 28 hail affected districts, Nagpur district with about 25 % losses was the worst hit. The hailstorm has havocked most of the Marathwada region with huge losses in Osmanabad, Latur, Parbhani, Jalna and Aurangabad districts. Comparatively the extent of losses were less in North and Western Maharashtra regions, though economic losses were much more mainly because of damage to the high value crops like pomegranate, grapes, papaya, watermelons, onion, other vegetables and sugarcane.

In addition to the losses to high value agri-horticultural crops, the damage to farmland properties like polyhouses, greenhouses, cattle shades, poultry shades was enormous. Approximately 2700 farm animals including cattle, sheep and goats and poultry birds have been reported died and scores of other injured due to hail damage, accounting huge economic losses to the farmers. Fish and prawn species which were usually monitored and caught by fishing community near the riverine / reservoir coasts has shown a spatial migration either in benthic region or far away from the coast.

While surveying throughout the hailstorm affected areas in Maharashtra, two main types of hail damages in crops were observed. Interestingly, the damage occurred mostly on windward side of the stems or branches. The leeward sides of the plants/trees were seen without or very less damage due to hailstones.

Primary injuries: heavy defoliation, shredding of leaf blades, breaking of branches and tender stems, lodging of plants, peeling of bark, stem lesions, cracking of fruits, heavy flower and fruit drop, death of farm animals and poultry birds etc.

Secondary injuries: dieback or wilting of damaged plant parts, loss of plant height, staining, bruises, discolouration of damaged parts like leaves, fruits affecting their quality, rotting of damaged fruits and or tender stems and branches due to fungal and bacterial infections.

4.1. Damage to field crops

Lodging and breaking of ear head in wheat

Shredding of leaves in sugarcane

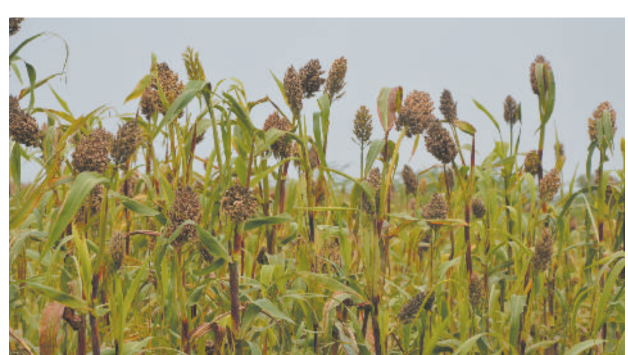
Stem lesions on maize plants

Leaf shredding and top breaking in maize

Lodging and pod

Defoliation and boll damage in cotton

Shredding of ear heads in sorghum



Secondary infection of sooty mould in sorghum

4.2. Damage to vegetable crops

Rotting of hail damaged cabbage heads

Shredding in cabbage

Lesions on stem and fruits of tomato

Fruit drop and breaking of twigs in Tomato

Damage to fruits in muskmelon

Cracking of water melon fruits

Lesions on Pumpkin fruits

Shredding of leaves in chilli

4.3. Damage to horticultural crops

Lesions on stem and fruits of banana

Banana

Heavy dropping of grape bunches

Staining/ discolouration of damaged grape

Heavy dropping of pomegranate flowers

Cracking of pomegranate fruits

Lesions on fruits and breaking of crown in papaya

Heavy dropping of fruits in lemon

Lesions on fruits of guava

Defoliation in fig

4.4. Damage to poultry and birds

Mortality of poultry birds due to direct hitting by hailstone

Mortality of parrots due to direct hitting by hailstone

4.5. Damage to agricultural structures

Damage to shade-net

Damage to fish-net near Ujani dam Solapur

Breaking of Plastic pots

Damage to cement base of grapevine trellis

4.6. Damage at NIASM campus

Complete lodging and shattering of wheat

Lesions on stems and cobs maize

Lodging and damage to earheads of sorghum

Leaf shredding and lodging in sugarcane

Crown breaking and fruit damage in papaya

Apical damage in mango sapling

Peeling of bark and defoliation in pomegranate

Heavy dropping of fruits in lemon

Peeling of bark and defoliation in guava

Defoliation and heavy fruit drop in tomato

Breaking and scrapping of cactus leaves

Shredding of leaf blades in *Agave*

Shredding of leaf blades in napier grass

Heavy defolation and lesions on bark in Subabul

Breaking and scrapping of *Aloe vera*

Stem lesions on drum stick

5. Post hailstorm management

5.1 Existing technologies

As hail is the sudden event, and highly unpredictable, it is always better to take some precautions to minimise the hail damage. However once the damage has occurred, the coping strategies would depend upon the severity of damage and nature of crops. Some of these measures are listed as follows:

Precautions

- It is always advisable to have shelter belts and wind breaks around orchard to avoid heavy damage to the main crop. These will also lower the water requirements and other stresses.
- In areas with higher probability of hailstorm occurrence, shade nets can be a good option especially for high value crops.
- Nylon nets used for protection against bird damage can also protect the crop from hail damage.

Fig. 5.1. Nylon nets intended for protection against birds actually gave good result towards protection against hail

Coping strategies

- For orchard crops, it is advised to remove all the broken branches and twigs. Recommended chemicals should be sprayed to avoid secondary infection by fungus.
- Remove the fallen fruit to reduce the spread of disease and pests during their decay. Large wounds on trunks and branches should be covered with a water-based paint to avoid desiccation and disease infection.
- In case of likely rainfall 3/4th maturity harvest is advisable going for selection. Fruit thinning of hail damaged fruit this will improve yield and quality of remaining fruit.
- Contingency crops like green gram and black gram may be taken to take the advantage of soil moisture and to recover a part of losses.
- Farmers need not be panic if the damage is less severe. Wait till the next sprout to decide whether totally abandon orchards or replacement of trees will suffer.
- Pruning may be necessary to retain young trees and optimize new growth.
- Bud breaking chemicals and growth regulators may be applied to induce the vegetative growth in orchard crop along with fertilizers.
- Proper drainage facilities are to be provided to avoid water logging and to avoid

secondary infection of diseases. Near maturity bulb crops like onion and garlic may be harvested to avoid rotting.

5.2 Crop specific management strategies

The following section describes certain crop specific management strategies that need to be followed for long term management of hailstorm damaged plantations. This will allow the growers to better plan for next crop season and to recover to some extent the losses incurred by adopting integrated crop management for the upcoming season.

Mango

- Maharashtra has large area under Kesar mango in Aurangabad, Jalna, Beed, Latur districts of Marathwada region.
- The flowering in mango starts somewhere around December-January and harvesting takes place in May-June. During February-March of this year, when hail damage occurred, majority of the orchards were at peak blooming and fruiting stage. Due to hailstorm, unseasonal rains and high speed winds, heavy flower and immature fruit drop has occurred in most of the mango plantations in Marathwada region.
- In order to prevent further losses due to flower and fruit drop, the mango orchards should be sprayed with Potassium nitrate 1.0%.
- The chances for incidence of powdery mildew and insect pests like mango hoppers, thrips are very high due to persistence of cloudy weather, increased humidity and wet conditions on foliage. Hence affected orchards should be sprayed with fipronil (5% EC) @ 1.5 ml/litre or spinosad (45% SC) @ 0.3 ml/litre for pest control and with hexaconazole @ 1.0 ml/litre for powdery mildew disease control.

Banana

- The most frequently observed damages to the banana orchards were shredding of leaf blades, lodging of plants due to breaking of pseudo stems and lesions on fruits.
- Generally, in banana the new growth of leaves ceases after emergence of fruit bunches. For a normal growth and development of fruit bunches till maturity, presence of minimum 8-10 healthy and active leaves on plant is necessary. However, in hail damaged orchards with developing fruit bunches, as there will be no further new growth of leaves it has become necessary to keep the shredded leaves active for longer by adopting proper nutrition and protection measures. In case of orchards with severely damaged leaves, thinning of fruit bunches should be done to ensure proper growth and development of fruits.
- Spraying of 5 g potassium di hydrogen + 10 g urea per litre of water on plants with newly emerged fruit bunches to sustain the leaf growth and allow the development of immature fruits. Additionally, soil application of urea and MOP can be given to boost the growth and fast recovery.
- To avoid losses due to physical injuries and subsequent infection by fungal pathogens to the leaves, pseudo stems and developing fruits spray the orchards with Mancozeb @ 2.5 g/litre or Carbendazim@ 1.0 g/litre of water. To minimize the chances of incidence of cigatoka blight, a deadly disease of banana plantations, spray the propiconazole @ 0.05 % @ 15 days interval depending on the intensity.
- Removal and destruction of newly generated

suckers, damaged leaves, fruits and pseudo stems to avoid secondary infestations of the pest and diseases.

- Draining of excess stagnated water from banana fields to facilitate proper aeration
- Cover the fruit bunches with polypropylene bags or dried banana leaves to avoid direct damage and also pest and disease infestations.
- Protect the orchards by putting nylon/ green shed net around the field especially in areas where future predictions have been made for unseasonal rains, hail or wind storms in coming days.

Pomegranate

- Due to continuous cloudy cover and humid climate, the chances for prevalence of oily spot/bacterial bight disease caused by *Xanthomonas punicae* are higher in majority of the pomegranate growing areas. Hence, implementation of integrated preventive measures is necessary. For this, damaged leaves, branches, fruits should be collected and destroyed and spraying of Bordeaux mixture (1.0%) or copper oxychloride (@ 2.5 g/ liter of water) should be carried out immediately. If warm and humid climate still persists, spray Bromopal @ 2.5 g/ liter after one week.
- Taking into account the age of damaged plant and extent of losses due to hail damage, remove the damaged fruits from trees and keep optimum number of fruits per tree by thinning excess flush.
- In orchards with *Ambia bahar*, if the damage intensity is almost 100%, plan for taking next flush i.e. *Mrig bahar*. For this remove half broken and damaged branches by pruning them. Apply the recommended dose of NPK @ 250-300 g/ tree, provide light irrigation to the field and leave the orchard for rest till next flush comes.
- In orchards with less than 50% damages, apply recommended dose of fertilizers to allow the plants to recover from damage, apply 1.0% Bordeaux paste on wounded portions or spray with 1.0% Bordeaux mixture or copper oxychloride @ 2.5 g/ litre.
- Provide support to the bent/ damaged tress with bamboo sticks and earthing up.
- Provide light irrigation to soften the fields that are hardened/ compacted due to hailstorm.

Sapota

- The hailstorm leads to heavy flower and fruit drop and damages the fruits in Sapota. The white latex oozes out from the damaged fruits which attract development of rot fungus subsequently causing complete spoilage of damaged fruits. To prevent this, spray the orchards with Mancozeb @ 2.5 g/litre or Carbendazim @ 1.0 g/litre of water.

Guava

- In most of the guava growing areas, the crop of *Hast bahar* has already been harvested before hailstorm occured. The orchards where *Ambia bahar* crop is taken, the fruits are in developing stage and were damaged due to hailstones. The damaged and fallen fruits should be collected and destroyed promptly. Spraying of copper fungicides should be done to prevent the disease infection to the damaged plant parts.

Grapes

- In cases where flowers of grapevines have been extensively damaged and little crop is anticipated, growers may consider knocking the remaining shoots off to allow secondary buds to burst. The economics of undertaking this operation should be carefully considered.

- If the shoots extending up to the trellis wire are badly scarred, then cutting them back and retraining a new shoot should be considered. The scarring on a shoot that will eventually become a trunk can interfere with sap flow and may provide sites for trunk diseases in the future. Unless the damage is extensive, the vine will often recover quickly.

- If the weather remains dry, mature vines that are properly managed should heal wounds quickly. Early-season injury just after budburst allows time for fruitful buds to be initiated in the regrowth from latent, secondary and lateral buds, with minimal effect on bud fruitfulness or crop in the following season.

- Later season damage, leading up to and after flowering, has been shown to reduce fruitfulness and crop in the following season. Thus winter pruning may need to be adjusted to develop spurs in appropriate locations for future crops and to retain extra buds to compensate for the anticipated lower fruitfulness.

- Damaged plants are more susceptible to pests and disease. It is necessary to watch and guard against diseases like Botrytis rot that is not common in India but can infect any damaged tissue and if weather conditions are wet toward the end of the season the crop can be extensively infected.

- Fertiliser programs should also be continued to maintain vine health.

5.3 Control of secondary damage due to insect pests and diseases

Consequent to the hailstorm, cloudy weather followed by intermittent drizzling rains is being continuously experienced by the crops during this period. Considering the increased humidity in atmosphere, persistence/retention of wet conditions on foliage/leaves and soil moisture, there is increased risk of incidence of insect pests and diseases in both crops standing in the field as well as in post-harvest produce. Hence, following measures are suggested for prevention of pest and disease spread in hail storm affected orchards and field crops.

(a) Grey sooty mold developing on grape bunches damaged by hailstone at Khandali, Malshiras, Solapur

(b) Rotting of hailstome affected pomegranate fruits at Gherdi, Sangola, Solapur.

Fig. 5.2. Secondary losses in hailstorm damaged fruits due to microbial infections

In fruit crops like pomegranate, grapes, guava, etc. heavy flower and fruit drop has occurred due to hail damage. The damaged flowers and fruits started rotting due to cold shocks and infection by bacterial and fungal pathogens like grey sooty mould. Hence, such fruits, flowers should promptly be collected and destroyed to avoid further spread of infection. This will help in preventing spread of insect pests like fruit borers that are hiding inside damaged fruits.

Since the severely damaged barks on branches and stems become very susceptible to attack by insect pests like stem borers, bark borers, and infection by fungal diseases like blight, rot, wilts, etc, the damaged/broken branches of plants should be pruned immediately. The spraying of 1% Bordeaux mixture (1 g Copper sulphate, 1 g lime, 100 litre of water) should be carried out which helps in healing of wounds. Alternatively, spraying of copper oxychloride @ 2- 2.5 g/litre can also be done.

(a) Peeled bark of pomegranate plants

(b) Powdery mildew on hail damaged grape leaves

Fig. 5.3. Wounds and disease in fruits crops damaged by hail storm in Solapur

Due to cloudy weather coupled with increased atmospheric humidity and wet foliage conditions, the plants suffered from hail damage were likely to be affected severely with sucking pests like thrips, jassids, mites, and diseases like powdery mildew, leaf blights, fruit and flower rot, etc. For the control of sucking pest attacking new foliage/growth, spraying of systemic insecticides/acaricides like Spinosad (0.3 ml/ litre), fipronil (@ 1.5 ml/litre) should be done. For controlling powdery mildew, spraying of Hexaconazol (@ 1 ml/litre), propiconaole (1 g/ litre) was useful. Spraying of Mancozeb (@ 2.5 g/ litre) or Carbendazim (bavistin) (@ 1 g/ litre) helped to prevent infection of blights and rot diseases.

5.4 Research initiatives at NIASM

The institute campus at Malegaon and areas around witnessed unprecedented hail storm on March 9, 2014 for about half an hour with hail size of 2 - 3 cm. Crops in various field experiments were destroyed by the hailstorm. However, to hasten the recovery of damaged crops and orchards and minimize risks of pests and disease, possibilities of stimulating growth through additional fertilizers and use of bio-regulators through foliage as well as soil and various pesticides were evaluated. Results of these treatments are as follows:

- Two month old sugarcane crop damaged by hailstorm that was initially treated with foliar spray of Bavistin + Copper oxychloride mixture @ 2 g/litre, responded well to additional dose of N (50 kg/ha) along with either spraying of KNO_3 (1.5 %) or drenching of N (1.0 %) and $P_2O_5 + K_2O$ (2.0 % of each) (Fig. 5.4). But the farmers in the areas are still of the view that the new auxiliary buds emerging from injured part of > 5 month old plants will ultimately be of lower quality in terms of sugar recovery. This will be confirmed at harvest.

(a)

(b)

Fig. 5.4. Sugarcane crop on the day (a) and 26 days after (b) hailstorm

- Wheat crop was completely damaged and flattened due to heavy and intense hails. It looked like a combine harvested crop. The only probability to recover losses seemed to go in for a catch crop since the sufficient soil water storage was available following hailstorm and rainfall of 56 mm. Thus, mungbeanwas directly seeded without removing the wheat residues. However, being an off-season crop, its performance was not satisfactory. Anyhow it is expected that at least a part of the losses will be recovered and the following crop will be benefitted from the N fixation by mungbean (Fig. 5.5). Nevertheless, the mungbean sown after proper tillage is performing well and application of vigore, an organic formulation has further improved its growth and has

(a)

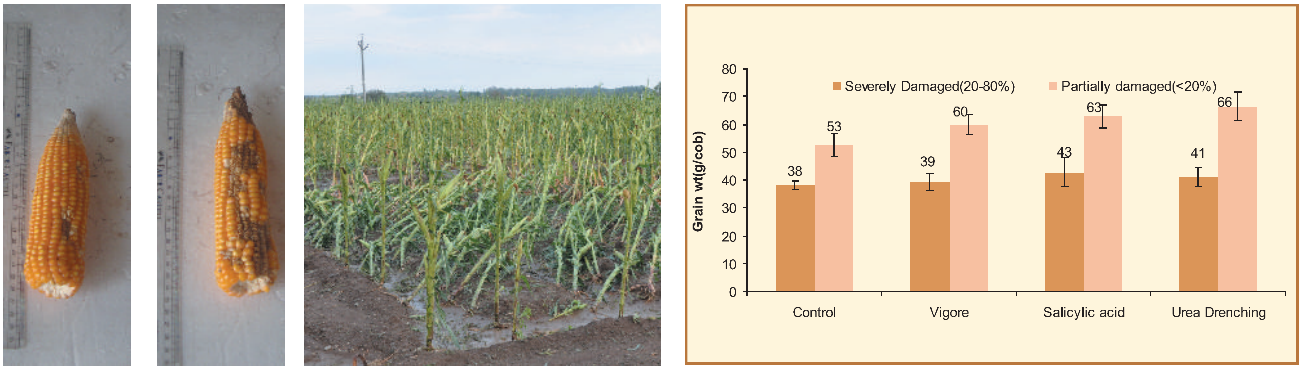
(b)

Fig. 5.5. Wheat crop after hailstorm (a) and mungbean sown without removal of residue (b)

increased its pods per plant.

- The effect of different bioregulators was also assessed on hailstorm damaged maize plants. Grain weight of major cob increased due to salicylic acid and urea drenching especially when damage to cob was < 20 %, while recovery was not possible in case of higher damage (20-80 %) (Fig. 5.6).

Amongst the fruit crops, pomegranate plants were almost totally defoliated, had broken twigs and had all its flowers and fruits withered. These could recover rapidly from hail damage in response to post disaster management that included application of



(a) (b) (c) (d)

Fig. 5.6. Effect of bio regulators on grain/cob weight of maize affected by hail storm; < 20% damage (a) 20-80% damage (b); maize field after hail storm (c) and effect of growth regulators (d)

bioregulators and pesticides. Copper oxychloride was sprayed the day after hailstorm to prevent secondary infection and then plants were treated with chemicals like cytozyme (100 ppm), vigore (0.1%), thiourea (0.02%), potassium nitrate (2%), hydrogen cyanamide (0.02%), silixol (4 ml/litre), C7 (bio-formulation which can prevent fungal infection and stimulate the growth) (Fig. 5.7). This helped in recovery of plants to original level in about a month's period. Pruning, removal of broken twigs and fertigation through drip also helped to recover custard apple orchard (Fig. 5.8), which was severely damaged by hail storm, while guava showed no recovery (Fig. 5.9).

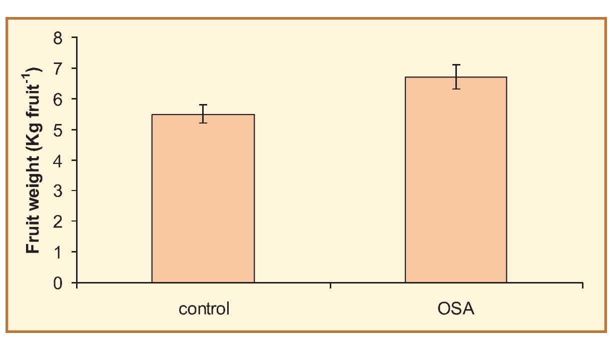
Fig. 5.7. Pomegranate orchard on the day and 26 days after hailstorm

Fig. 5.8. Custard apple a day after (left) and 27 days after (right) hail storm

Fig. 5.9. Guava a day after (left) and 27 days after (right) hail storm

- Bioregulators were also evaluated on watermelon in a farmer's field. Here the field was drenched with silixol at 20 days after transplanting and again the foliar spray (4 ml/litre) was done at 60 days after planting which coincided with initial fruiting stage. Silixol stimulated crop growth, increased the greenness, number of flowers, shortened the crop cycle and increased the fruit size (Figs. 5.10 a, b). The crops drenched and sprayed with ortho-silicic acid (OSA) produced bigger size fruits (5 - 8.5 kg/fruit) than control (2.5 – 6 kg/fruit) without compromising much on fruit numbers per vine (Fig. 5.10c). With timely intervention and application of bioregulators, the farmer earned more than Rs. 3 lacs per acre as the demand for water melon was not being met due to damage of crop in other parts of the state.

(a) (b)



(c)

Fig. 5.10. Water melon field with (a) and without (b) ortho-silicic acid and comparative fruit weight (c)

- Similarly cutting management (at 10-15 cm above ground level) and sprays of bioregulator (thiourea) and also the KNO_3 helped in fast recovery of indeterminate crop of brinjal that was severely damaged with hail. The plant vigour and number of fruits also increased with these treatments (Fig. 5.11a, b)

(a)

(b)

Fig. 5.11. Brinjal crop damaged by hailstorm (a) and post-hailstorm recovery of crop growth after 30 days (b)

6. References

Berthet, C., Dessens, J. and Sanchez, J. (2011) Regional and yearly variations of hail frequency and intensity in France. Atmospheric Research 100, 391–400.

Brandes, E., Vivekanadan, J., Tuttle, J. and Kessinger, G. (1997) Hail production in Northeast Colorado hailstorms, Proceedings 27th Conference on Radar Meteorology, American Meteorological Society, Boston, MA, 527-530.

Brooks and Dotzek (2008) The spatial distribution of severe convective storms and an analysis of their secular changes. http://www.nssl.noaa.gov/users/brooks/public_html/papers/brooksdotzekcup.pdf.

Cao, Z. (2008) Severe hail frequency over Ontario, Canada: Recent trend and variability. Geophysical Research Letters 35 (14), DOI: 10.1029/ 2008GL034888.

Changnon, S. A. (2001) Thunderstorms across the nation: An atlas of storms, hail, and their damages in the 20th Century. Changnon Climatologist Mahomet, IL, 93pp.

Changnon, S.A. (1973) Hail sensing and small scale variability of windblown hail. Journal of Weather Modification 5, 30-42.

Chaudhury, A. and Banerjee, A.K.(1983) A study of hailstorms over northeast India, Vayu Mandal 13, 91-95.

Depue, T. K., Kennedy, P. and Rutledge, S. (2007) Performance of the hail differential reflectivity polametric radar hail indicator. Journal of Applied Meteorology and Climatology 46, 1290-1301.

Dessens, J. (1986) Hail in Southwestern France: Hailfall characteristics and hailstorm environment. Journal of Applied Meteorology 25, 35-47.

Donovan, R. A. and Jungbluth, K. (2007) Evaluation of a technique for radar identification of large hail across the upper Midwest and central plains of the U.S. Weather and Forecasting 22, 244-254.

Doswell, C., Brooks, H. and Dotzek, N. (2009) On the implementation of the enhanced Fujita scale in the USA. Atmospheric Research 93, 554–563.

Down to Earth (Flat in 20 days), Apr 30, 2014 Press, 465pp.

Eccel, E., Cau, P., Riemann-Campe, K. and Biasioli, F. (2012) Quantitative hail monitoring in an alpine area: 35 year climatology and links with atmospheric variables. International Journal of Climatology 32, 503–517.

Edwards, R., and Thompson, R.L. (1998) Nationwide comparisons of hail size with WSR-88D vertically integrated liquid water and derived thermodynamic sounding data. Weather and Forecasting 13, 277-285.

Gokhale, N.R. (1975) Hailstorms and hailstone growth. State University of New York.

http://en.wikipedia.org/wiki/List_of_costly_or_deadly_hailstorms

http://ndmindia.nic.in/NPDM-101209.pdf

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Kennedy, P. C., Rutledge, S. and Petersen, W. (2001) Polametric radar observations of hail formation. Journal of Applied Meteorology 40, 1347-1366.

Kunz, M., Sander, J. and Kottmeier, C. (2009) Recent trends of thunderstorm and hailstorm frequency and their relation to atmospheric characteristics in southwest Germany. International Journal of Climatology 29, 2283-2297.

Mezher, R. N., Doyle, M. and Barros,V. (2012) Climatology of hail in Argentina. Atmospheric Research 114-115, 70–82.

Morgan, G. M. (1973) A general description of the hail problem in the Po Valley of northern Italy. Journal of Applied Meteorology 12, 338-353.

Morrison, S. (1997) Causes and extent of damage related to structure, material, and architectural failure. Hail, Hail The Disaster's Here, Employers Reinsurance Corporation Overland Park, KS, 12pp.

Mueller, E., and Morgan, G. M. (1972) Colorado-Illinois operational and analytical program utilizing a dual wavelength radar facility. Contract Report 130, Ill. State Water Survey, 31pp.

Ramamurthy, B. V. (1983) Some cloud physical aspects of local severe storms, Vayu Mandal 13, 3-11.

Touvinen, J. P., Punkka, A., Rauhala, J., Hohn, H. and Schultz, D. (2009) Climatology of severe hail in Finland: 1930-2006: Monthly Weather Review 137, 2238-2249.

Xie, B. G., Zhang, Q. H. and Wang,Y. Q. (2008) Trends in hail in China during 1960-2005. Geophysical Research Letters 35, L13801.

Xie, B., Zhang, Q. and Wang, Y. (2010) Observed characteristics of hail size in four regions in China during 1980–2005. Journal of Climatology 23, 4973-4982.

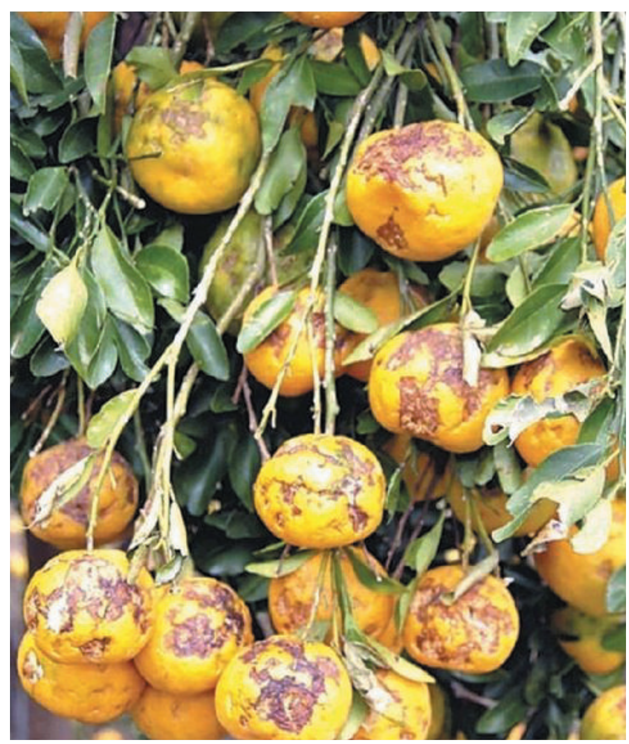
Zhang, C., Zhang, Q. and Wang, Y. (2008) Climatology of hail in China: 1961-2005. Journal of Applied Meteorology and Climatology 47, 795-804.

Zipser, E. J., Liu, C., Cecil, D. J., Nesbitt, S. W. and Yorty, D. P. (2006) Where are the most intense thunderstorms on Earth? Bulletin of American Meteorological Society 87, 1057–1071.

7. Newspaper reports on hailstorm damages in Maharashtra

Source: Daily Sakal, dated March 01, 2014 http://epaper3.esakal.com/01Mar 2014/Normal/PuneCity/index.htm

Source: Daily Sakal, dated March 01, 2014 http://epaper3.esakal.com/01Mar 2014/Normal/Pune City/index.htm



Source: Daily Sakal, dated March 03, 2014 http://epaper3.esakal.com/03Mar 2014/Normal/Pune City/index.htm


Source: Daily Agrowon, March 07, 2014. http://epaper.agrowon.com/Agrowon/07Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 07, 2014. http://epaper.agrowon.com/Agrowon/07Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 07, 2014. http://epaper.agrowon.com/Agrowon/07Mar2014/Enlarge/Pune/index.htm

Huge hail fall in the Baramati town of Maharashtra on 9th March, 2014 [source: Sakal Newspaper, 10thMarch, 2014]

Source: Daily Agrowon, March 10, 2014. http://epaper.agrowon.com/Agrowon/10Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 10, 2014. http://epaper.agrowon.com/Agrowon/10Mar2014/Enlarge/Pune/index.htm


Source: Daily Sakal, dated March 11, 2014 http://epaper3.esakal.com/11Mar 2014/Normal/PuneCity/index.htm


Source: Daily Agrowon, March 11, 2014. http://epaper.agrowon.com/Agrowon/11Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 13, 2014. http://epaper.agrowon.com/Agrowon/13Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 13, 2014. http://epaper.agrowon.com/Agrowon/13Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 14, 2014. http://epaper.agrowon.com/Agrowon/14Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 14, 2014. http://epaper.agrowon.com/Agrowon/14Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 14, 2014. http://epaper.agrowon.com/Agrowon/14Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 15, 2014. http://epaper.agrowon.com/Agrowon/15Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 17, 2014. http://epaper.agrowon.com/Agrowon/17Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 18, 2014. http://epaper.agrowon.com/Agrowon/18Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 19, 2014. http://epaper.agrowon.com/Agrowon/19Mar2014/Enlarge/Pune/index.htm


Source: Daily Agrowon, March 21, 2014. http://epaper.agrowon.com/Agrowon/21Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, March 21, 2014. http://epaper.agrowon.com/Agrowon/21Mar2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, April 22, 2014. http://epaper.agrowon.com/Agrowon/22Apr2014/Enlarge/Pune/index.htm

Source: Daily Agrowon, April 22, 2014. http://epaper.agrowon.com/Agrowon/22Apr2014/Enlarge/Pune/index.htm

भाकृअनुप
ICAR

हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद

Agrisearch with a human touch

राअप्रस
N I ASM

National Institute of Abiotic Stress Management

(Deemed to be University)

Indian Council of Agricultural Research
Malegaon, Baramati 413 115, Pune, Maharashtra, India
Phone : 02112-254057, Fax : 02112-254056
Web : www.niam.res.in