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भाकृअनुप
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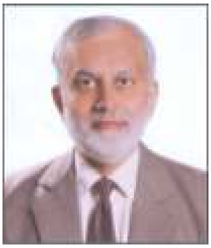

FOREWORD

The recent report of Intergovernmental Panel on Climate Change on extreme events and disasters, projects an increase in extreme weather events in future for Indian sub-continent. In recent years these extreme events posed a great challenge not only at the farm production level but also at the scientific level because of the inability to forewarn their occurrence accurately. Indian agriculture is becoming more vulnerable to climate extremes as area under highly remunerative orchard and other such cash crops has been increasing.

The hailstorms during February-March, 2014 highlighted the importance of weather forecast to the fore. This has compelled for a concerned scientific approach to this natural disaster. Hailstorms usually occur within short period of time and cause extensive damage depending on local weather and crop conditions. These are very difficult to forecast given the present state of technology. Nevertheless, management strategies need to be evolved to minimize the risks for the hail frequented regions. The adverse impact of extended hail episodes can be minimized through forecast with sufficient lead period coupled with appropriate management practices.

In the present document, an attempt has been made to identify hailstorm vulnerable areas in the country, including frequency and time of hail occurrence, physics behind the hailstorms, current forecasting capabilities and management strategies for different field and orchard crops.

I appreciate the efforts of the Scientists of AICRPAM, CRIDA and NRM Division, ICAR in bringing out this timely document and believe that this publication will be of immense use in managing the episodes of hailstorms in the future.

(S. Ayyappan)

Dated the 14th July, 2014
New Delhi

Acknowledgements

The geographical spread of 2014 hailstorms and extent of damage they caused to Indian agriculture has compelled us to have an insight on the physics of this natural hazard, its frequency of occurrence, spatial distribution, vulnerability of agriculture and allied sectors, currently available mitigation and adaptation strategies which may ultimately guide in prioritizing research efforts to minimize field level losses.

Authors are grateful to Dr S. Ayyappan, Director General, ICAR for his keen interest in addressing the hailstorm threat and for his constant support and guidance in bringing out this publication.

Information that lie scattered in various publications of India Meteorological Department, publications of Indian and abroad origin and print media were sourced for this piece of work. Apart from the historical count, field information were also collected with the help of coordinating units of AICRPAM and we express our gratitude to the staff of AICRPAM units at Akola, Anand, Anantapur, Bangalore, Hisar, Jabalpur, Parbhani, Raipur, Solapur and Udaipur. We are highly thankful to Dr H. Venkatesh, AICRPAM, Bijapur for providing the critical analysis on the climatology of 2014 hail episodes.

We place on record the assistance rendered by I. R. Khandgond, P. Pani in the compilation of data and analysis.

AUTHORS

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1.0 Introduction

The water that gets deposited on the Earth's surface from the atmosphere either in solid or liquid form is called precipitation. Hail is a solid form of precipitation. Hail is possible within most thunderstorms produced by cumulonimbus clouds. Cumulonimbus clouds are seen along with low altitude cumulus clouds (appear as a heap of white cotton). These clouds grow vertically. The base of the cloud may be anywhere from 150 to 4000 meters (Fig 1). The top of the cloud may reach as high as 6000 meters to even 23000 meters in some extreme cases. A fully developed cumulonimbus cloud is characterized by a flat anvil like top.

Fig 1: Appearance of cumulonimbus cloud

Hail formation requires environments with strong upward motion of air and/or lowered heights of freezing level. In the middle latitudes hailstones are formed near the interior of continents while in tropics, they tend to be confined to higher levels of freezing. Based on the size of the hailstones, the possible damages can be anticipated.

2.0 Formation of hailstorm

Clouds form when air containing water vapour rises and expand with the lowering of pressure. They cool until some of the vapour condenses into visible aggregates of minute particles. The characteristics of clouds are dictated by the amount of water vapour, the temperatures at that height, the wind and the interplay of other air masses. Clouds are divided into four families; high (Cirrus, Cirrocumulus, Cirrostratus), medium (Alto-Stratus, Alto-Cumulus), low (Strato-Cumulus, Stratus, Nimbostratus) and clouds with vertical development (Cumulus, Cumulonimbus). The cumulonimbus clouds (Fig 2) occur in the tropics close to the Earth's surface with the base anywhere between 0.5-2.0 km and extend to a height of 18-20 km. Due to evaporation and the greenhouse effect, this region produces a lot of

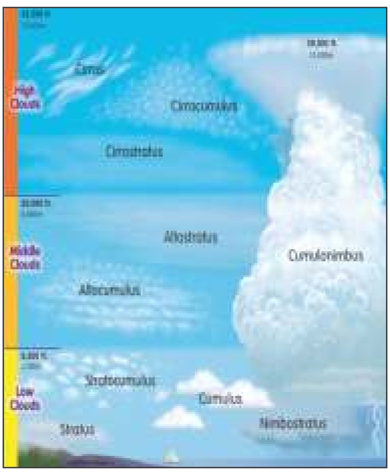


Fig 2: Types of clouds

warm updrafts. Since they are formed relatively close to the ground, they are generally laden with heavy moisture. Cumulonimbus clouds need warm and humid conditions to form upward drafts. The pre-requisite conditions for the hailstorm to form are a) there must be a deep layer of unstable air; b) the air must be warm and moist and c) a trigger mechanism must cause the warm moist air to rise. The trigger mechanism could be anyone among convection, orographic lift and mass ascent. Cumulonimbus cloud commonly forms in the late afternoon after the peak diurnal heating leading to thunderstorms (Fig 3). Thunderstorms of this type occur in many areas of the tropics. Orographic uplift is caused by the rising ground level, forcing the air upwards.

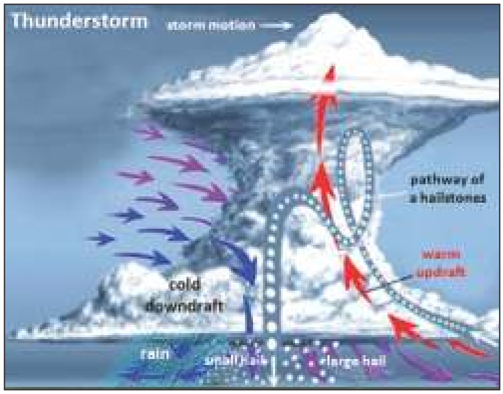


Fig 3: Formation of a convective thunderstorm

There are three distinct phases in the development of cumulonimbus clouds *viz.*, building, mature and dissipation phases (Fig 4). In the building phase, as the moist air rises, it becomes saturated and forms clouds. The latent heat released due to moisture condensation warms the air causing further rise. The air within the cloud is warmer than the air outside it and thus more air is drawn into the cloud from the base as well as the sides. The cloud grows in height rapidly, sometimes as far as the tropopause. As the temperature of the rising air drops below freezing point, the water droplets get super cooled and join together. In the second phase (mature phase), precipitation begins to fall as the top of the cloud reaches maximum height. The falling rain, snow and/or ice (hail) cools the surrounding air creating downdrafts (Fig 5). The friction between ice particles descending through the cloud and being carried aloft by the updrafts, creates a static charge of electricity in the cloud. This charge is positive at the top of the cloud while it is negative at the bottom. Eventually the difference in electric potential is so great that powerful electrical discharges (lightning) occur, accompanied by thunder. The top of the cloud begins to flatten out and cirrus like cloud, consisting of ice crystals, spreads out creating a distinctive anvil shape. In the dissipation phase, the cooling effect of the downdrafts on the air beneath the cloud reduces the strength of the updrafts until updrafts stop. The lower cloud begins to dissipate where as the upper cloud will still linger for some time. The active cycle of the cumulonimbus lasts little more than an hour. However, many thunderstorms contain several active cloud cells in various stages of development spread over several hours and a large area. Active cells are difficult to detect visually as they get embedded into large cloud mass along with clouds at various levels around them including the remains of decayed cells.

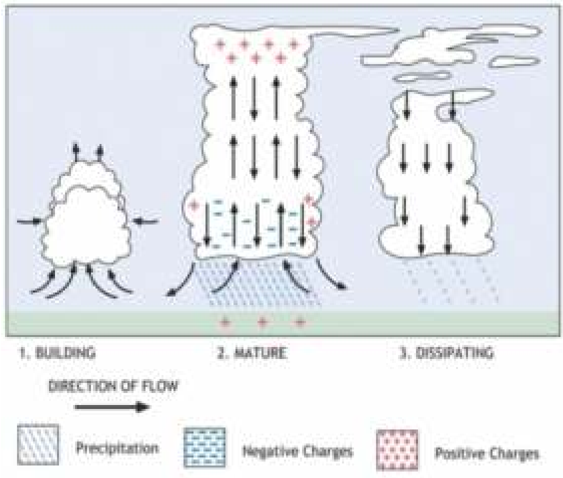


Fig 4: Life cycle of a cumulonimbus cloud

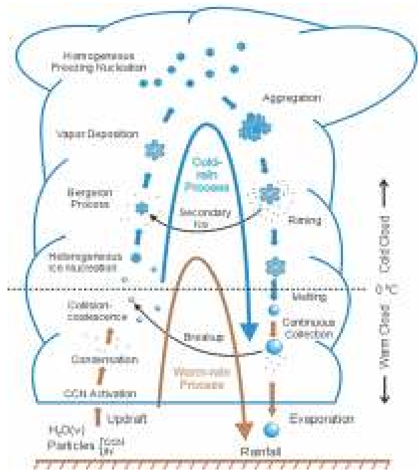


Fig 5: Hail development mechanism in a cumulonimbus cloud

In cumulonimbus clouds, hail begins as water droplets. As the droplets rise and the temperature goes below freezing, they become super cooled water and will freeze on contact with condensation nuclei. The storm's updraft with upwardly directed wind speeds as high as 180 km/hr blows the forming hailstones up in the cloud. As the hailstone ascends it passes into areas of the cloud where the concentration of humidity and supercooled water droplets varies. The hailstone's growth rate changes depending on the variation in humidity and supercooled water droplets that it encounters.

The accretion rate of the water droplets is another factor in the hailstone's growth. When the hailstone moves into an area with a high concentration of water droplets, it captures the latter and becomes a translucent layer. It acquires a layer of opaque white ice when the hailstone moves into an area where mostly water vapour is available.

The hailstone will keep rising into the thunderstorm until its mass can no longer be supported by the updraft. This may take at least 30 minutes based on the force of the updrafts in the hail-producing thunderstorm, whose top is usually greater than 10 km high. It then falls toward the ground while continuing to grow, based on the same processes, until it leaves the cloud. It will later begin to melt as it passes into the air above freezing temperature. The diameter of the hailstone may range between 5 mm to 15 cm (Table 1). Thus the key characteristic of hail damage lies in its size. The high energy of large stones when they impact crops is the principal cause of hail damage. Additional damage to crops/buildings can arise from the combined effects of hail impact, wind and rainfall.

Table 1. Hailstone size and typical damage that can be anticipated in agriculture

Hailstone diameter (mm)	Example	Damage
1-5	Ice pellets and not hailstones	Virtually no damage
5-20	Pea, marble chips	Slight damage to plants
20-30	Five rupee coins (Old)	Fruits and vegetables can be extensively damaged
30-40	Table tennis ball	Branches broken from trees, poultry birds killed in open
>40	Lawn tennis ball or even bigger	Risk of serious injuries to humans and animals and severe damage to farm structures

3.0 Hailstorms in India – A historical perspective

The data on climate anomalies, extremes and disastrous weather events in respect of the area lies scattered in the published literature of the India Meteorological Department (IMD) as well as in scientific and technical papers. The intensity of hail is a function of number of stones, their sizes and the wind. Often hailstone size may be small but damage due to associated gales could be severe. Thus hails with wind becomes a critical factor in crop loss. While designing any insurance product, one has to consider both these effects. It also depends on the time of the year. Damage by hail differs across regions and with the stage of growing plants. Philip and Daniel (1976) observed that hail storms occur with an average frequency of 10 hailstorms per year (slight, moderate and heavy) over extreme northeast Assam, six over west Uttar Pradesh, Agartala and portions of east Bihar, and about two to three over east Madhya Pradesh and west and north Bihar. The area with maximum activity in the southern peninsula was stated to be Madurai with one to two hailstorms (April and May). April-May months were identified as the period with highest hailstorm activity over the north-west and northern parts of the country. Over central and north western parts, March was observed to be the month of hailstorm activity (Philip and Daniel, 1976).

Changes in hail occurrence are generally difficult to quantify because hail occurrence is not well captured by monitoring systems because of in-homogeneities in the historical data. However, the atmospheric conditions are typically estimated from re-analyses or from radiosonde data, and the estimates are associated with high uncertainty. As a result, assessment of changes in hail frequency is difficult (Seneviratne *et. al.,* 2012).

The statistics on hailstorms in India were first compiled for the period 1883-1897 and published by Sir John Eliot (1898). Ramdas *et. al.,* (1938) analyzed and published hail reports received from 141 observatories during the years 1898-1935. It was from 1957 onwards only fairly representative reports in large numbers from the observatory and state raingauge stations were documented. However, most of the hail events prior to 1967 were not recorded. Cataloguing of disastrous weather events by the IMD started in 1967. In some of the worst disasters associated with hailstorms, nine persons were killed in Nagpur (Maharashtra) in February 1979, and eight persons were killed in Kanpur (UP) on 28th February 1982. Gokhale (1975) and Ramanamurthy (1983) reproduced the time and space dimensions of hail occurrences for a hundred year period given by Ramdas *et. al.,* (1938). We tried to figure out the source of the original data quoted in the classic work of Ramdas *et. al.,* (1938) and found that the data used were from 141 stations with period ranging from 21 to 38 years. For inter-comparison, these data were converted into frequency for 100 years. The data reported in Ramdas *et. al.*, (1938) was collected at meteorological stations manned by IMD. De *et. al.,* (2005) made a systematic attempt to bring the information on extreme weather events over India for the period 1901-2004 into the ambit of a review paper. The information on hailstorms in their work is also scanty. In the present study, however, the data were used for events noticed on a district scale.

Based on the annual reports of IMD from 1982 to 1989, Nizamuddin (1983) found that there were 228 hail days (about 29 per year) of moderate to severe intensity. Hail size comparable to mangoes, lemons and tennis balls had been observed. Records indicate that the largest size hailstone occurred in association with a thunderstorm in April in 1888 at Moradabad. Eliot (1893) analyzed that out of 597 hailstorms in India, 153 yielded hailstones of diameter 3 cm or greater. These events killed 250 persons and caused extensive damage to winter wheat crops. A cropped area of 0.46 m ha in 1994-95, 0.74 m ha in 1995-96, 1.2 m ha in 1997-98 and 2.9 m ha in 1998-99 in the states of Haryana, Punjab, Himachal Pradesh, Rajasthan, Uttar Pradesh, Maharashtra and erstwhile Andhra Pradesh was badly hit by hailstorms. During 5-8 January 2002, many parts of Karnataka state were lashed by hailstorm and the estimated loss suffered by the farming community was around Rs. 27.5 crores. In the state of Odisha about 375 villages were affected due to hailstorms and whirlwinds during the year 2005. In the erstwhile Andhra Pradesh, hailstorm caused a huge damage to 77,000 ha of agricultural fields in 2005-06. The state of Madhya Pradesh was badly hit during 2–14 March 2006 by heavy hailstorm causing widespread damage to standing winter crops. During February 2007, most parts of Rajasthan were badly hit by hailstorm. In March 2007, heavy rains accompanied by hailstorm damaged wheat, sugarcane and oilseed crops in thousands of hectares in Punjab and Haryana. The estimated loss ran into billions of rupees and crops were severely damaged over 50,000 ha of land (Bhardwaj *et. al.*, 2007).

The above review suggests that regional differences exist in the season of hail activity, time of day that hail occurs as well as the size of hailstones. It is noticed, however from the review that, hailstorms occur only in isolated regions, say a few districts in a state, rather than over a few states put together. Whereas the case in point during the fortnight of February 26 - March 2014, was a unique event, with much wider and prolonged coverage.

The data on hailstorm occurrences for the period 1967-2011 were sourced from IMD publications for different districts. The information listed in IMD reports from 1968-1971 was either on state or regional basis, while it is available at district level for the subsequent period. From these inputs, we present here the frequency maps on annual and monthly time scales. The events which caused considerable damages were only reported in IMD publications. There could be several hail events, but went unnoticed because of their mild damaging nature or absence of the administrative/scientific infrastructure to record such phenomena. For instance, Jammu & Kashmir is one such state, where most of the terrain is uninhabitable and hence information on hailstorm frequency is very scanty.

The hailstorm data of 38 years for the period 1972 - 2011 (excluding 1977 and 1984, for which data are not available), has been used for frequency analysis (Fig 6). Though the frequency maps are prepared at the district level, it is not always necessary that the entire district gets affected due to hails. It is only to be inferred that the hailstorm event took place in the corresponding district. In most of the cases the events were very much localized. The lone exception was the recent 2014 episode; where in most part of the affected districts were engulfed.

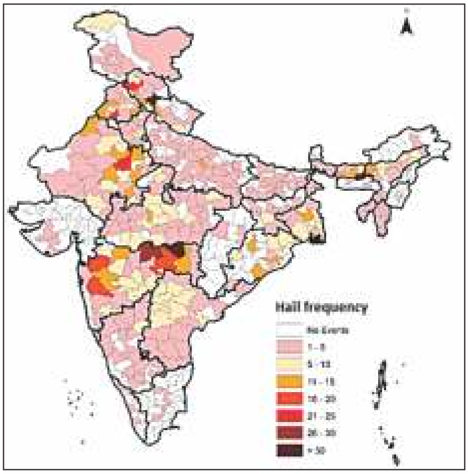


Fig 6: Spatial distribution of hail frequency over a 38 year period

The total hail frequency map indicated that more than 61 per cent of the districts have experienced at least one hail event in a 38 year period. Highest frequency is noticed over districts in the northern parts of Vidarbha region of Maharashtra that are adjoining the state of Madhya Pradesh. This is the region in Deccan plateau where the moisture laden warm winds from the Bay of Bengal and cold dry air masses descending from mid-latitudes under the influence of western disturbance converge.

The highest frequency exceeding 30 events is noticed in only three districts of India - Nagpur district of Maharashtra (40), Shimla district of Himachal Pradesh (35) and the Kamrup district of Assam (32). The frequency ranged between 25-30 in Akola and Amravati districts of Maharashtra. The severity of the damage they cause to the agriculture sector depends on the timing of the episodes and size of hail stones.

It would be interesting to compare hail events of the present (1972-2011) with those reported by earlier workers for the period 1898-1935, to understand if there are any changes in the spatial frequencies. A comparative analysis is carried out by converting the data of both the periods in to frequency for 100 years and presented in Fig 7. It can be noticed that hail events covered most of the geographical area in the recent past compared to earlier times. Apart from the changes in the weather phenomenon, growing awareness on the losses and development of communication network might have led to the differences in the frequency in both the periods.

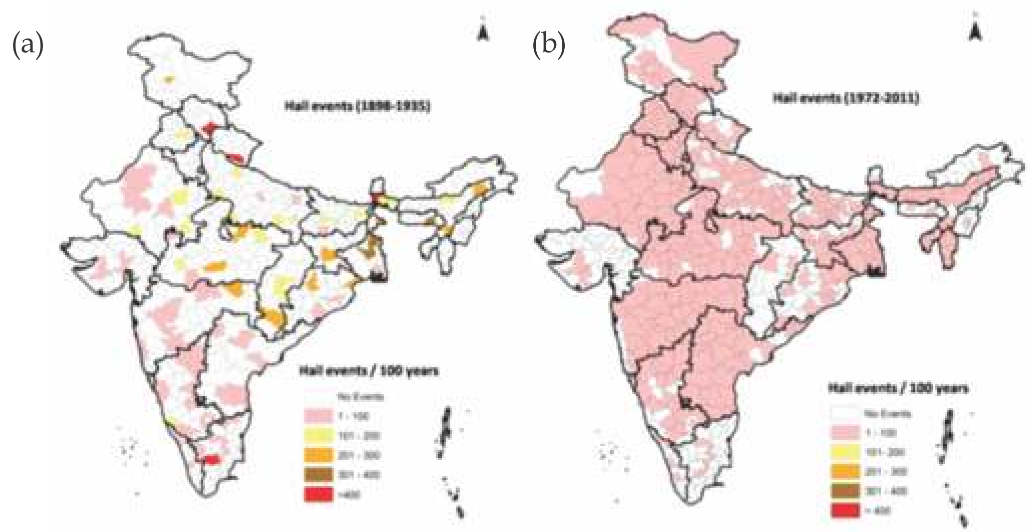


Fig 7: A comparison of hail events of (a) past (1898-1935) and (b) present (1972-2011)

The two main growing seasons for field crops in the country are *kharif* (June-October) and *rabi* (October-March/April). Generally, damages to field crops are severe if hails struck when crops are nearing maturity and in orchards during bearing to ripening. *Rabi* field crops attain a post reproductive stage by January/February and hail occurrence at this stage and beyond would cause a greater loss. Orchard crops come to bearing at different time periods depending upon the type of crop.

Understanding the frequency of hailstorms on a monthly basis would thus enable to identify sensitive districts for crop losses. Analysis of the spatial distribution of monthly hailstorm events showed that, most of the hailstorm events in India are confined to January-May period. Hailstorms are seldom noticed in July and August months during which the south west monsoon is generally vigorous and thunderstorm activity is very rare.

In the month of January, Amravati, Nagpur and Nashik in Maharashtra were the most frequent hail hit districts (Fig 8). Down south, a lone district (Raichur) in Karnataka experienced highest hailstorm events during this month. Compared to January, hail events are widespread and more frequent during February and March.

In February, Nagpur followed by Akola district in Maharashtra faced highest number of hailstorm occurrences (Fig 9). Apart from Maharashtra state, hailstorm activity was also recorded in many parts of Madhya Pradesh, Rajasthan, Punjab and Haryana. Sporadic events were also reported from Odisha, West Bengal, Bihar, Jharkhand, Uttar Pradesh, Uttaranchal, Karnataka, Assam, Mizoram and Telangana.

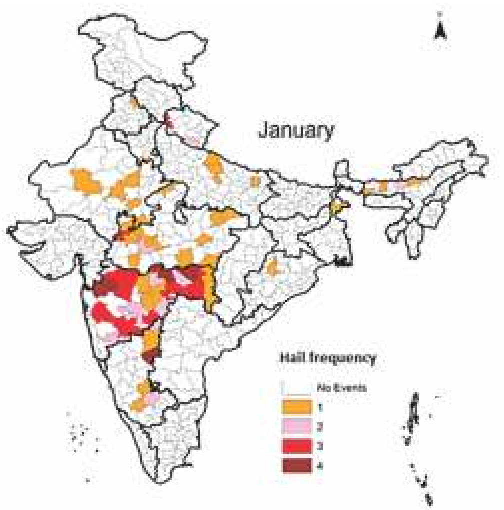


Fig 8: Spatial distribution of hail frequency during January

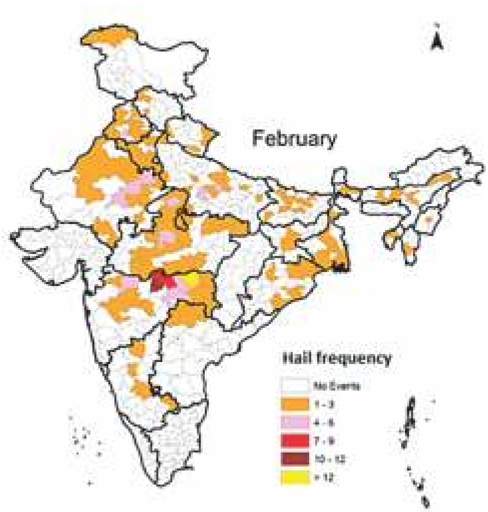


Fig 9: Spatial distribution of hail frequency during February

During March more number of districts experienced hailstorm activity with Amravati followed by Nagpur in Maharashtra and Kamrup in Assam (Fig 10). High incidences were also noticed in Wardha and Akola districts of Maharashtra and Jaipur district of Rajasthan. Most of the districts in Rajasthan, Madhya Pradesh, Maharashtra, West Bengal, Telangana and Andhra Pradesh experienced hailstorms whose frequency ranged from 1-6 over a 38 year period. In Gujarat, Tamil Nadu and except for a lone district in Kerala (Wayanad), hailstorm activity was not observed during March.

During the month of April, hail occurrences were noticed in almost all states barring Arunachal Pradesh and Gujarat (Fig 11). Most districts of Telangana and Andhra Pradesh, Himachal Pradesh, Punjab, Assam and West Bengal and the entire state of Mizoram had the experience of hailstorms. In the entire country, Kamrup district of Assam experienced highest frequency (14) of hailstorms during April. Kangra of Himachal Pradesh and Dhubri in Assam are the two other districts where the hail frequency exceeded seven. Southern parts of Telangana and Krishna district of Andhra Pradesh in southern India and Shimla of Himachal Pradesh in northern parts of the country witnessed hailstorms events exceeding six. Vidarbha, an agro ecological sub-region in Maharashtra is another area where the events were widespread.

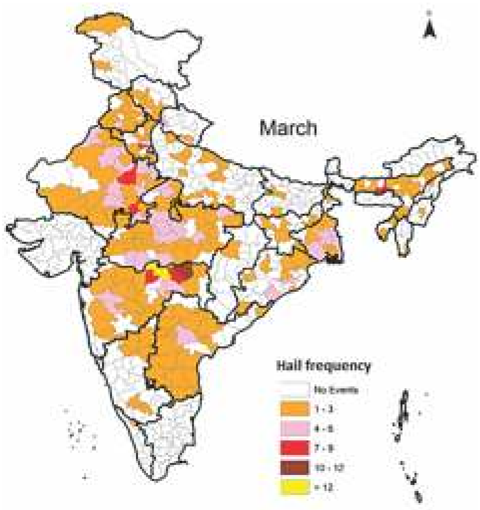


Fig 10: Spatial distribution of hail frequency during March

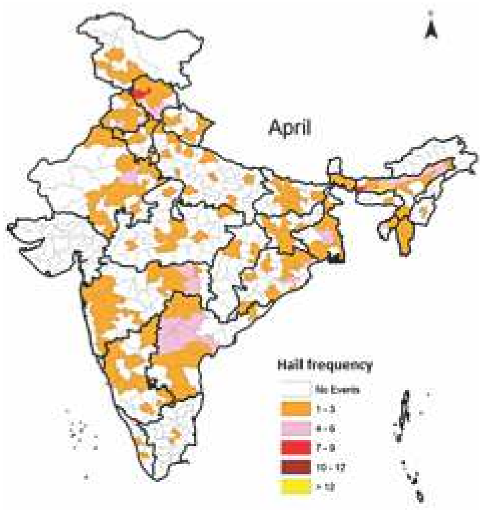


Fig 11: Spatial distribution of hail frequency during April

During the month of May, majority of the districts in Maharashtra experienced hailstorm events. Chhattisgarh, Arunachal Pradesh and Tamil Nadu (except Salem district) were free of hailstorms (Fig 12). Highest frequency (19) was recorded in the Shimla district of Himachal Pradesh followed by Kamrup (8) district in Assam and Kangra (7) in Himachal Pradesh.

In the month of June, it appears that the hailstorm activity gets subdued, with hailstorm frequency confined to very few districts with the setting in of southwest monsoon (Fig 13). Two districts in the north and north-western India *viz.,* Shimla in Himachal Pradesh and Ganganagar in Rajasthan, recorded frequency exceeding three hailstorms during June. Rajasthan and Maharashtra are the states where hailstorm frequency was relatively widespread.

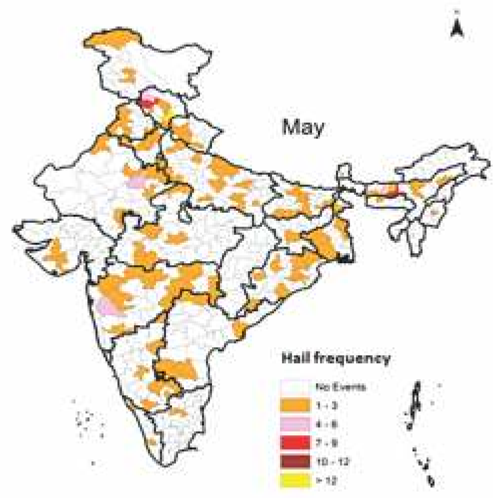


Fig 12: Spatial distribution of hail frequency during May

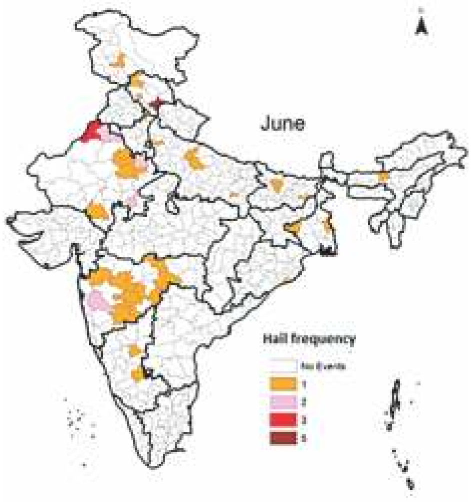


Fig 13: Spatial distribution of hail frequency during June

The months of July (Fig 14) and August are relatively hailstorm free. September is the month in which, the southwest monsoon starts withdrawing from the sub-continent. Sporadic incidences of hailstorms were noticed in this month in the country with Bhatinda and Faridkot districts in Punjab and Anantnag in Jammu & Kashmir topping the list with events exceeding two each (Fig 15).

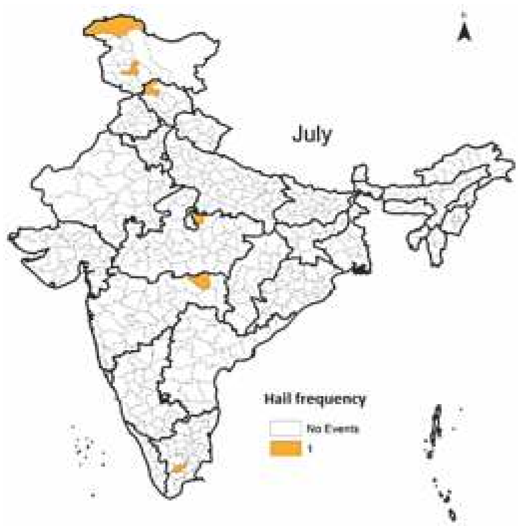


Fig 14: Spatial distribution of hail frequency during July

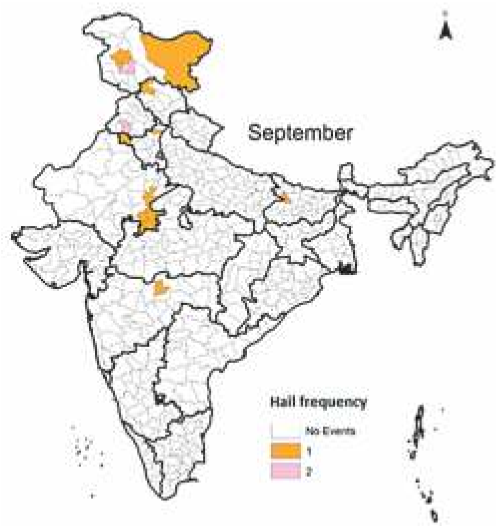


Fig 15: Spatial distribution of hail frequency during September

During the month of October, hailstorm activity was slightly more frequent and widespread compared to its preceding and succeeding months. This can be attributed to the fact that in October, with the retreat of the southwest monsoon the remnant moisture in the atmosphere and the considerable availability of solar radiation induce convective activity and cumulonimbus development.

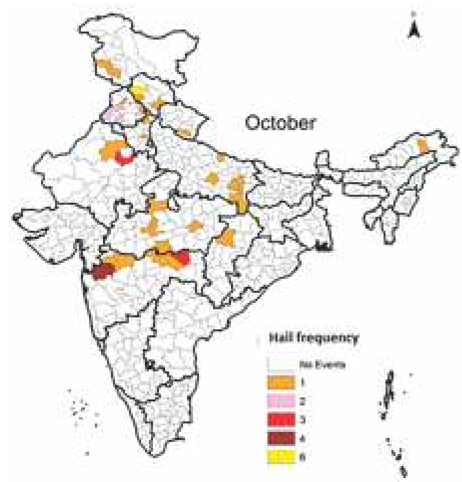


Fig 16: Spatial distribution of hail frequency during October

In November both these factors get diminished considerably. Kangra in Himachal Pradesh (6) and Nashik (4) in Maharashtra are the two districts which experienced highest frequency (>3) during October. Nagpur in Maharashtra and Sikar in Rajasthan followed the above districts with three events each (Fig 16). During the month of November also the frequency (3) was isolated with highest events noticed in Akola district of Maharashtra, followed by Azamgarh and Chandauli districts of Uttar Pradesh each with two events (Fig 17). At the end of the year, the hailstorm frequency increased and widespread.

During December, about 13 districts of Maharashtra recorded hail events with highest frequency in Dhule (4). A few districts in Rajasthan and Uttar Pradesh also experienced at least one hail event in the 38 year period during this month (Fig 18).

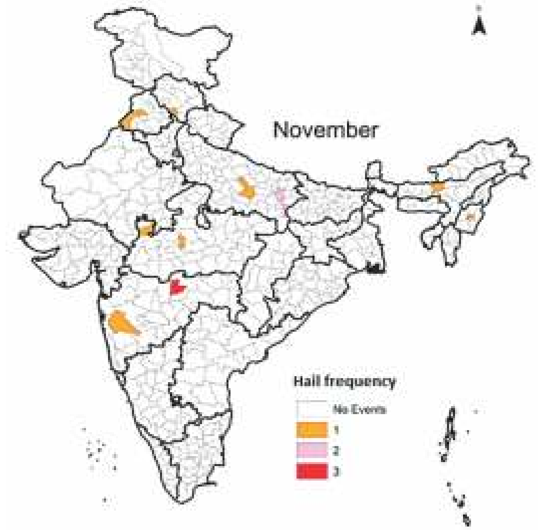


Fig 17: Spatial distribution of hail frequency during November

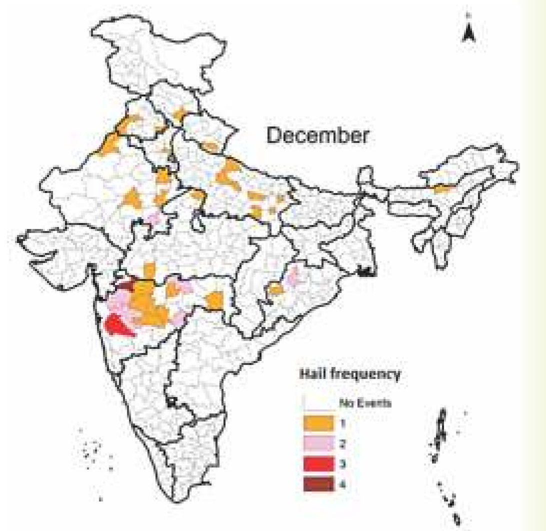


Fig 18: Spatial distribution of hail frequency during December

4.0 Hailstorms during February-March 2014 – A case study

Peasants of Maharashtra, Madhya Pradesh, Rajasthan, Haryana, Karnataka and Telangana were expecting a good *rabi* crop of 2013-14 and overcome the losses they suffered from excess rains during the August and September months of the preceding season, i.e. *kharif* 2013. However, when *rabi* crops were in maturity and ready for harvest, the weather behaved otherwise and shattered their hopes by battering the fields with hails that reached the size of a tennis ball at several places. These hailstorms were mostly associated with gales and heavy rain, but in some cases it was pure hail-fall without rainfall. The spatial distribution and severity of damage from February-March 2014 hailstorm is unknown for almost 80 years of recorded history. Reports that appeared in the media accounted for damage ranging from Rs. 10,000 to 15,000 crores, with all fields and orchard crops were put together. Apart from crop damage, loss suffered to live stock and infrastructure was also substantial. Starting from 26th February 2014, series of hailstorms struck central India and went on unabated till 15th March. Such an extended period of hailstorm or/for that matter even thunderstorm activity caught farmers and officials, and people at large, unaware and they were left clueless with this sudden development for more than a fortnight. The entire episode has brought into limelight the fragility of Indian agriculture to extreme weather situations and the agony of the affected farmers has compelled the state governments to announce immediate relief measures.

In-view of the widespread occurrence of these hailstorms and the extensive damage they have caused, the Indian Council of Agricultural Research (ICAR) felt it necessary to understand the physics of the hail phenomenon, its frequency of occurrence and spatial distribution, particularly over India, to evaluate the sensitivity of Indian agriculture to such events, to identify the currently available mitigation and adaptation strategies and finally prioritize research efforts to minimize the field level losses.

The Council first responded to the February-March 2014 hailstorm episode by immediately deputing teams of scientists from various ICAR institutes to the affected areas for having first hand information on the nature and extent of damage and to interact with the farming community. With this cue, All India Coordinated Research Project on Agrometeorology (AICRPAM) has taken the lead in addressing this problem in a positive and more realistic way. Information was sourced from different agencies, records and publications in order to document the history of hailstorm events and their effects. The following objectives were kept in view while sourcing the information; i) identify regions with high hail frequency, ii) describe the nature of damage to agriculture sector, iii) assess current knowledge of hail suppression and iv) to suggest policy actions.

Climatology is the basis for planning agricultural strategies. Similarly, knowledge of detailed climatology of the hail occurrence, quantity and size of hail, will help in planning various adaptive strategies. From such data, the hail risk under Indian conditions can be assessed. Further, cost benefit analysis can be established when this information is combined with the knowledge of the damaging potential of hail to agriculture and allied sectors. The present study may not be able to completely resolve issues related to hailstorms in India, but will surely bring the issues into sharper focus and suggest measures that can lead to better future strategies.

4.1 Regional spread of hailstorm activity

We provide here a glimpse of the impact of hailstorm occurrences in different states of the country. In Maharashtra, the extended hailstorm activity of 2014 has adversely affected most parts of Marathwada, western Maharashtra, north Maharashtra and Vidarbha. Districts like Pune, Beed, Latur, Osmanabad, Nashik, Akola, Buldhana, Nagpur, Chandrapur, Amravati, Yavatmal, Washim, Jalgaon, Nanded, Nadurbar and Dhule are among the worst hit. Large sheets of hail were formed over extensive land areas resembling snow hit areas like Kashmir (Plates 1-4). The hailstones formed into large lumps of irregular shape, in some cases weighing more than 5 kg, after reaching the ground due to agglomeration. It took several hours to 2-3 days for the hails to melt away completely. Crop canopies that came in contact with hails sustained physiological damage which has led ultimately to decay of plants. Apart from this, the crops experienced severe mechanical damage, caused due to the impact of the hails, weighing between 2g - 200g as is evident from the images collected (Plate 5).

Plate 1: Aftermath of hailstorm in a) Beed Dt., b) Hingoli Dt., and c) Baramati Dt.

Plate 2: Hail covered land forms at a) Agulgaon, Nasik Dt., b) Devatan, Nasik Dt., c) Gunthagola, Raichur Dt., d) Balloli, Bijapur Dt., and over a shade net at e) Najina Pimpalgaon, Vaijapur Taluk, Aurangabad Dt.,

Plate 3: Bed of hails at different locations in Bijapur Dt. of Karnataka

Plate 4: Sheets of hailstones on different terrains of Belgaum and Bijapur Districts, Karnataka

In view of the rarity of the hailstorm events on such a large scale, there has not been a methodical and scientific documentation of the past or the present hailstorm events. We do not have information of hailstone weight or size. The impact due to hail stones was so severe that temporary or even permanent structures on the farms and in some village locations got destroyed (Plate 6). Farm workers and public sustained wounds as they were caught unaware due to the timing of the events and very short

Plate 5: Lumps of hailstones formed due to agglomeration on reaching ground near Nagpur, Maharashtra

time allowed to take any shelter. Damage to the infrastructure has added vows to the already grieved peasants. On many occasions, hailstorms were associated with gales which have compounded the physical impact of the storms. High speed winds broke open not only the twigs, branches of the well established orchards, but also electrical poles were twisted and in some instances even got uprooted.


Plate 6: Damages to on-and off - farm infrastructure due to hailstorms at various locations

4.2 Hailstorms and associated atmospheric conditions - 2014

Hailstorms that struck central India in the fourth week of February were initially considered as a one-off phenomenon, but they continued for almost two to three weeks. The synoptic conditions that led to the continued activity of hailstorms in 2014 as observed by the Bijapur center of AICRPAM, and used to subsequently forewarn the client farmers regarding further prospects of thunder shower during the period, are detailed below.

The incessant flow of atmospheric water vapour prevailed in the lower troposphere peninsular India from southwest to northeast (from Arabian Sea / Indian Ocean to north of Bengal) and from West Asia through Maharashtra-Odisha belt alternately since mid February in the lower/mid troposphere. Coupled with this, multiple atmospheric systems formed and moved across Gujarat, Odisha, Chhattisgarh and south of the Indian peninsula. These, along with the occasional southward shifting of western disturbances, resulting due to protrusion of extra-tropical cyclones well inside the tropical belt, resulted in frontal activity. Prevalence of water vapour at lower temperatures moving across the warm dry air and further interaction with another warmer moisture air belt - all combined resulted in instability in the lower troposphere over western and central India as well as over the Indian peninsula for nearly 20 days during 25th February to 15th March 2014. Continuous moisture availability over one region and excessive heating over the adjacent region combined to create extreme convection and thunderstorm activity, thereby causing heavy rainfall, squally winds and ultimately hailstorms.

We present here three sets of satellite images (Image 1, 2 & 3). Image 1 is of water vapour, downloaded from the Dundee website 'www.sat.dundee.ac.uk'. Image 2 and 3 are Infrared images of cloud pictures from the *eumetsat* website 'oiswww.eumetsat.org'. The downloaded images were edited for contrast and mid-tone adjustments using the MS Office Picture Manager. These are examples of how AICRPAM visualized the occurrence of hailstorms this year.

Image 1 is a clear example of how a small water vapour vortex can create havoc under favourable conditions. The red circle over north Arabian Sea shows influx of moisture into the small vortex situated just above the circle. One could see, with the progress of time, how the sweeping action of the vortex tried to push the large southwest-northeast water vapour flux. In between these two systems, the heated dry air over central India pushes the moisture further up forcefully developing into thunderstorms. The combination of these dynamics caused a sort of “traffic jam” over central Indian upper atmosphere. Even though regular thunderstorm activities do cause hailstorms, they are only isolated, and are caused mostly by the local up-liftment of moist air from ground level. These generally get unnoticed if they do not cause damage. However, in this present case, the convection took place from the ground, but the large amount of water vapour already available with cooler temperature in the upper levels, which made it easier for condensation, super-cooling and sublimation, thereby converting to large sized ice crystals and subsequently falling down as hailstones. This simple, non-mathematical explanation provides a clear understanding of the process involved. This may not be sufficient for forecasting and forewarning of hailstorm events as such, but certainly helpful in at least advising of thunderstorm activity in more area-specific manner. It has helped in the forecasting of rainfall associated with thunderstorm activity every day during the period 4-10 March 2014 in north Karnataka by AICRPAM Bijapur, and advising the contact farmers accordingly to complete the field activities before evening and to protect their crop produce during night time.

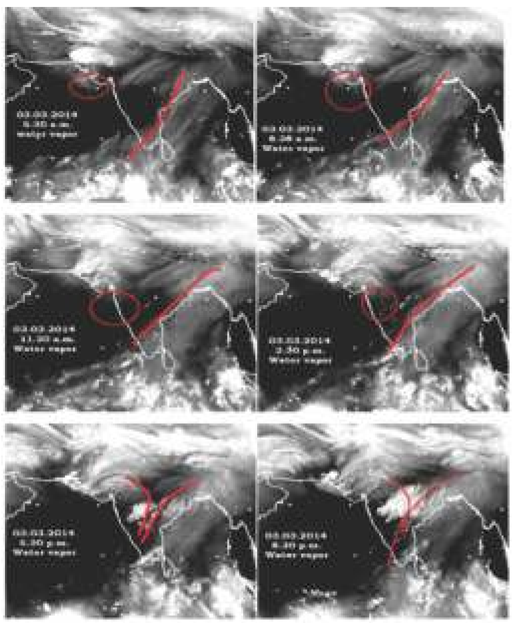


Image 1: Process of frontal activity leading to hailstorm as seen from satellite images

From Images 2 and 3 we could clearly identify the areas where hail storms have occurred in different parts of India for the respective days and time mentioned on the images.

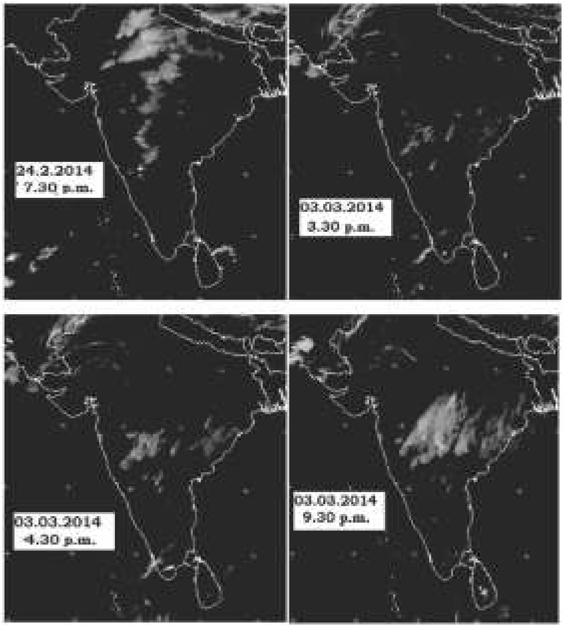


Image 2: Zeroing in on hailstorm locations on 26th February and 3rd March 2014

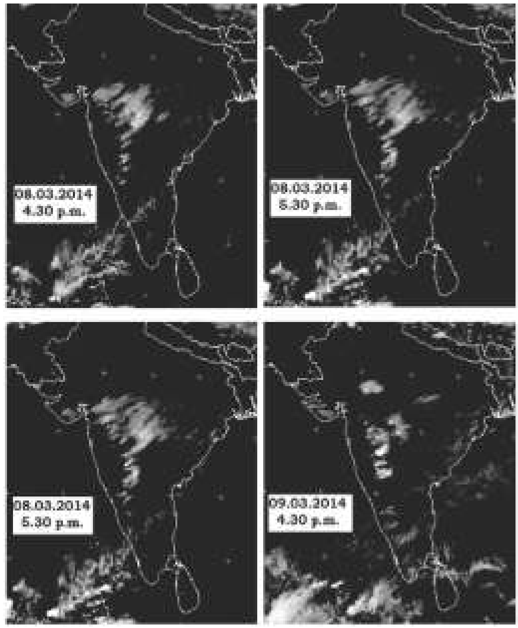


Image 3: Zeroing in on hailstorm locations on 8th and 9th March 2014

An important feature of these images is that, the areas were hailstorms occurred lie in the low moisture zone over central parts of India rather than the high moisture zone in the east and west indicated in Image 1, making it clear that not just the airmass advection resulting in frontal systems, but also intense convective activity has played an important role in the development of the hailstorms. The unstable atmosphere in the central parts of India, while rising upwards seems to have drawn water vapour from the neighbouring west and east for quick development of cumulonimbus and heavy ice crystal formation in the upper, colder parts of the cloud masses. These examples show the utility of satellite imageries in not only understanding role of the atmospheric events that prevailed during the hailstorm period of late February to mid March 2014, but also in forewarning of thunderstorm activity during 4-10 March 2014. We are sure; this knowledge can be helpful in preparing to face such exigencies in future.

4.3 Impact of hailstorms and damages to agriculture in different parts of the country

All the crops existing in the field were devastated in Madhya Pradesh. Heavy rains accompanied by hailstorm lashed parts of Malwa and Mahakoshal regions of the state and caused extensive damage to wheat and gram. The districts where these crops suffered considerable damage are Seoni, Chhindwara, Burhanpur, Dewas, Shajapur, Jhabua, Vidisha, Indore, Neemuch, Raisen, Balaghat, Hoshangabad, Sagar, Sehore, Betul, Katni and Bhopal. Husk on the maize cobs was torn apart on standing plants and subsequent wetting led to *in situ* sprouting; stems were broken; maize plants were dislodged at several places (Plate 7 & 8); wheat grains were shattered; chickpea pods and seeds were shattered (Plate 9); wheat plants got dislodged (Plate 10); linseed pods got detached and plants dislodged; mustard and linseed plants got dislodged with shattered pods (Plate 11). In areas where the crops like wheat and chickpea were in the grain filling stage, the physical impact of hail stones has turned the fields yellow; grains discoloured and ill-filled. Dislodging has also resulted in poor quality of the produce in wheat.

Plate 7: Dislodged a) maize with b) damaged husk at Warangal, Telangana and at c) Akola, MS; d) Dislodged sorghum at Akola, MS

Plate 8: Dislodged and Damaged maize fields at (a) & (b) Sholapur; (c) & (d) Savali, Buldhana Dt.

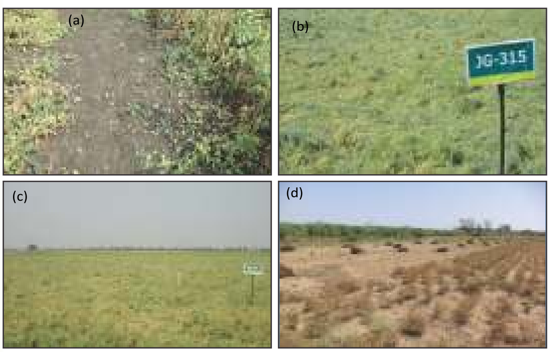


Plate 9: Chickpea at Hisar with (a) pods shattered; (b)& (c) crop turned yellow and (d) at Sholapur post harvest losses

Plate 10: Wheat- partial dislodging (a) to (c) at Jabalpur; complete dislodging (d) at Rajasmand

The damages to orchards and fruit crops were colossal. In mango (Plate 12), guava, pomegranate (Plate 13), sweet orange, lime orchards (Plate 14 & 15) and ber (Plate 16), fruits got detached and fell to the ground due to the impact of hail stones. Hail impact and dropping damage could be noticed distinctly on the fruits, and it has led to their poor marketability. Famers realized very low prices because of both quality losses as well as a sudden glut in the local markets.

Plate 11: Hail hit (a) & (b) linseed at Jabalpur; (c) & (d) mustard at Hisar

Plate 12: Partially matured mango fruits (a)&(b) at Bijapur ; developing fruits (c) & (d) at Jabalpur got damaged and detached

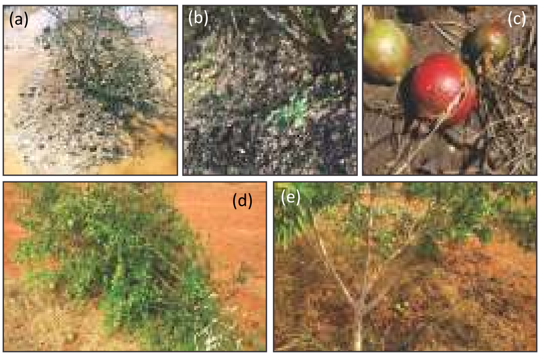


Plate 13: Pomegranate orchards damaged (a) to (c) at Akola; (d) at Anantapur and (e) guava at Anantapur

Plate 14: Damaged sweet orange and lime orchards at Akola

Plate 15: Damaged sweet orange at Akola

Plate 16: Damaged ber orchard in (a) Jind; and Banana in (b) Baramati; (c) to (d) Akola districts

Hails with gales has uprooted entire trees, broke open the twigs, branches and made lesions on the bark of the trunks of perennial orchards at several locations. Grape gardens were the most hit among the fruits. Vines were uprooted with their staking badly damaged. Fruit bunches mostly got detached and those intact with the vines were spoiled. Hail events coincided with the harvesting time of grapes and there was hardly any garden that got escaped in the hail hit areas (Plate 17 & 18). Costs involved in reviving these well established orchards need to be considered in enumerating the losses suffered due to the hailstorms.

Plate 17: Grapevine damaged in Aurangabad district

Seasonal fruits like banana (Plate 16), watermelon and papaya could not escape from the hail damage. Banana plantations were uprooted over extensive areas and fruits were damaged on the bunches (Plate 18 and 19). Papaya plantations were battered with their tops almost lost and visible lesions on the immature fruits were a common sight (Plate 20). Watermelon fields were another casualty to the hailstorms. Watermelon vines came into direct contact with hails leaving the fruits immature and lesions formed on the fruits making them unmarketable (Plate 21).

Plate 18: Grapevines damaged in (a)&(b) Akola; (c) Bijapur; (d) Bagalkot; (e) Aurangabad and (f) Beed districts

Plate 19: Banana plantations damaged in (a)&(b) Akola; (c) Parbhani and (d) Solapur districts

Plate 20: Perished papaya plantations with damaged fruits in (a) Akola; (b); Bijapur and (c) to (e) Solapur districts

Plate 21: Damaged vines and fruits of watermelon in (a) Warangal; (b) & (c) Akola and (d) & (e) Bijapur districts

Vegetables like tomato, cabbage, pepper and bell pepper that were about to be marketed, were caught in the melee of hailstorms. Tomato fruits fell to the ground and lesions were deep. Staking to the tomato got disrupted and was broken at many places. On the bell pepper also, lesions were deep enough to make their marketing worthless. Cabbage leaves were torn apart, leaving no chance for the head to form (Plate 22).

Plate 22: Vegetables like tomato, bell pepper and cabbage bore the brunt of hailstones in (a) Warangal; (b) Akola; (c) Parbhani and (d) Jabalpur districts

Livestock, mostly cattle and sheep, grazing in the open became the first victims of the hailstorms. Those animals which could take shelter under trees survived, but with grave wounds (Plate 23). Hails did not leave even stall-fed animals as the roof of the structures gave in due to the impact of the hails. Poultry sector was another allied sector that was badly hit. Birds housed in temporary or semi-temporary sheds were the first casualty.

The devastations described above suggest the need for a thorough understanding on the formation and occurrences of hailstorms.

Plate 23: Lethal damage to (a) - (c) poultry in Anantapur; (d) sheep flock in Bijapur and wounds sustained on milch animals in (e)Akola & (f)Parbhani

5.0 Hailstorm forecasting in India

Hail can be detected using Doppler radar. Doppler radar emits beams (pulses) of microwave energy from a transmitter into the atmosphere. When these beams collide with objects in the atmosphere such as rain drops, hail stones, snowflakes, cloud droplets some of the energy bounces back towards the radar. A receiver on the radar, then collects the reflected energy (echo). Reflectivity measurements from properly calibrated radar are used as an objective technique for identifying hail (Fig 19). An echo, whose top is higher than the tropopause has a high probability of containing hail. By considering both echo height and intensity, the radar is being used with a high degree of success to identify thunderstorms containing hail.

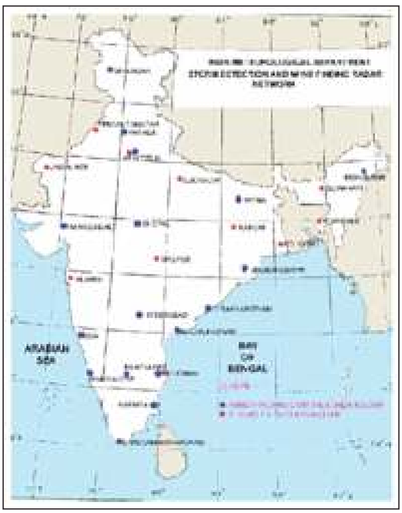


Fig 19: Storm Detection and Multi-Met Radar network

The current state of IMD's hailstorm forecasting capabilities is detailed here. Apart from 630+ surface weather observatories, IMD is currently operating a network of 44 radars. Of these, 10 are the S-band type used for cyclone detection, 29 are the X-band type used for storm detection and dual purpose (weather-cum-wind) and 5 doppler weather radars. IMD is planning to install 14 more S-band, doppler weather radars at Bhuj, Kochi, Mumbai, Paradip, Nagpur, Patna, Lucknow, Patiala, Karaikal, Bhopal, Agartala, Mohanbari, Delhi and Goa.

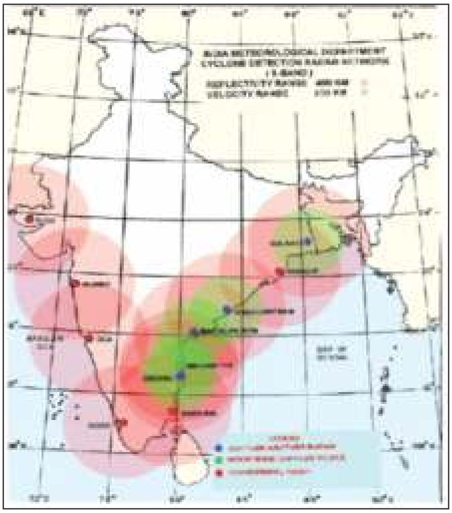


Fig 20: Cyclone Detection Weather Network

The effective range of X-band radar is 250 km and for S-band it is 400 km (Fig 20). One could see the overlapping nature of effective areas of radars on the east and west coast. However, there lies an area uncovered in the central region of India, where the hail frequency is relatively high. With the plans of commissioning 14 new radars afoot, it is expected that entire sub-continent will be covered by the envisaged IMD radar network.

6.0 Recording of hail events and size of hailstones

As vulnerability of different sectors including agriculture to hail damage is increasing, recording of not only the event but ancillary data like size of hailstones, density over unit area, nature and type of damage caused is gaining prominence. As hailstones melt away quickly, time at the disposal of the observer is governed by ambient temperature. Size of hailstones can be recorded by hail-pads in unmanned stations or in remote areas. Hail-pads can be kept in open as shown in Fig 21, and size of the hailstones can be measured from the impressions made on the hail-pads. Size of the hailstones can be measured with the help of foot-scale, metallic or cloth tape or Vernier calliper or by comparing with a known object like coins, tennis ball etc., as shown in Fig 22. It is always advisable to take a visual of the hailstone as well as damage. The

Fig 21 : Measurement of hail size using hail-pads

Fig 22: Different approaches to record the size of individual hailstone

number of hailstones per unit area may also be recorded and visuals taken. This helps in damage assessment and development of insurance products. In the absence of hail-pads or measuring devises, the size of individual hailstones can also be recorded by measuring out the water after the hailstone gets melted with a measuring cylinder.

7.0 Hailstorm control and preventive measures

Attempts have been made for many years and in diverse ways globally to minimize the damages of hail. With the discovery of the artificial formation of ice crystals after the World War-II and the subsequent developments in understanding cloud physics, innumerable attempts have been made to suppress this hail formation with varied success. Broadly the damage by hail can be minimized in two ways - both being the preventive actions; a) by suppressing the formation or reducing the hail size through cloud seeding, b) protective measures to minimize damage.

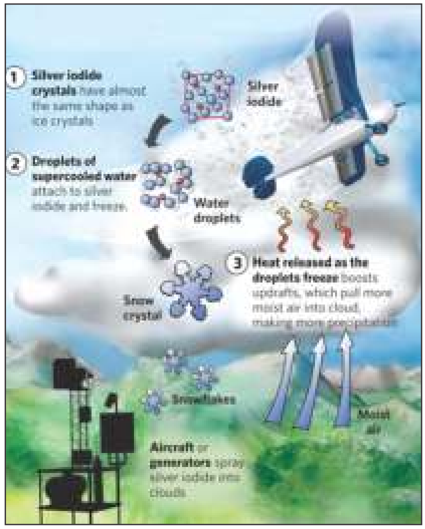


Fig 23: Concept behind hail suppression by seeding

The concept behind hail suppression is to inject a high enough concentration of ice nuclei (usually silver iodide), prevents them to get sufficiently big to enable them to fall downward (Fig 23).

In other words, the available amount of moisture in the cloud environment needs to be distributed among many more hailstones, and hence their growth is curtailed, thereby leading to even melting before they reach the ground. Even if they did not melt completely to form rain, by the time the hailstones reach the ground they would be too small to cause any serious damage. The material generally used for the increase of the embryos is silver iodide (AgI), which is first being evaporated and then quenched, forcing its molecules to form big quantities of microscopic particles (1019 particles/kg of AgI).

The success of hail suppression depends largely on two aspects; i) detection of hail-forming clouds with sufficient accuracy as well as with enough lead time to carry out cloud seeding and ii) placement of seeding material in the right quantities and at the right place.

7.1 Problems in cloud detection

Considering the time elapsed from the formation of the hailstorm and its dissipation which is hardly 30 minutes, a highly efficient weather monitoring system is required. Radars are generally used to detect this small scale weather phenomena.

Atlas and Ludlam (1961) first proposed that the magnitude of the simple ratio of radar echo powers from one pulse volume at two wavelengths might indicate the presence or absence of hail. Sulakvelidge (1974) claimed much success later based on this technique. In the earlier studies, a dual-wavelength radar with 10 cm and 3 cm wavelengths was used. The ratio of the each power (P) received from a pulse volume from the 10 and 3 cm wavelengths was considered as an indication of the presence or absence of hail. If the ratio is unity, rain only is present. If the ratio is greater than unity, then hail is present (with or without rain). Recent efforts to use satellite data to detect hail forming clouds are encouraging (Cecil, 2009; Sharma and Dutta, 2012) but the technology appears pre-mature for field application.

7.2 Placement of seeding material

Once the hail forming cloud and a portion of it is detected, the tasks that would follow are estimating the quantity of seeding material and ways to release this material at the targeted place in the cumulonimbus cloud. Attempts made in the past with ground based generators, cannons, mini-rockets and ground based hail guns have met with success of varying degrees. These were started on a commercial scale as early as 1956 in the USA and then in several countries like Kenya (1968-1975), South Africa (1973-1977), Australia (1961-1966), Bulgaria (1972-1978), Hungary (1976-1982), France (1965-1982), Greece (1981-1985), Spain (1979-1983) and in USSR (1968-1984).

Seeding was carried out at heights of 4-6 km with anti-hail shells, 100 mm in calibre, weighing about 12 kg and containing about 1.6 kg of explosive mixed with 1-5% of Silver Iodide. In another study, anti-hail rockets 'Oblako' made of plastic material, 125 mm in calibre and about 2 m long, weighing 33 kg were used (Fig 24). The rocket carried a payload of 5.2 kg pyrotechnic cartridge. These rockets were fired from a stationary launching van releasing the seeding material in the cloud up to a height of 8 km. In the erstwhile USSR, anti-hail rockets called 'PGIM' were used. They weighed about 3 kg, with a 82 mm calibre, 50 cm long and carried a payload of 170 g silver iodide was released in the altitude range of 1.5 to 2 km. These rockets were made of plastic material and totally self-destroying. The earlier claims made by Russian scientists in hail reduction ranged from 50-80%, depending upon the area and severity

Fig 24: Anti hail rockets being fired from ground launcher

of storms. However, randomised experiments have not so far demonstrated a significant seeding effect. It is worthwhile to quote the statement of the World Meteorological Organization (WMO, 1986) here ***"the requisite combination of physical and statistical evidence of hail suppression is lacking".***

Ground based radar or sensors fitted to an aircraft first detect the appropriate cloud that is to be seeded. Aircraft makes several passes to collect data and analyse cloud characteristics to determine the amount of seeding material to be released. Once this is accomplished, seeding material (mostly silver iodide) is released by burning the flares fitted to the aircraft (Fig 25).

Fig 25: Flaring ejectors fitted to aircrafts releasing seeding material

In India most cloud seeding experiments have been confined to increase rainfall, but not suppression of precipitation. As such the only work relating to hail suppression on a scientific basis was undertaken in the year 2010 by the government of Himachal Pradesh, which attempted using ground based anti-hail guns. These experiments were based on the high success rate claimed initially in the early 1970s, even though either on the field, laboratory or modelling tests a plausible theory could not be established yet for anti-hail guns (List 1963; Mezeix et. al., 1974; Huang *et.al.,* 1981; Dessens, 1985). The experimentation in Himachal Pradesh ran for 2 years and was discontinued in the year 2013. The experience gained from this experiment is discussed at length in the succeeding section.

7.3 Preliminary assessment of hail control system (HCS) in Himachal Pradesh

Fig 26: A hail control system in operation

The Himachal Pradesh state government originally planned to install 300 HCS (Fig 26) also called as anti-hail guns in the state at a total cost of Rs. 374 crores. Three anti-hail guns were installed for pilot testing at selected sites *viz.,* Deorighat, Kathasu, and Bareonghat in Shimla district of Himachal Pradesh with one central RADAR in the year 2010. This experimentation was carried out with a central government funding of Rs. 3.29 crores. The HCS, according to the manufacturer, works on the principle of creating an explosive charge of acetylene gas in a chamber. The resulting energy passes through the neck then into the cone and develops into a force that becomes a shock wave. This shock wave then travels at the speed of sound through the cloud formation above, a disturbance claimed by the manufacturer of HCS that disrupts the growth phase of hail storms (Fig 27). The efficacy of HCS, still a matter under debate, mainly depends on timely identification of hail forming clouds before hails commence. Given the state of technology at present, the detection of hail forming clouds well in advance is a Herculean task, especially with simple radars like the one

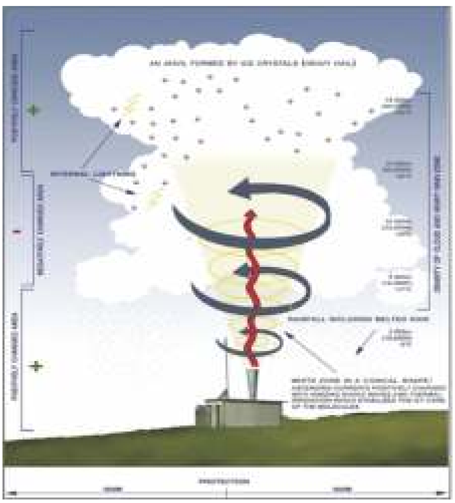


Fig 27: Mechanism of hail suppression by anti-hail guns

supplied with HCS. The claim of the HCS manufacturer to the extent of the area protected is only 80-90 hectare for one HCS. The state government constituted a high level expert committee to evaluate the efficacy of HCS. The committee did not find scientific evidence for use of HCS in hail suppression for Himachal Pradesh climatic conditions. Based on the committee's recommendations, the state government has stopped the use of the three HCS and eventually increased the farm subsidy on anti-hail nets from Rs. 25,000 to Rs. 50,000.

8.0 Protective measures to minimize losses due to hail damage

The impact of hail damage can be minimized in two ways; one is preventing physically (hail abatement) and the other on the economic front. In the hail abatement, physical barriers such as hail nets or other protective screens can be used to intercept the incoming hailstones. Usefulness of hail nets in protecting the apple orchards in Himachal Pradesh is the best example for this type of protection (Fig 28). The durability and effectiveness of these nets are directly proportional to the quality of material used in their making. The material used for erecting shade nets may sustain the impact of small sized hails. Apart from Himachal Pradesh, this type of nets can be tried in most hail sensitive districts. In high value orchard crops like pomegranate, grapes and to some extent in sweet orange and in vegetables like bell pepper they look promising. Micro-climatic affects of the cover and its lasting properties would need to be considered and in evaluating the merits of such screens. Prior to their large scale adaption, their cost effectiveness needs to be assessed. Hail abatement can also be accomplished through planting trees in areas where hail incidence is frequently associated with strong winds. This can have three types of 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 on the leeward side is partially 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 speeds, will be less. If the most predominant wind

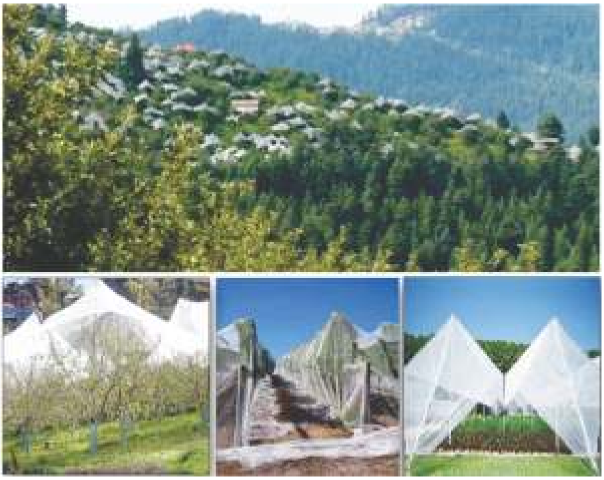


Fig 28: A range of anti-hail nets used to protect orchards in India

direction of the place is known then shelter belts can be planted perpendicular to this direction to reduce crop damage (Vento and Malossini, 1982). The wind direction and estimated speed during hailstorms are additional information that should be included in developing local hail climatologies.

8.1 Change in land use

Another way of abatement of hailstorm in regions with high frequency is to grow those crops that are less subject to hail damage. In the majority of hail prone districts in India, two or more crops can be grown successfully, but increased net returns from some crops might have favoured more area to come under their cultivation. For instance, in the state of Maharashtra, the area under fruit crops increased steadily from 2.42 lakh ha in 1990 to 15.74 lakh ha by 2008. In some of these predominant horticultural areas, which are often subjected to extreme hail damage, wheat or other crops could be grown instead of fruit crops that are more susceptible to hail. This alternative approach is again limited by physical factors like soil, rainfall and temperature apart from differential net returns and farmers choice.

8.2 Risk management

Another approach to minimize the hail losses to the farmers is through insurance. Insurance is the most widely used adjustment tool on the economic front to crops and property damages due to hail. Various levels of coverage and types of policies are to be made available to farmers at affordable premium rates. In India, the Agricultural Insurance Company (AIC) of India insures against hail damage with add-on premium. Insurers in India may develop products that cover three categories of probability of hail occurrence *viz.*, high, moderate and low. But, the insurance companies operating in India are mostly constrained in developing appropriate products due to lack of data on hail frequency, crop damage etc. Hence, maintaining a systematic record of hail and its damage becomes a pre-requisite for all stakeholders including insurers. This would also provide some guidance for carrying out any hail suppression effort. Since hailstorms are very localized events, sometimes confining to very small spatial scales, providing insurance to individual farmers may become a better option under Indian conditions. In such a scenario, a mechanism has to be developed to inform the insuring agencies on the calamity without loosing time so that, the loss assessment can be made on a realistic basis and claims can be settled within reasonable time.

In order to save the crops as well as valuable lives, forecasting of impending hailstorms with sufficient lead period is very much vital. Since, time taken between the formation of a cumulonimbus cloud and its dissipation is generally not more than a couple of hours, the accuracy of forecasting must be very high. Even though with better forecast and warning systems, the range of protective options available to the farmers are quite limited. Emphasis should be laid on accurate forecast of the hailstorms for small areas. Compared to minimization of crop losses, damages to property and livestock can be avoided to some extent and damages to the human lives can be totally avoided with an effective forecasting. IMD is the nodal agency responsible for issuing weather forecasts that include hailstorms.

9.0 Management options in the event of hailstorm occurrence

Top most priority may be given to save the human lives followed by livestock in the event of a hailstorm forecast. Avoiding damage to the infrastructure, including vehicles and other farm machinery/equipment may be taken up given enough time for the commencement of the hail-fall. Undoubtedly agriculture is the main stakeholder in India gets affected due to hailstorms.

In the event of a hailstorm damage to field and horticultural crops, actions to be resorted are mostly crop and area specific. If the hail event is associated with heavy rainfall, farmers are advised to drain out excess water from standing fields either through land modifications or pumping out the water. Drained water may be collected in farm ponds, if feasible. As a compensatory mechanism for the production losses due to hail damages, the possibilities of making best and timely use of available *in-situ* soil moisture and surface water (stagnated) to be explored for raising short duration crops including forages and vegetables. Early sowing of greengram/blackgram is better with seed treatment/zero-till sowing after paraquat/glyphosate application.

9.1 Some measures for field crops

9.1.1 Maize/Sorghum:

Open trenches to drain out excess water from the field. Apply Dithane M-45 @ 0.2% on ear heads immediately after cessation of rains. If these crops are at harvesting stage, harvest mature cobs immediately and dry to avoid fungal growth. If they are at dough stage, earthing up may be carried out. Store the grain/cobs and fodder after proper drying for 4-5 days.

9.1.2 Sugarcane:

If the cane is in grand growth phase and lodged, drain off excess water, lift the lodged canes and prop up. Earthing up may be done and a booster dose of fertilizer @ 50 kg urea and 50 kg MOP /ha may be applied.

9.1.3 Cotton:

Open field channels to drain excess water and avoid surface ponding. Incessant rains may trigger grey mildew incidence and foliar spray with sulphur @ 25 g/10 litre water may be carried out to prevent its incidence. Spray with carbendazim @ 0.1% immediately after cessation of rains to protect against boll rot. Carry out timely picking of cotton and avoid drenching and soiling. Store it in a safe place after drying, if it gets wet due to rain.

9.2 Horticultural crops

In the first instance, drain the stagnated water and strengthen the field bunds. Resort to field sanitation after the event by moving detached fruit and other plant parts to avoid disease infestation. As a blanket recommendation, it is recommended to apply growth regulators to induce vegetative growth and apply additional dose of fertilizers at optimum soil moisture condition.

For those orchards that are in the flowering stage, remove damaged parts and apply one fungicidal spray. To prevent flower drop, spray with NAA @ 20 ppm + 1 % urea. For bearing orchards, where the trees have partially fallen or touching the ground, provide mechanical support. Completely damaged banana and papaya should be uprooted and new plantation should be done. Uprooted plants of mango, pomegranate and acid limes may be replanted. Damaged branches of mango, pomegranate, acid lime should be pruned and preventive measures be taken against infection by pathogens by application of fungicides. Collect the fallen fruits, grade them after washing, apply wax and market it as quickly as possible.

9.2.1 Mango

Spray potassium nitrate @ 1.0% to arrest flower and fruit drop. If cloudy conditions persist after the hail occurrence, orchards may be sprayed with fipronil (5% EC) @ 1.5 ml/litre or spinosad (45% SC) @ 0.3 ml/litre to control hoppers and thrips and hexaconazole @1.0 ml/litre to control powdery mildew disease.

9.2.2 Banana

At the time of damage if the fruit bunch is beyond three quarters maturity, harvest and market it as soon as possible. At other stages prune severely damaged leaves up to base of petiole. Apply booster dose of urea and MOP to partially damaged orchards. Spray potassium sulphate (5g/litre water) and urea (10g/litre water) solution on plants with newly emerged fruit bunches. Spray mancozeb @ 2.5 g/litre or carbendazim @ 1.0 g/litre of water on leaves and pseudo-stems and developing fruits to avoid secondary infection. In areas with high hail frequency, cover the fruit bunches with polypropylene bags or dried banana leaves to avoid direct exposure to hailstones.

9.2.3 Pomegranate

Spray Bordeaux mixture (1.0%) or copper oxychloride (@ 2.5 g/litre of water) on the damaged parts to avoid oily spot/ bacterial blight incidence. If warm and humid conditions prevail even after one week of hail occurrence, spray Bromopal @ 2.5 g/litre. Prune the half broken and damaged branches and apply NPK @ 250-300 g/tree at optimum soil moisture conditions.

9.3 Vegetables

Drain out excess water from the fields. In hailstorm damaged fields of tomato, spray 1% potassium nitrate. Apply copper fungicides if fungal/bacterial diseases are noticed. In case of onion, apply fungicide and micro nutrient sprays to rejuvenate the affected crop. If watermelon fields are partially damaged, fruit fly traps may be installed @ 10/ha.

9.4 Research initiative at ICAR-NIASM, Baramati

Research initiatives taken up at National Institute of Abiotic Stress Management (NIASM), Baramati, post February-March 2014 episode resulted in encouraging management options (Bal *et al*., 2014). Some success examples are listed here. Pruning, removal of broken twigs and fertigation through drip helped to recover custard apple orchard (Plate 24).

If the damage to the individual maize cobs was less than 20%, drenching them in salicylic acid and urea solution improved the grain weight (Plate 25).

In brinjal crop, cutting management (at 10-15 cm above ground level) and sprays of bioregulator (thiourea) and KNO_3 helped in fast recovery of indeterminate crop that was severely damaged with hail. The plant vigour and number of fruits increased (Plate 26).

Secondary infection was prevented by spraying copper oxychloride one day after hail storm in badly damaged pomegranate plants. Plants that were treated with cytozyme (100 ppm), vigore (0.1%), thiourea (0.02%), potassium nitrate (2%), hydrogen cyanamide (0.02%), silixol (4ml/litre), C7 (a bio-formulation that prevents fungal infection and stimulates growth) helped in recovery of plants to original level in about a month's period (Plate 27).

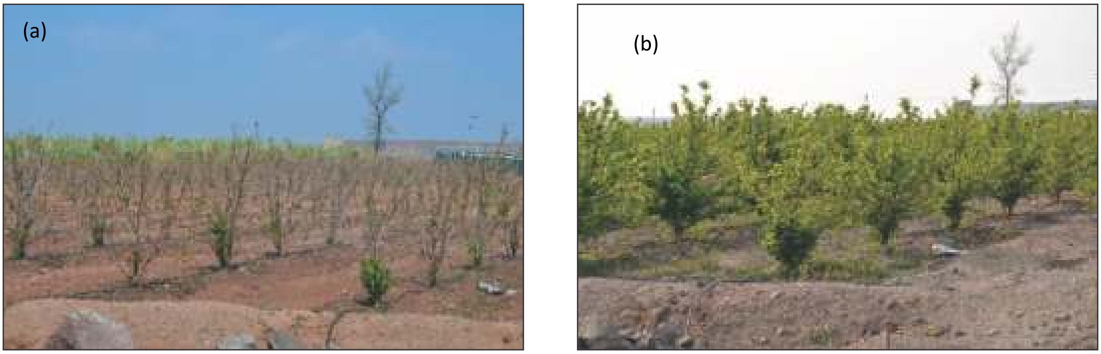


Plate 24: Custard apple (a) day after and (b) 27 days after hailstorm

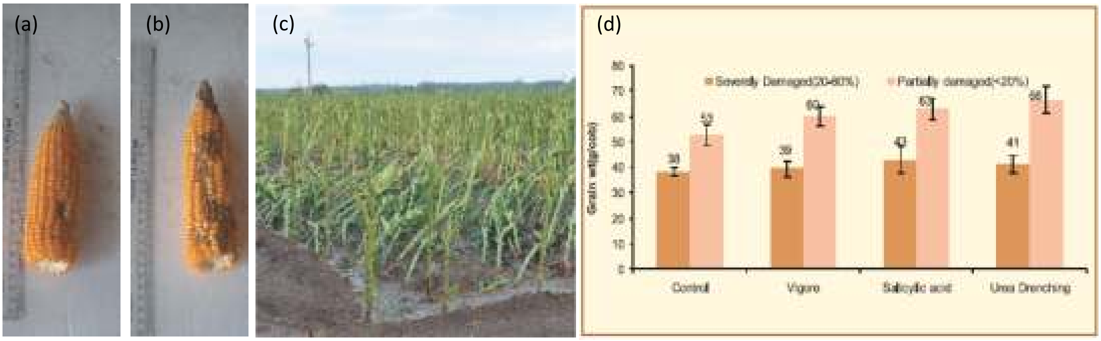


Plate 25: Effect of bio regulators on grain/cob weight of maize affected by hail storm; (a) < 20% damage (b) 20-80% damage (c) maize field after hail storm and (d) effect of growth regulators

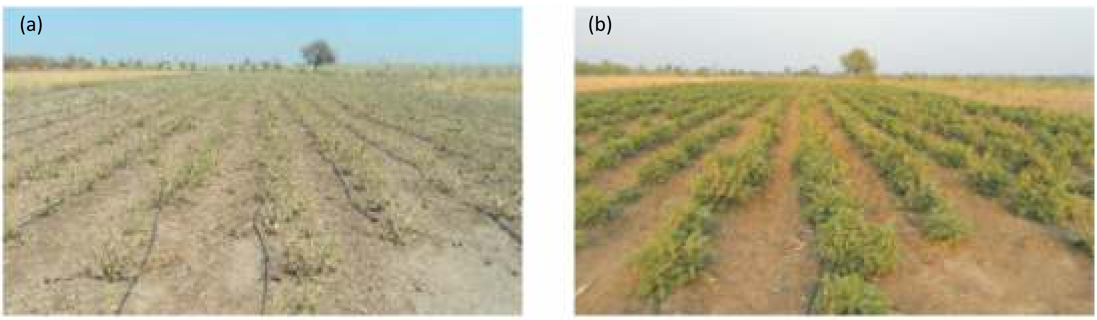


Plate 26: Brinjal crop (a) damaged by hailstorm and (b) post-hailstorm recovery of crop growth after 30 days

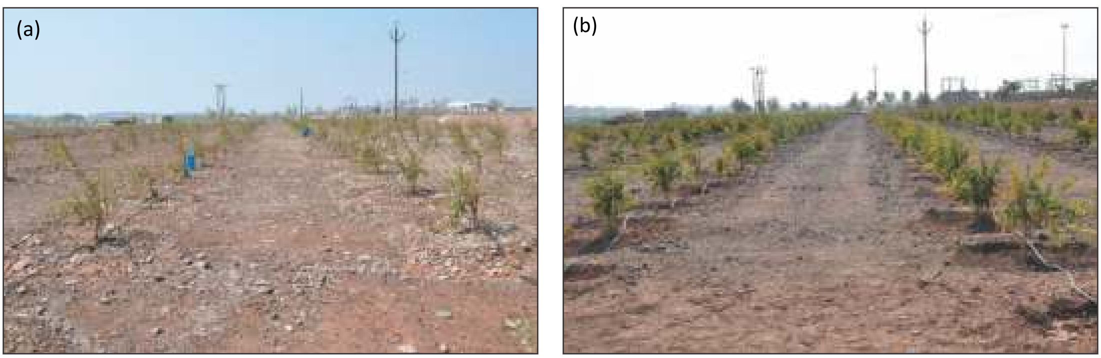


Plate 27: Pomegranate orchard (a) on the day and (b) 26 days later

10.0 Conclusions

- Hailstorms can sporadically occur in India as a local phenomenon or even cover large geographical areas as it happened during 2014.
- Hailstorms can cause severe damage to arable crops, orchard crops, and farm structures apart from seriously injuring livestock, poultry and humans.
- The data on temporal and spatial distribution of hailstorms as well as size of hailstones with the consequent damage have to be documented systematically which facilitates identification of vulnerable areas more scientifically.
- As per the available records, the hailstorms are found to occur more frequently over large areas in some parts of Maharashtra, Assam and Himachal Pradesh causing considerable damage to agriculture sector.
- There is a need for adequate RADAR network in the country to forecast the occurrence of hailstorms over larger areas. The mechanism of alerting farmers has to be developed as it is difficult to predict hailstorms well in advance in tropical countries like India.
- There is a need for formulating a pilot project involving IMD, SAUs, AICRPAM and progressive farmers to undertake studies on suppression of hailstorms and to explore economically viable protection strategies to minimize the losses from hailstorms.

References:

Atlas, D. and Ludlam, F. H. 1961. Multi-wavelength radar reflectivity of hail storms. *Q. J. Roy. Meteor. Soc.*, 87: 523-534.

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, pp 44.

Bhardwaj, J., Surender Singh, and Diwan Singh. 2007. Hailstorm indiced crop losses in India:Some case studies. 4th European Conference on Severe Storms 10 - 14 September 2007, Trieste, Italy.

Cecil, D. J. 2009. Passive microwave brightness temperature as proxies for hailstorms. *J. Appl. Meteor. Climatol.*, 48: 1281-1286.

Chowdhury, A. and Banerjee, A. K. 1983. A study of hailstorms over north-east India. *Vayu Mandal,* 13: 91-95.

De, U. S., Dube, R. K. and Prakasa Rao, G. S. 2005. Extreme weather events over India in the last 100 years. *J. Ind. Geophys. Union.* 9(3): 173-187.

Dessens, J. 1985. Hail in South Western France. II: Results of 30-year hail prevention project with silver iodide seeding from the ground, *J. Climate Appl. Meteor.*, 25: 48-58.

Eliot, J. 1893. Report India Meteorological Department, Pune.

Eliot, J. 1898. Hailstorm in India during the period 1893 - 1897 with a discussion on their distribution. Memoirs. IMD Vol. VI Part IV, IMD, Pune.

Gokhale, N. R. 1975. Hailstorms and hailstone growth, SUNYA Press, Albany.

Huang, M. Y., Xu, H. Y., He, A. S., Chen, Y. Y. and Xu, N. Z. 1981. Studies of the influence of explosion upon the development process of convective clouds. *Journal of Weather Modification,* 13: 226-30.

List, R. J. 1963. On the effect of explosion waves on hailstone modols, *J. Appl. Meteor.*, 2: 494-493.

Mezeix, J. F., Segarra, M., Tondut, J. L. and Vaissieres, B. 1974. Etude preliminaire d'un canon detonnant pour la prevention de la grele. Unpublished report of Groupement, Interdepartmental d'Etudes des Fleaux Atmospheriques, Valence, France.

Nizamuddin, S. 1993. Hail occurrences in India. *Weather*, 48:90-92.

Philip, N. M. and Daniel, C. E. F. 1976. Hailstorms over India, IMD Meteorological Monograph, Climatology No. 10, IMD, Pune.

Ramanamurthy, Bh. V. 1983. Some cloud physical aspects of local severe storms. *Vayu Mandal*, 13: 3-11.

Ramdas, L. A., Satakopan, V and Rao, S. G. 1938. Agricultural meteorology: frequency of days with hailstorms in India. *Indian J. Agr. Sci.*, 8:787-805.

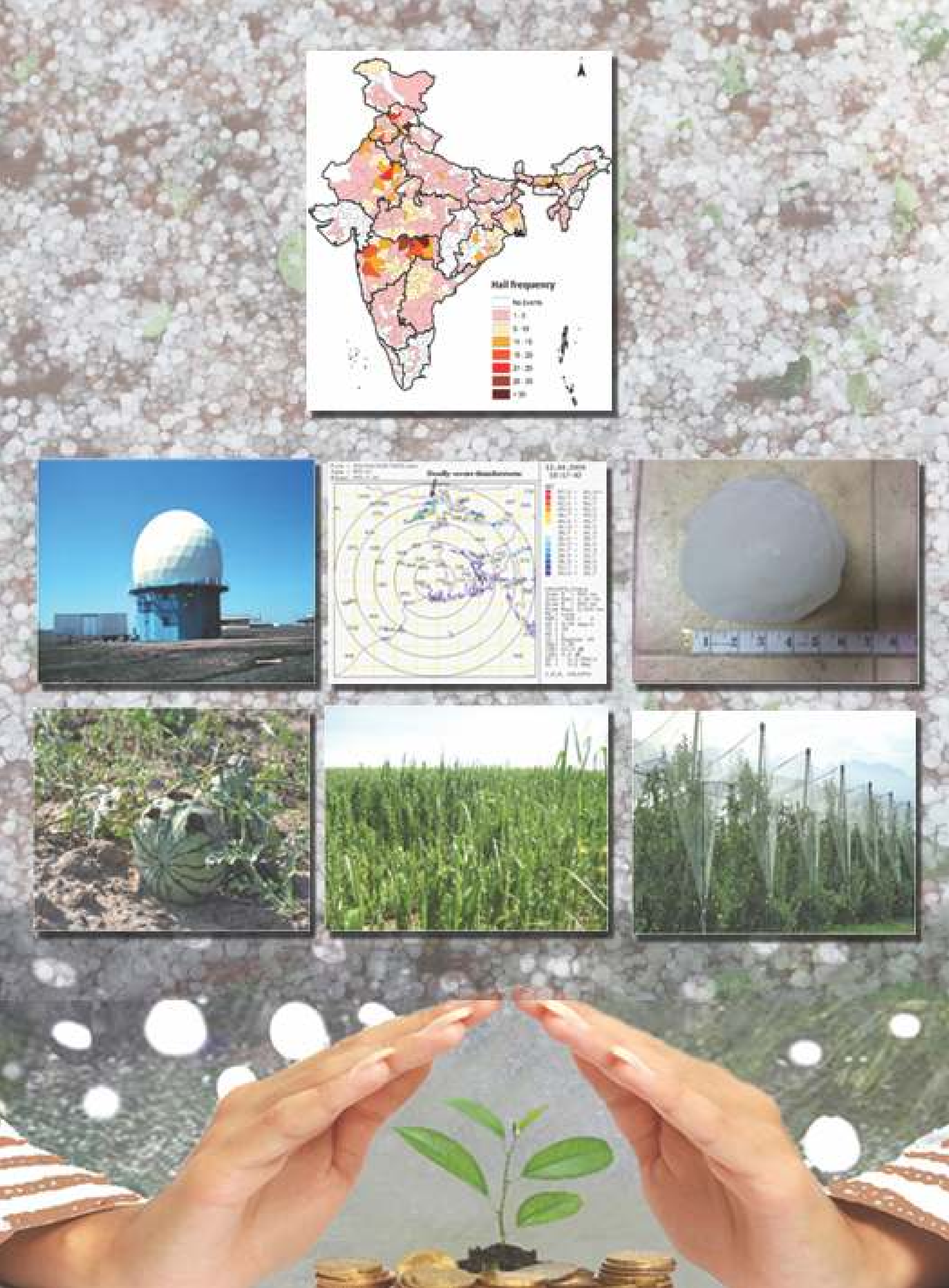
Seneviratne, S. I., N. Nicholls, D. Easterling, C. M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera. and X. Zhang. 2012. Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken,K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, pp 109-230.

Sharma, S. and Dutta, D. 2012. Study of hail storm features in mesoscale convective systems over south east Asia by TRMM- precipitation radar and TRMM-microwave imager. Paper presented at ERAD-2012, The Seventh European Conference on Radar in Meteorology and Hydrology. Available at http://www.meteo.fr/cic/meetings/2012/ERAD/short_abs/RCS_360_sh_abs.pdf.

Sulakvelidze, G. K., Kiziriya, B. I. and Tsykunov, V. V. 1974. Progress of hail suppression work in the USSR. Chapter 11 of Weather and Climate Modification (Editor: W. N. Hess), Wiley, New York, 410-431.

Vento, D. and Malossini, A. 1982. La diffesa attiva contro la grandine. Report issued by II Dipartimento Agricoltura e Alimentazione, regione Emilia-Romagna, Itali, pp 47.

World Meteorological Organization. 1986. Information concerning weather modification directed to government decision makers, Weather Modification Program, Report No. 6, Technical document WMO/TD - No. 123, Geneva, pp 14.


Hail frequency
No Events