POLITECNICO DI MILANO

Scuola di Ingegneria Civile, Ambientale e Territoriale

POLO REGIONALE DI COMO

Master of Science in

Environmental and Land Planning Engineering

Correlation between weather events and crop-damages in northern Italy

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Corso di Laurea Specialistica in Ingegneria per l'Ambiente e il Territorio

Correlazione tra eventi atmosferici e il danno sulle colture agricole nel nord Italia

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“The future belongs to those who believe in the beauty of their dreams”

Eleanor Roosevelt

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Acronyms

AIA	(*Associazione Italiana di Aerobiologia*) National Association of Aerobiology
ANIA	(*Associazione Nazionale fra le Imprese Assicuratrici*) National Association of Insurance Companies
ARPA	(*Agenzia Regionale per la Protezione dell'Ambiente*) Regional Agency for Environmental Protection
DUSAF	(*Destinazione d'Uso dei Suoli Agricoli e Forestali*) Land use for agricultural and forest soils
EEA	European Environmental Agency
ERSAF	(*Ente Regionale per i Servizi all'Agricoltura e alle Foreste*) Regional Agency for Agriculture and Forestry Services
EUROSTAT	Statistical Office of the European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
IASMA	Istituto Agrario di San Michele all'Adige
IIT	(*Infrastruttura Informazione Territoriale*) Spatial Information Infrastructure
INEA	(*Istituto Nazionale di Economia Agraria*) National Institute of Agricultural Economics
IRER	(*Istituto Regionale di Ricerca della Lombardia)* Regional Research Institute of Lombardy
ISTAT	National Institute for Statistics
POLIMI	Politecnico di Milano
SIARL	(*Sistema Informativo Agricolo Regionale*) Regional Agricultural Information System
SIMN	(*Servizio Idrografico e Mareografico Nazionale*) National Hydrographic and Mareographic Service
SINA	(*Rete Nazionale di Informazione in Campo Ambientale*) National Network of Environmental Information
WMO	World Meteorological Organization

Introduction

Northern Italy is the region with the highest GDP in the entire country. According to report by Eurostat (2011), among 5 regions with the highest GDP in Italy, 4 are placed in north: Lombardy (1st place in Italian ranking and 2nd place at European level with 328 billion Euros), Veneto (3rd place in Italy with 149 billion Euros), Emilia-Romagna (4th place with 139 billion Euros) and Piedmont (5th place with 127 billion Euros).

As will be explained in next chapters, much of this richness is the result of work in agriculture, a key sector for the economy of these regions.

But this economic development scenario suffer every year major production losses due to extreme weather events such as hail, storms of wind and rain, temperature changes and intense heat or cold.

Hail is the main cause of these damages to crops which can be explained by a combination of *hazard* (hailstorms frequency, intensity and localization of event), *high exposure* (huge area used by agriculture sector) and *vulnerability* (high susceptibility to damage).

The objective of this study is to identify each of these parameters in a hail event context, connecting the available data and developing correlations between some climate variables to explain the entire process.

Chapter 1 has a description of studied area, Northern Italy. Some aspects of geography, economy and climatology will be discussed. The importance of agriculture sector in the economy of region will be also treated. Chapter 2 has a description of the method adopted in this study. There will be defined also certain important concepts such *risk, hazard, vulnerability* and *exposure.* Chapter 3 presents the Italian Insurance System and defines the most dangerous events for agriculture sector. Chapter 4 brings the hazard maps for Lombardy region. Chapter 5 presents five crop cultures that are going to be studied and their vulnerabilities for the hazards. Chapter 6 treats of spatial and temporal exposure aspects and finally in Chapter 7 details of calibration process and the results of this research.

Studying intense weather events characteristics and linking them with damages in agriculture can seems to be an ambitious choice and maybe scientifically inaccurate, due to many doubts related to this phenomena. However, this work was carried out trying to minimize uncertainties using the best available information, always coming from homogeneous regions.

1. Area of study description

This chapter will deal with various aspects of the region of interest of this study, i.e. the Northern Italy. In this area live almost a half of the Italian population, or approximately 28 million people distributed in about 120.000km² (around 40% of entire territory), according to ISTAT census. Despite this, only 4 of the 10 most populous provinces of Italy in this area are: Milan (3.1 million in 2nd place), Turin (2.3 million in 4th place), Brescia (1.2 million in 6th place) and Bergamo (1 million in 9th place), which can be explained by the relatively low density of inhabitants in these regions.

Relevant geographical and climatic conditions that contribute significantly to the formation of atmospheric disturbances as well as general aspects of meteorology, the behaviour of variables such as temperature, precipitation and intense winds will be treated in the following paragraphs.

It will be also discussed some economic aspects like the participation of agriculture sector in Italian GDP and details of how is the crops distribution in the regions Lombardy, Piedmont, Trentino-Aldo Adige, Veneto, Friuli-Venezia Giulia and Emilia Romagna.

1.1. Geography aspects

Regarding the climate, Italy is placed in temperate zone. Due to the considerable length of the peninsula, there is a variation between the climate of the north, attached to the European continent, and that of the south, surrounded by the Mediterranean. The Alps are a partial barrier against westerly and northerly winds, while both the Apennines and the great plain of Northern Italy produce special climatic variations.

The Alps are the youngest and most important mountain in Europe. These mountains are formed during the Mesozoic and Cenozoic as a result of tectonic plate collision between the African and European plates.

The mountain range extends over a thousand kilometres from Geneva (Switzerland) to Vienna (Austria), with a width of between 100 and 400km about. Its development in the Italian territory covers an area of about 80.000km^2, where the most important peaks are Hochfeiler (3.510m), Monte Leone (3.560m), Monte Viso (3.841m), Piz Bernina (4.049m), Gran Paradiso (4.061m), Matterhorn (4.478m), Monte Rosa (4.638m) and finally the Mont Blanc which with its 4.810m is the highest point of Europe.

On the south side of the Alps are placed in the Po Valley, which covers about 46.000km^2. In this area are the River Po and all its tributaries: the Adige, the Rhine and the river from Romagna region. The activity of all these rivers is the main cause of the formation of the current environment of floodplain with significant influences also due to glaciations.

The Po Valley has two zones with different characteristics: the high and low plains. The adjectives do not refer to high and low latitude but the altitude. There is a clear distinction between these two areas, not only different in height, but also the nature of the land, the water regime and vegetation. The high plains, also known as the dry plains, is situated close to the foot of the Alps and the foothills of the Apennines. Its soil is permeable, consisting of sands and gravels, and is unable to retain rainwater. For this reason, the rain gets under the surface until reach a layer of impermeable material, flowing over it until re-emerge out, giving rise to springs[1]. Here is where begin the low plains begin, also known as irrigated plain. Soils in this area are formed by fine materials, usually clay, impermeable or with low permeability, where the waters stagnate easily rise to wetlands.

The Italian region considered for this study belongs to the so-called “Continental Italy”. This distribution includes the southern slopes of the Alps, the Po-Venetian Plain and the Ligurian Apennines until to the imaginary line that joins the La Spezia (in Tyrrhenian coast) to Rimini (Adriatic coast).

1.2. Climate behaviour

The Italian territory (between 47º and 35º parallel to the north) is located near of centre of the northern hemisphere temperate zone. From the climatic point of view is also favoured by the large body of water that surround the Mediterranean Sea from almost every side. These seas create, especially for the Italian peninsula, a benefit heat and humidity reservoir.

In accordance with the schedule of general distribution of climates, the Italian peninsula falls entirely within the Mediterranean climate that belongs to mesothermal climates and more specifically to the subtropical dry summer, according to the classification of W. Koppen[2] (Figure 1). In fact, due to numerous factors such as territory location respect seas and European continent, orographic structure, and influence of latitude and Mediterranean typical climate, there are other areas with mesothermal climates or situations of climate and microthermal altitude.

[1] Springs are also known as risings or resurgences, are the site where the acquifer surface meets the ground surface.

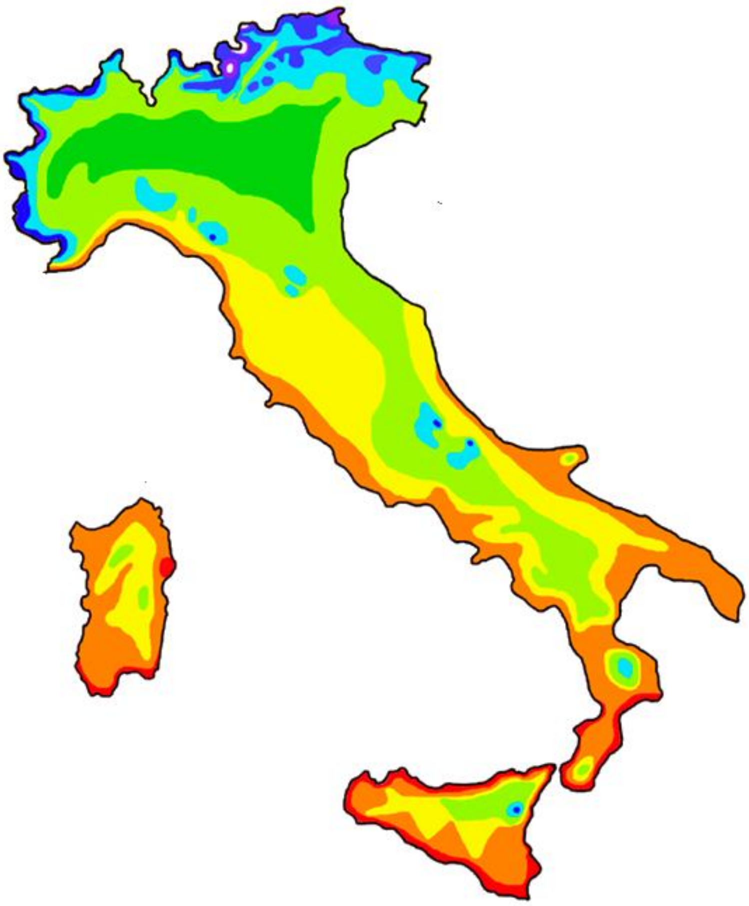
[2] The Köppen classification of climates is the most widely used classifications of geographical climatic purposes. It was first proposed in 1918 by Wladimir Köppen

Figure 1. Italian climate regions

(source: AIA)

Legend

- Subtropical temperature
- Warm temperature
- Sub-coastal temperature
- Sub-continental temperature
- Continental temperature
- Cool temperature
- Cold temperature
- High altitude
- Ice



Even not having a vast territory, Continental Italy has a wide variety of climates. It is possible to observe some differences along the peninsula. Areas such as the Po Valley and Adriatic coast have spring and autumn rainfall, with summer and winter drier. The foothills of the Alps, instead, have heavy and frequent rainfall also in summer. The area of the highlands of the Piedmont has a warm summer and the Alpine area presents winters long and severe, and generally summer rainfalls.

Northern Italy is one of the most subjected to precipitation in the country. The rain is distributed almost uniformly depending on altitude. The mountain areas are those most at risk, having an annual average over 1500mm and being able to exceed 2000mm. The foothills of the Alps, instead, receive every year between 1000 and 1400mm of rain. The Po Valley is the region less susceptible to rain phenomenon, presenting, on average, more than 1000mm of rain per year, as shown in Figure 2. The Po Valley and foothills of Alps have the biggest agriculture area concentration, as will be discuss in Chapter 1.3.

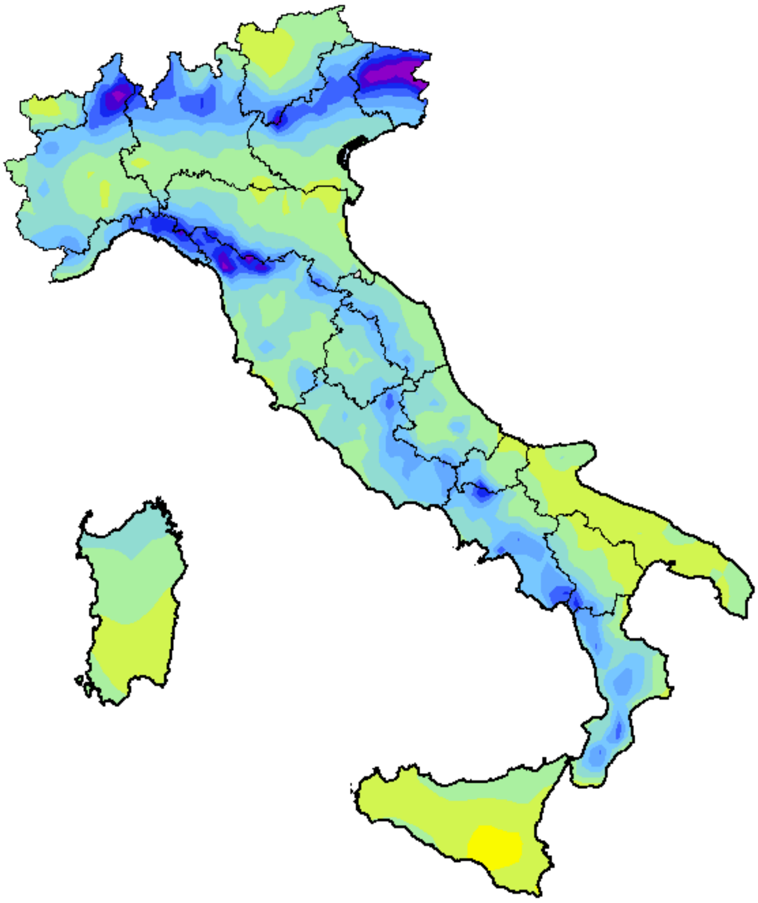


Figure 2. Average annual precipitation, 1961-1990

(source: SINA)

Legend

2250
2050
1850
1650
1450
1250
1050
850
650
450
250
(mm)

Also high intensity of daily total rain is located on Northern Italy area. This variable however is subject to other factors, such as streams of wind and temperature, and does not follow the same distributions of annual totals. We can see from Figure 3 that the most subjected regions to thunderstorms are Liguria, Friuli-Venezia-Giulia and Piedmont foothills. Areas where at least one day a year is expected a rain exceeding 150mm. For most of the Lombard area, this value drops to about 100mm while the Veneto plain is about 90mm.

Other conclusions that can be obtained from the analysis of Figure 2 and Figure 3 are:

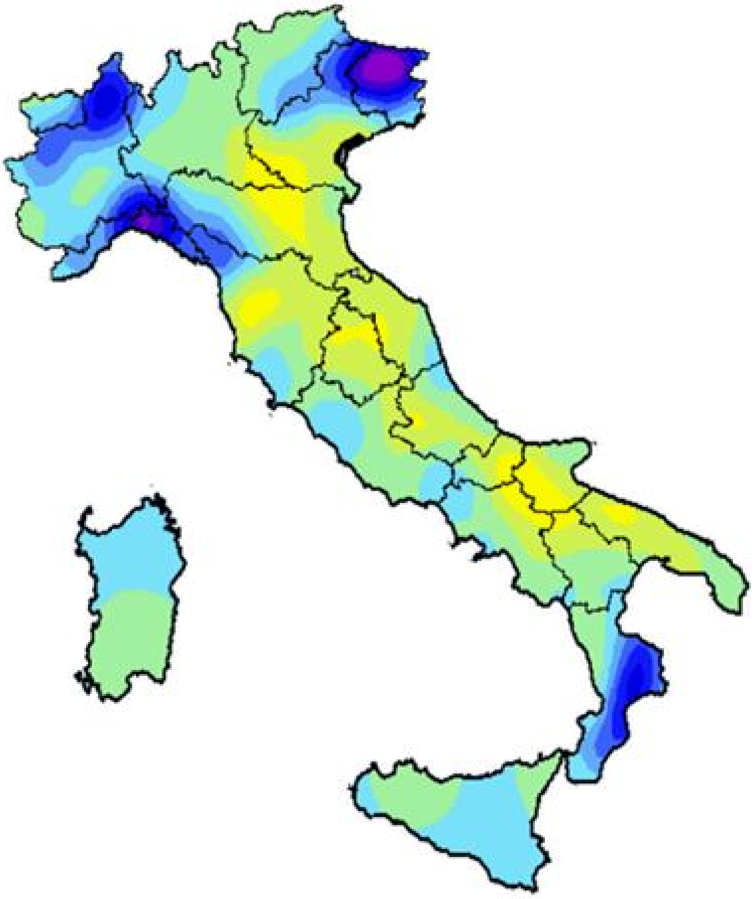
- Total annual precipitation is greatest in Northern Italy;
- Tyrrhenian coast is generally more subject to rains than Adriatic coast, at the same latitude;
- The greatest amount of rain is in mountain areas, even in the Italian peninsula;
- The southern regions of Campania and Calabria are very subject to rainfall events, with similar results to those obtained in the north;
- The region of Puglia and the islands of Sardinia and Sicily are the areas less affected by rainfall events.

Figure 3. Average daily precipitation, 1961-1990

(source: SINA)

Legend

167.9
159.2
150.5
141.9
133.2
124.6
115.9
107.3
98.6
90.0
81.3
(mm)



Hailstorms are most common where surface temperatures are warm enough to promote the instability associated with thunderstorms, but the upper atmosphere is still cool enough to support ice.

As shown in Figure 4, most of the Northern Italy has an annual average surface temperature about 15°C, especially in the plains, while in mountain area this value drops considerably, being able to reach below 0°C.

It is important to note that, although treating the area with the lowest average temperatures, this does not imply that it is impossible to have a hailstorm in Northern Italy. Calculation of average temperature involves a mean between a long period of rigorous winter and a hot summer. For a hailstorm it important to analyse the trend of temperature in a single day, like will be show in Chapter 7.

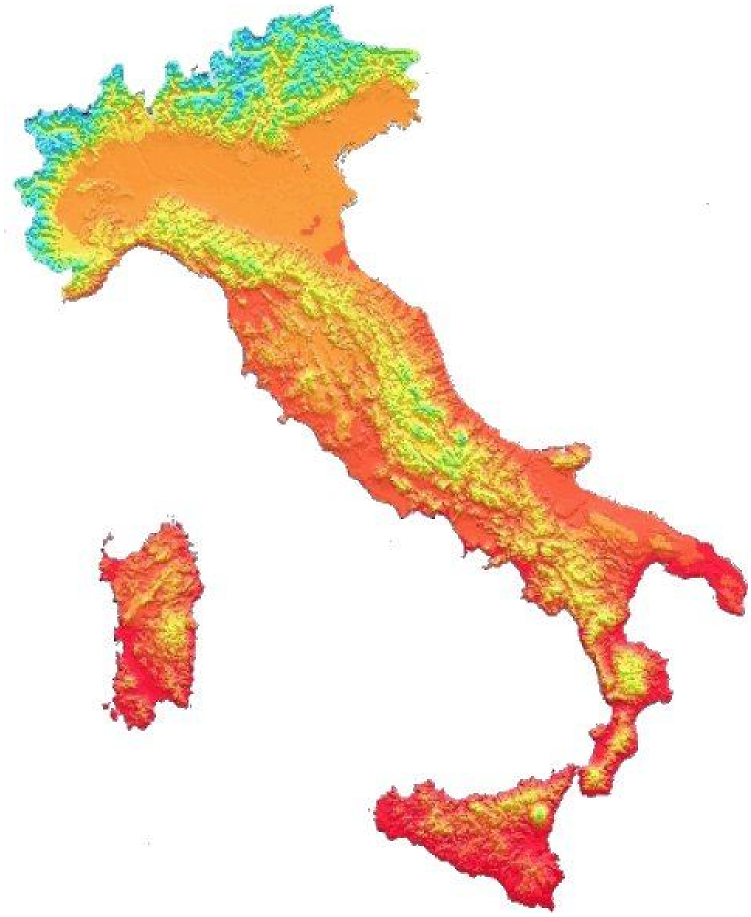


Figure 4. Average temperature, 1961-1990

(source: SINA)

1.3. Agriculture in economy of northern Italy

The 6th General Census of Agriculture shows the structural framework conditions at October 24, 2010 in Italy. The study reveals that there are 1,630,420 farm operators in Italy. The total agricultural area amounts to 17,277,023 hectares and the utilized area amounts to 12,885,186 hectares.

According to Figure 5, Northern Italy is among the areas that have the largest agricultural use, especially Lombardy, Piedmont, Emilia-Romagna and Valle d'Aosta.

According to Pieri & Pretolani (2010), the Lombard agriculture sector is the most important in Italy and among the firsts in Europe. The production value is around 12 billion Euros, more than 15% of Italian total and corresponds to 3.7% of regional GDP.

Figure 5. Average agriculture utilized area by company, 2010

(source: ISTAT)

Legend

< 6

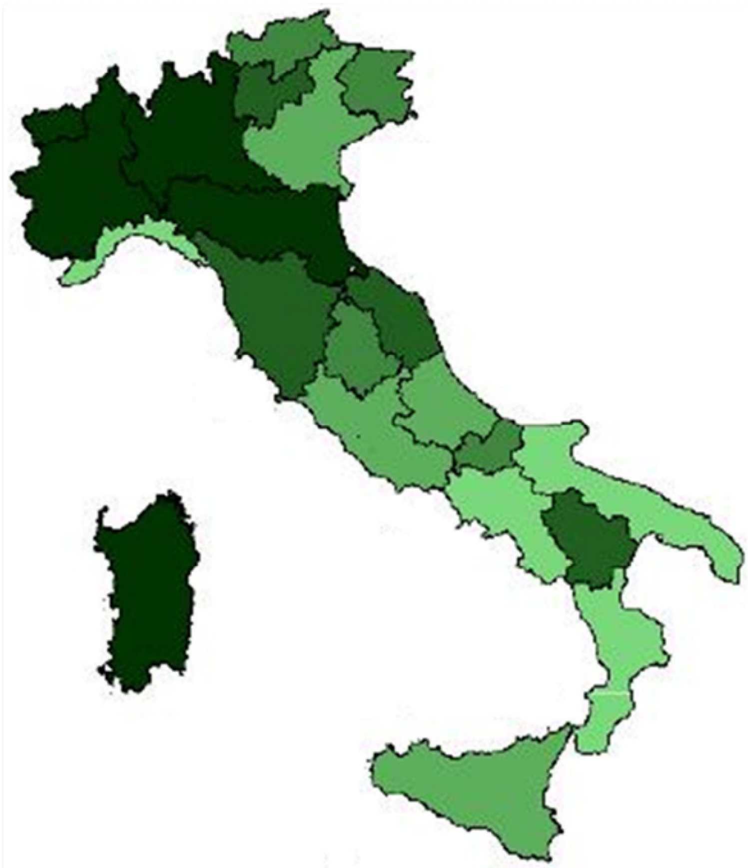
6 – 7

7 – 10

10 – 14

14 - 20

(ha)



Agricultural production and food processing activities take place in more than 70,000 structures just in Lombardy, where there is a substantial difference in composition respect to the national: the livestock represent over 60% of regional production while cultivation, 31%; nationally the proportions are reversed, with 56% to the crops and 32% of herd farms. In Lombardy 70% of regional production is composed of only six types of products: rice, corn, forage crops, pigs, cattle and milk.

In Trentino Alto-Adige, according to De Silvestro *et al.* (2009), there are more than 20,000 farm operators and the most part of them consist of small settlements with less than 1 hectare. Fruit production is the sector with the greatest weight on the regional GDP, with about 150 million Euros a year, dominated by production of apple, with nearly 70% of turnover. The main distinguishing element of the orchards of Trentino is the high quality, given not only by climatic conditions, but also by the ability and skills of its operators.

According to Aimone *et al.* (2009), the Piedmont production is characterized mainly by cultivated fields of cereals and rice, grapes and wine, beef and milk. There, the 2008 crop year was characterized by a late spring climatically very rainy and cold, which had negative results on the production volumes of many important crops such as rice (-6.8%), fruits (-4, 5%) and grapes (-10.5%).

The report Censori & De Zanche (2011) indicates that after negative results of 2009 campaign, in which Venetian agriculture has suffered a decline of turnover amounted to 7.1%, 2010 was characterized by a significant recovery in production, in value estimated at 4.75 billion Euros, up 2.5%. The corn crop is the largest in the region with about 276,000 hectares and 2.2 million tons of production average.

The results of the agricultural sector report of Cesaro & Marangon (2007) show that the numbers of farm operators in Friuli-Venezia Giulia region have been falling since 1997 and this year is slightly below 20,000. The sector is divided mainly in cultivation (53%) and livestock (35%), where the main productions are viticulture and dairy cattle.

The annual report produced by Boccaletti *et al.* (2011) indicates that, after ups and downs of Emilia-Romagna gross marketable production, in 2010 the value of production reached a maximum of 4.2 billion Euros, mainly because of the strong increase in prices of most of the sectors (in particular cereals, fruit and milk).

2. Methodology

This chapter will briefly discuss the definition of *risk* for this study and how is its relation with *hazard, vulnerability* and *exposure* parameters.

Then, some important aspects of the interaction between atmospheric variables and crop damages will be treated using the prior available bibliography.

2.1. Risk: principles and definition

One of the main characteristics of agriculture sector is to be in constant high exposure to risk, often caused by climatic events. According to Hardaker *et al.* (1997) the most important risks affecting agriculture are:

- Human and personal risks: health problems with farm operator;
- Price risks: risk of falling or raising prices after a production harvesting has been done;
- Institutional risks: policy changes which intervene with issues and cause negative impact on revenues;
- Financial risks: increase of interests, insufficient liquidity or loss of equity;
- Asset risks: like theft, fire or other damage or loss, generally covered by insurance or governmental aid in case of calamities;
- Production or yield risks: include weather events, plant and animal diseases.

As defined by Bielza et al. (2008), a disaster is an unforeseen and often sudden event that causes damage, destruction and human suffering. In agricultural sector, the disaster is typically caused by natural event. They can be:

- Climatic events: hail, flood, drought, storms;
- Pest damages: snails, insects;
- Diseases: foot and mouth disease, fever.

In this study, the adopted definition to risk is the combination of potential danger (hazard), inability to reduce the potential negative consequences (vulnerability) and large number of objects subject to damage (exposure).

$$Risk = f\ (Hazard, Vulnerabiliy, Exposure)$$

The variables of prior equation can be defined as:

- Hazard is the probability that a phenomenon of certain intensity occurs in a given period of time in a given area. For instance, the probability to have a hailstorm with hailstones bigger than 10mm in Province of Como in August month;
- Vulnerability indicates the susceptibility of an object to tolerate the effects of a given event intensity. For example, a high elasticity of a plant can help it to resist against a wind gust, or harder leaves can protect fruits against hailstorms;
- Exposure indicates the element that must tolerate the event and can be expressed either by a quantitative or a value (natural or economic), subject to the hazard. For example, the total vine crop area in Province of Como;
- Risk is the combination of prior factors and expresses the expected number of property damage, destruction of natural resources or economic activities, due to a particular damaging event. For instance, the risk to damage against vine crops in Province of Como in case of hailstorm with minimum 10mm hailstone size.

Figure 6 presents seven possible combinations among the three variables that define *risk*.

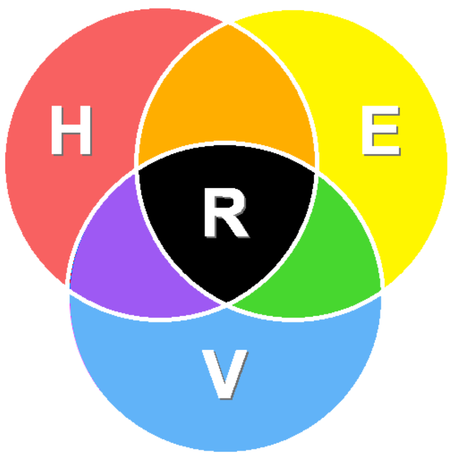


Figure 6. Risk mechanism

Legend

Risk
Hazard
No exposure
Vulnerability
No hazard
Exposure
No vulnerability

Risk situation is the case when all three factors are present. However it is possible to be in 3 danger cases:

- “No Exposure” is a relatively safe situation because, even if there is high potential to a hazard and a high vulnerability of a crop, the damages will be reduced due to low area exposed to the event;
- “No Hazard” and “No Vulnerability” are dangerous cases. In first case, when dealing with natural events, that are difficult forecast, it is impossible to assert that there is no possibility of happening, even if remote, to succeed in a given area. In the second case, for an analogue reason, vulnerability is linked to a natural event of a particular intensity. If some crop has a low

vulnerability to a certain event, is not possible to affirm that is true also for an event even more destructive.

To define the *hazard* in an analysis of crop damages, it is necessary to find a map of frequency of a certain event for the entire studied region. In Chapter 3, the Italian Insurance System will be presented and the most dangerous weather events to produce crop damages will be shown. In Chapter 4, the aspects and the maps of hazard will be largely discussed.

In the same context, vulnerability can be defined as a measure of resistance against a certain type of damage. Generally vulnerability is a characteristic of the plant and changes along its growth stage . This parameter will be better discussed in Chapter 5.

Still, the aspects of exposure will be showed in Chapter 6. Will be explained the importance of evaluation of both crop spatial and temporal distribution to have a correct analysis of the problem.

Finally, in Chapter 7 will be presented a calibration of the adopted model and some results of this methodology.

3. Italian insurance system: main hazards

The objective of this chapter is to define the main hazards to agriculture crops. This answer will be given using data from insurance companies, provided from ANIA. Therefore, some concepts of the role of insurer in the agriculture environment must be describe.

A contract of insurance against damage is a voluntary insurance and can be defined according to the 1882th paragraph of Italian Civil Code (1942) as the "contract whereby the insurer undertakes to retaliate the insured to pay a premium, within the agreed limits, for damage to it from an accident, that pay a capital or an annuity upon the occurrence of an event related to the object insured."

3.1. Hail insurance

The activity of the agricultural production of vegetables, crops, industrial crops, vineyards and fruit orchards, when cultivate in open fields can be subject to damage due to climatic extremes such as hail, wind, frost and other natural disasters. These weather damages affect the work of farmers, damaging the crops, their annual income, and sometimes damaging the subsequent years and in some cases crop plants deferred.

The idea of defending crops from hail and weather events goes together with the history of agriculture, especially since this has become increasingly industrialized. From the beginning of 19th century up to now, with lightning and hail cannons, farmers have looked for "active defence" to oppose the hail, but with poor results. Since 1836, when by the work of a large company was born the first insurance policy for the protection of hail damage to crops, by the work of a large company, many insurance companies have been engaging in this way.

"Hail insurance" is the insurance contract which makes it possible for farmers to insure their agricultural products from hail damage and natural disasters.

Table 1 presents the main results for hail insurance in Italy between 2006 and 2009.

The total usable agricultural area is calculated by ISTAT and the table presents the only result of agricultural census made in Italy for the period. It is possible to note that the insured surface represents just 8% of usable agriculture surface for year 2007.

Table 1. Italian agricultural insurance market evolution

(source ANIA/ISTAT)

Description	2006	2007	2008	2009
Certified	212.583	238.501	267.694	228.967
Insured area (1000 ha)	1.125	1.051	1.450	1.355
Total area (1000 ha)	-	12.744	-	-
Insured product (1000 tons)	14.805	16.329	20.416	18.219
Insured value (millions €)	3.789.132	4.379.809	5.436.140	5.131.045
Total premium (millions €)	264.134	291.433	335.813	313.962
Compensated (millions €)	145.975	184.250	271.701	232.784
Average tariff (%)	6.97	6.65	6.18	6.12
Sinister rate (%)	55	63	81	7
Damaged (%)	3.8	4.2	5.0	4.5

Total premium is the total amount paid by all contractors to the insurance companies. Compensation is the total amount paid by the companies to cover contractors damages happened in the year. Average rate is the ratio between Total premium and Insured value and represents the value paid by each contractor to insure his production for one agricultural year. Sinister rate is the ratio between Compensation and Total Premium and represents the risk assumed by the insurance companies. Damaged rate is the ratio between Compensation and Insured value and represents the amount of insured products that are been damaged in the current agricultural year.

An analysis by sector shows that about 90% of the Italian insurance market consists of insures to cereal, fruit, vines and vegetables. Table 2 presents the breakdown of the insured value and surfaces according to the agricultural sector.

Table 2. Insures according to agriculture sector in 2009

(source ANIA)

Sector	Insured value (%)	Insured surface (%)	Compen sation (%)	Average rate (%)	Sinister rate (%)	Damage rate (%)
Cereals	28	44.7	16.6	3.67	78	2.9
Fruit	28	33.9	48.0	10.51	81	8.5
Vine	23	9.7	18.3	5.30	72	3.8
Vegetables	13	5.5	10.8	6.53	64	4.2
Industrial crops	5	3.8	5.8	10.17	66	6.7
Seed crops	1	1	0.4	5.05	74	4.2
Olive and others	1	1.1	0.3	2.84	65	2.0

Further description about some insurance terms is presented in Appendix A.

3.2. Insurable atmospheric events

According to the Legislative Decree no 102 (2004), the main concepts of insurable events defined by National Agricultural Insurance Scheme are presented in the following list:

- Hail: frozen water in the atmosphere that falls as ice grains of varying sizes;
- Freeze/frost: lowering temperature below 0 degrees Celsius due to the presence of cold air masses or freezing of dew or sublimation of water vapour on the surface of crops due to nocturnal radiation;
- Excess precipitation: excess water availability in the soil or prolonged rainfall exceeding the average of the period which has resulted in damage to insured production;
- Flooding: natural disaster that occurs in the form of flooding, due to exceptional weather events, courses, and natural or artificial ponds that invade the surrounding areas and are accompanied by transport and storage of solid and consistent;
- Strong winds: windy phenomenon that can reach at least 7 on the Beaufort scale, as described in Appendix C, limited to the direct mechanical effects on the insurance product, even if caused the killing of the tree;
- Sunstroke: Effect of direct sunlight under the action of strong heat and duration or intensity causes adverse effects to the product;
- Thermal shock: abrupt and sudden change in temperature and duration or intensity due determinative effect on the viability of plants with consequent impairment of the production;
- Excess of snow: rainfall from needles or blades of ice duration or intensity to adversely impact on the determinants of mechanical plant and the consequent impairment of the production;
- Sirocco winds: moving more or less regular or violent manner, warm air mass and duration or intensity causes adverse effects to the product.

These events could cause determinative effect on the viability of the plants covered by insurance with consequent impairment of guaranteed production and generally, the negative effects of violence or intensity of these adverse weathers to be found on a number of bodies or neighbouring crops.

The distribution of sinister is presented in Table 3 at the end of this chapter.

3.3. Insurable crops

The same decree mentioned in previous paragraph defines also agricultural products which are insured against damage caused by weather events.

They are divided by classes: cereals, oilseed, horticultural, legumes, pomes fruits, stone fruits, olives, vine and other fruits. In the Appendix A there is a list containing all the insurable crops in Italy.

The coverage considers the amount of loss suffered by the product. Generally starts in the early phases (emergence, tillering) and expires at commercial maturity of the product, by which time should be promptly collected, under penalty of exclusion from compensation if an event occurs.

3.4. Estimates of damages

According to Borin *et al*. (2001), the appraisal of the damage from bad weather is one of many situations where a technician performs an estimate, and one of the most complex areas of the estimator, therefore, the appraiser is a professional who must constantly attend meetings and courses training and updating knowledge and evolve both in the agricultural, that of cultural practices and refinement of estimation methodologies.

An operation of estimates of expertise is a process that starts from a request from the concerned party (farmer directly affected or local agricultural consortium that submits a collective application).

The purpose of the process of appraisal is to provide estimates on quantities of future production in the settlement expertise, or in other words, the amount of product that has not been damaged by the weather event.

The process starts with verification of certificates of insurance, going after to the operation in field, where further checks must be made to attest that the reality found on the territory is the same that provided in insurance contract, for example, the correspondence of the boundaries, species and variety, quantity product and date of insured weather event.

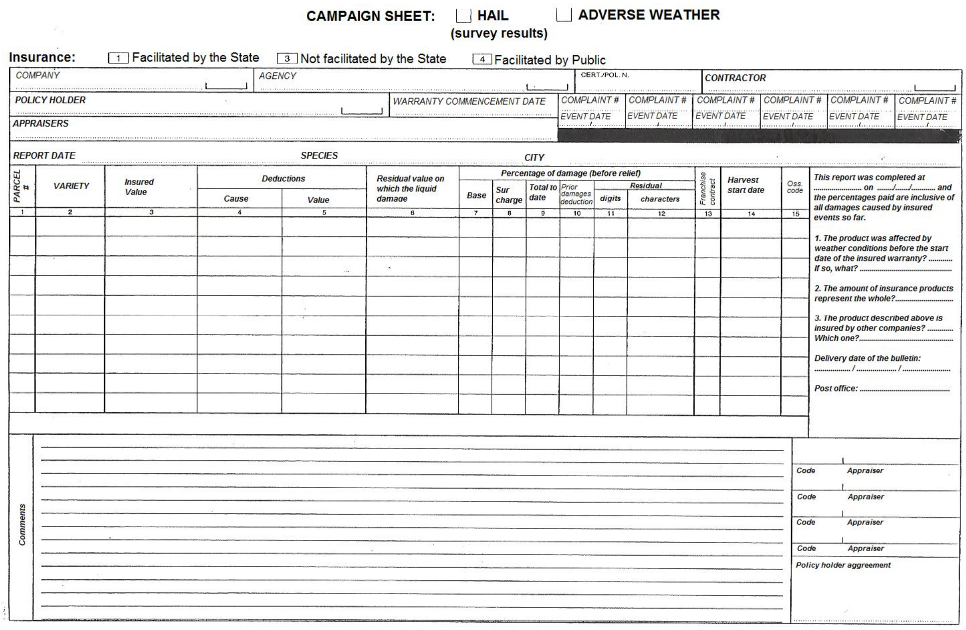
In addition, is also role of expert to quantify the early losses of part of the product, as when the flower or buds fruit fall in prematurely ages still far from harvesting.

Generally, the final audit is done in the vicinity of the normal harvest period of the variety ensured to minimize the possibility that more hail struck again forcing to a new job on the same parcel.

The estimate of the damage may be done through an analytical process or a synthetic. The analytical process consists of, from a representative sample, to calculate the total insured on any farmer. For each type of crop is expected to sample a different methodology. In the synthetic process is carried out the survey comparing with other sinister recorded in the same area.

The estimation process follows with the percentage calculation of the damage observed, with filling out a bulletin of work and final acceptance or rejection by the insured.

Borin et al. (2001) presents the standard bulletin campaign sheet (Figure 7) that is filled by the expert on time of the visit in the place where sinister is reported.


CAMPAIGN SHEET: HAIL ADVERSE WEATHER
(survey results)

Insurance: 1 Facilitated by the State 3 Not facilitated by the State 4 Facilitated by Public

COMPANY | AGENCY | CERT./POL. N. | CONTRACTOR

POLICY HOLDER | WARRANTY COMMENCEMENT DATE | COMPLAINT # EVENT DATE | COMPLAINT # EVENT DATE | COMPLAINT # EVENT DATE | COMPLAINT # EVENT DATE | COMPLAINT # EVENT DATE | COMPLAINT # EVENT DATE

APPRAISERS

REPORT DATE | SPECIES | CITY

PARCEL #	VARIETY	Insured Value	Deductions		Residual value on which the liquid damage	Percentage of damage (before relief)						Franchise contract	Harvest start date	Oss. code
			Cause	Value		Base	Sur charge	Total to date	Prior damages deduction	Residual digits	Residual characters			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

This report was completed at .... on ....../....../......... and the percentages paid are inclusive of all damages caused by insured events so far.

1. The product was affected by weather conditions before the start date of the insured warranty? .... If so, what? ....

2. The amount of insurance products represent the whole?...................

3. The product described above is insured by other companies? .... Which one?...................

Delivery date of the bulletin: ..../........../..........

Post office: ....

Comments

Code Appraiser

Code Appraiser

Code Appraiser

Code Appraiser

Policy holder aggreement

Figure 7. Campaign sheet

(source Borin et al. 2001 modified)

3.5. Database "Sinister"

Database with sinister information is in tabular format from the sinister database owned by ANIA of the years 2007, 2008, 2009 and 2010. This database is built with the information provided by all Italian insurance companies at the end of each year, with market information of its current policies. However, this data are protected by privacy and does not contain any information that make possible to trace the policy holder, the beneficiary, the insured and compensated values, as well as the exact localization of the crop. For this reason, one of the hypotheses that could be done in this work is that all sinister will be considered spatially distributed in a uniform manner throughout the municipal territory.

Data provided by ANIA for this study include information on the appearance of the sinister, on insured and damaged product and about the entity of the damages. The main fields present are shown in the following list:

- Location code of sinister occurrence: numerical code representing the region, province, agricultural district and municipality of the considered event. These codes are in a special database containing all the existing codes ANIA. In the case where the field was populated with a code that is not present in the database, the record is discarded;
- Product: three-digit numeric code representing the insurance product in question. These codes can be found in a separate table containing all existing codes ANIA. In the case where the field was populated with a code not present in that table, the record will be discarded;
- Variety: numerical code on the variety of insurance products. In the case where the field was not completed, the record will not be discarded but will be recovered by replacing with zero value in that field;
- Warranty: code of guarantee of the risk in question. These codes include: hail, frost, excessive rain, flood, high wind, drought, sunstroke, heat shock, heavy snow, sirocco winds, other adversity not covered by those specified;
- Quintals: it corresponds to a numeric value that represents the quintals[3] of insured risk under consideration.
- Date: is the date of the day during which there was a weather phenomenon. This date is communicated in the format "DDMMYYYY".
- Bulletin Type: This is the alphanumeric code for the type bulletin that is being analyzed. There are several codes that represent the outcome of the appraisal activity and settlement (payment) of the damages. For this study, all data will be considered, regardless of the value in this field.
- Percentages of damage: There are different rates for the damage analysis. The "pre-risk damage" is what happened before the validity of the insurance period. The "previous damage" is the damage from an appraisal made before the current one. The "total loss" is the cumulative damage to the sinister in the observation as reported in the Bulletin of the country. It is the most important percentage present on this study. There are still fields "liquidated damage", "major damage" and "basis damage" that will not be considered for this work.

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[3] A quintal (q) is a unit of mass used by the international system of units, but still widespread and used in Italy and in Europe, mainly as a measure of the amount of agriculture products. A quintal is equivalent to 100kg.

Table 3 consists in a distribution of sinister happened in Lombardy territory that has caused damage in culture crops analyzed in this study. Further, is possible to observe that hailstorms are the most hazardous weather event, causing more than 94% of all sinister occurrences.

	2008	**2009**	**2010**
Wheat	**2256**	**359**	**254**
Hail	1949	359	172
Wind	135	0	82
Rain	123	0	0
Others	49	0	0
Corn	**11231**	**3315**	**3998**
Hail	10873	3169	3318
Wind	302	93	580
Rain	15	7	0
Drought	16	46	84
Others	25	0	16
Soybean	**292**	**178**	**264**
Hail	291	177	242
Wind	0	1	22
Rain	1	0	0
Apple	**707**	**959**	**983**
Hail	607	912	961
Wind	73	47	17
Rain	0	0	5
Frost	19	0	0
Drought	8	0	0
Vine	**11263**	**3383**	**3082**
Hail	11190	3334	2740
Wind	0	0	330
Rain	3	0	0
Drought	2	49	0
Others	68	0	12

Table 3. Number of sinister in Lombardy

(source ANIA)

4. Atmospheric events: the hazard

This chapter will discuss relevant aspects of the main pillar of this study: the atmospheric component. The next sections will present the scientific details of the major hazards facing agricultural crops, the most critical periods and methods of measurement and the existing data.

4.1. Storms (wind and/or rain)

A thunderstorm or simply a storm is a form of weather normally characterized by the presence of lighting and thunders, its acoustic effect. Usually they are accompanied by strong winds, heavy rain or even hail.

Supercells thunderstorm are the strongest and the most common associated with severe weather phenomena. A supercell is a storm that is characterized by the presence of a mesocyclone, a deep, continuously-rotating updraft.

4.1.1. Storms data acquisition

A pluviometer is a cylindrical, horizontal opening, equipped with a funnel collector, which is used to measure the precipitation at the point where it is installed.

The ex-SIMN adopted in Italy the use of pluviometers with a $0.1m^2$ surface read once a day.

Pluviographs are a kind of evolution of pluviometers used to measure rainfalls in smaller time intervals. This tool consists of a sensor that detects the height of rainfall in the interval time and records the result in output device (paper, magnetic tape or electronic memory).

Anemometer is the device used to measure the wind speed. It consists in cups that spin when exposed to the wind. The number of revolutions is counted, and so wind intensity is calculated. It is necessary to define a base time interval (usually 1 hour), because the acquisition of data is continuous, and calculate the average of all readings within the period. In addition to the intensity, also the angle direction is acquired and the average calculated.

For this work have been acquired data of rain and wind with hourly intervals for the time period analyzed from the institutions in charge.

4.1.2. Storm hazard maps in Lombardy

According to method described in Baldi *et al.* (2011), maps of four classes of intensity wind have been build. They are produced interpolating 10 years time series of 116 meteorological stations, and correcting the results by factors like altitude and distance to the sea. The classes of intensity of wind are chosen to follow studies made of damages on properties. The results are show in follow Figure 8.

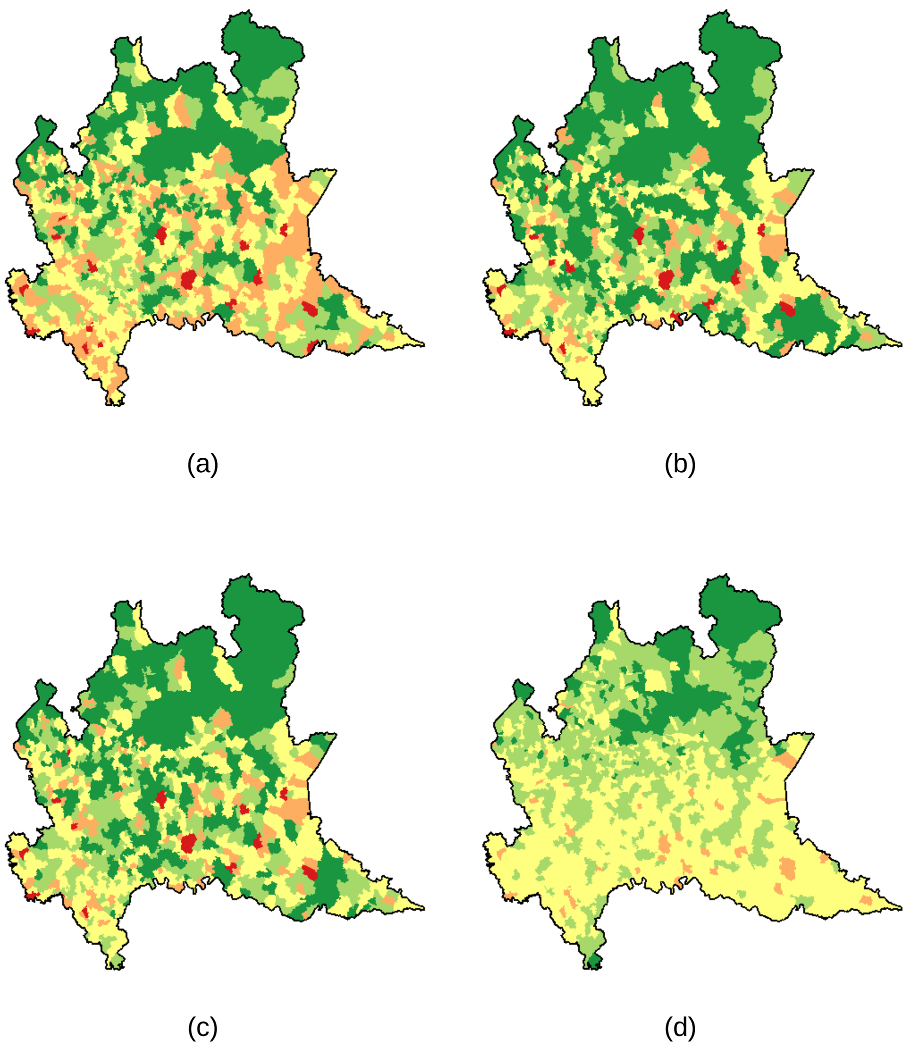


Figure 8. Annual wind frequency in Lombardy

(a) ≥ 75km/h

Legend:

> 2.0
1.0 – 2
0.5 – 1
0.25-0.
< 0.25

(b) ≥ 90km/h

(c) ≥ 100km/h

(d) ≥ 120km/h

Legend:

> 0.6
0.4 – 0
0.2 – 0
0.1 – 0
< 0.1

These maps indicate the probability to have a wind of certain intensity in a certain year. As a brief analyze, the Po Valley is the more subjected zone to have intense wind storms.

The maps presented in Figure 9 are built using a 30-years time series precipitation in Italy. The results, analogue with those from wind events, indicate that, from temporal distribution of precipitations, the biggest probability to have intense rainy days is Po Valley zone, but, it is important to note, this is absolutely different to affirm that this is the most rainiest region.

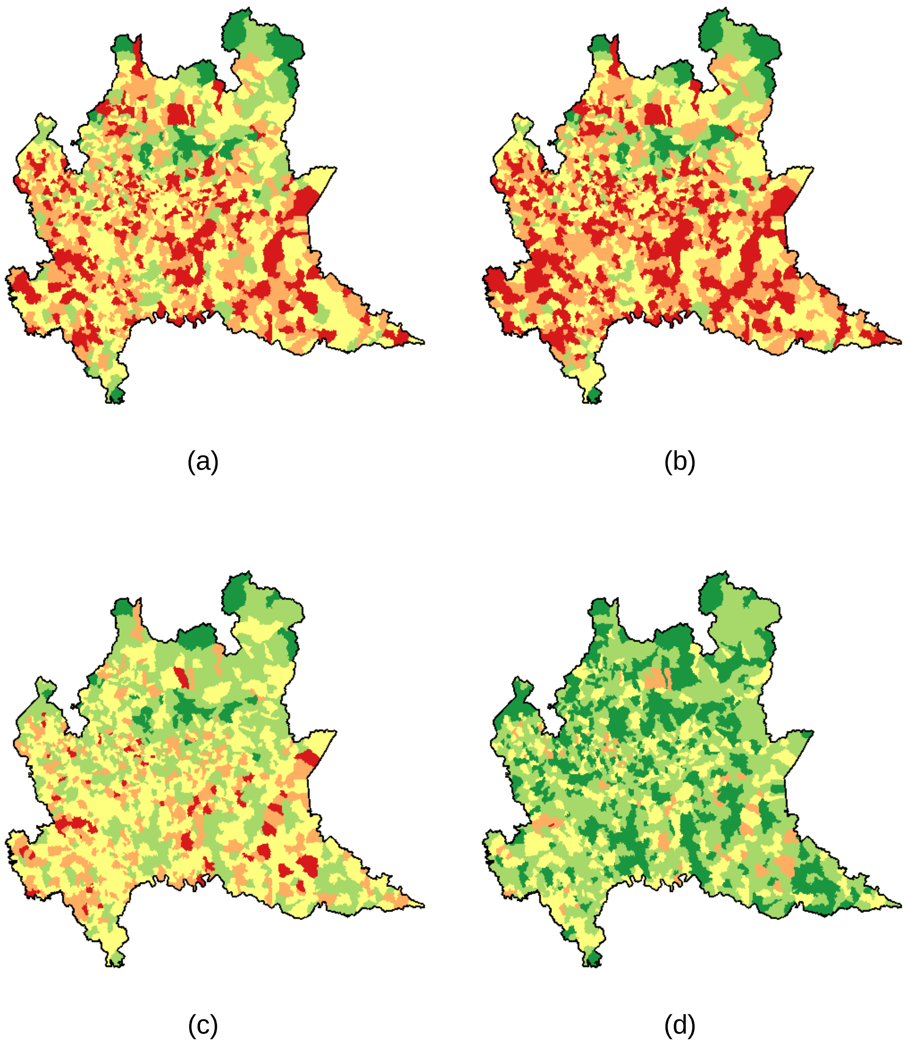


Figure 9. Annual precipitation frequency in Lombardy

(a) ≥ 10mm/h

Legend:

> 30

< 24

(b) ≥ 20mm/h

Legend:

> 13

< 10

(c) ≥ 50mm/h

Legend:

> 2.0

< 1.25

(d) ≥ 100mm/h

Legend:

> 0.5

< 0.2

4.2. Hail

The hail is an extreme weather event that can cause high damage to both agriculture and other human activities. Hail forms inside thunderstorm cumulonimbus clouds, known as supercell storm, mainly those with intense updrafts, high liquid water content, great vertical extent, large water droplets, and where a good portion of the cloud layer is below freezing temperature.

The growth of hailstones in thunderstorms has been described in Browning & Foote (1976) in three stages as indexed in Figure 10:

- small particles grow during a first ascent (a) in a region of relatively weak updrafts on the right flank of the main updraft by accretion of supercooled water droplets;

- some of these particles travel within weak updrafts (b) around the forward edge of the main updraft (embryo curtain) before entering the core of the main updraft as embryos with a diameter of several millimetres;
- although there might be minor oscillations owing to small fluctuations in updraft intensity, these recycled embryos gradually grow from graupel into hailstones (diameter > 5 mm) essentially during a single up-and-down trajectory.

As a result, hailstones reveal different shells (onion structure) with layers that can be either dry or wet, depending on whether or not all of the accreted supercooled droplets can be frozen by the forced ventilation process of heat conduction and evaporation from the hailstorm surface.

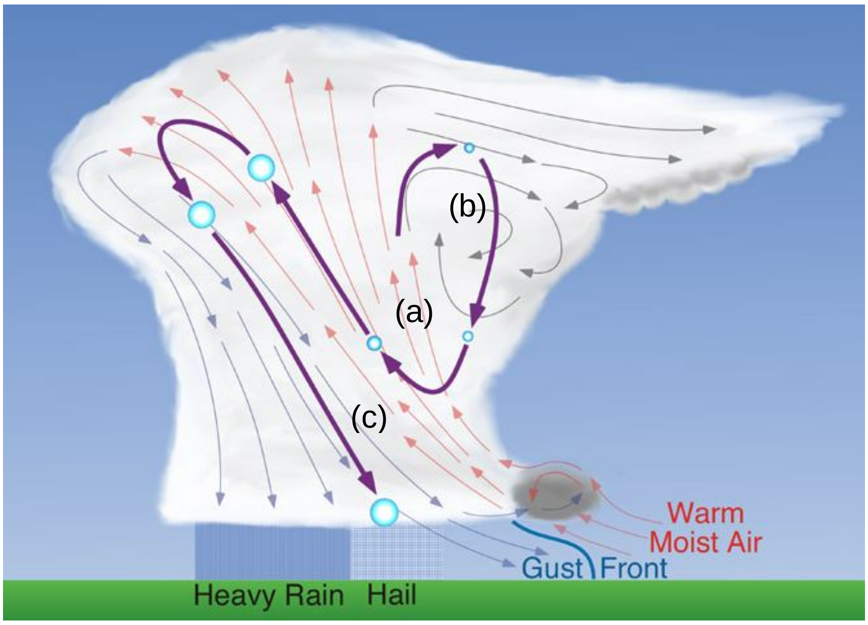


Figure 10. Hail formation in a supercell storm

(source Pidwirny 2006)

Once hailstones fall out of an updraft zone and start falling towards ground, melting starts below the 0°C isotherm as an influence of the fall distance between freezing level and ground, mean temperatures of downdrafts and fall velocities depending on the size and density of the hailstones.

During and after a hail storm the temperature is lowered (10°C could even drop in half an hour), because the solid ice to become liquid extracts heat to the atmosphere, sometimes with the possibility of generating some tornadoes.

This hail phenomenon is typical of areas located in the vicinity of large mountain systems, and therefore the northern Italy is particularly exposed. According to Nanni (2004), weather patterns are associated mainly two hail events in North Italy:

- A flow from the northwest with a cold front approaching the Alps;

- A flow from the southwest associated with a trough or depression at the middle troposphere, Western Europe.

The hailstones, which size can be like a pea but can reach also that of a walnut, an egg or even an orange, can get very high speeds, especially when their fall is associated with descending currents in the cumulonimbus, the current that often can reach speeds of 50-100 km/h. These current descendants are able to produce a significant increase in damage. In presence of a hailstorm, high winds can increase the kinetic energy or hailstones and blow them at angles significantly off the vertical, thus increasing damages against crops.

The phenomenon of hail is very variable in time and space – sometimes in a few meters away it is possible to pass from an area with heavy damage to an area completely free of them.

According to Hohl (2001), most damaging hailstorms produce large numbers of medium-sized hailstones, whereas only a small percentage are giant hailstones. Patterns of hailfall on ground reveal a fragmented structure on both temporal and spatial scales, where the average area affected by hail is usually only a few tens of square kilometres large.

According to Khan et al. (2009), on annual basis, hailstorms cause more than 1 billion dollars in property damage in United States.

Efforts for mitigation of hail damages had started before science was able to explain hail formation and processes. In the 14th century, people in Europe attempted to ward off hail by ringing church bells and firing cannons. Hail cannons were especially famous in the vine-producing regions of Europe during the 19th century, and modern versions of them are still used in parts of Italy. After World War II, scientists across the world experimented with cloud "seeding" as a means of reducing hail size. Cannons that fired silver iodide into thunderclouds from the ground were also used.

The methods of defence against the hail will not be further discussed in this study.

4.2.1. Hailpad device

The hailpad is a simple and low cost device created to measure the impact of hailstorms and analyze the hailstones distribution (Long *et al*. 1980). The physical parameters from the hailstones are measured in laboratory by the calibration between the sensitive material in the hailpad and the hailstone.

Basically, a hailpad is a square of Styrofoam covered in heavy duty aluminium foil, placed in an open area subject to the atmospheric events. After each hailstorm, the pad is changed and passed by a treatment with roll paint, usually in dark colour, to give it a high contrast and make it able to an automatic scanner software. Figure

11 show some examples of different intensity hailstorms measured by the Trentino Alto-Adige hailpads network.

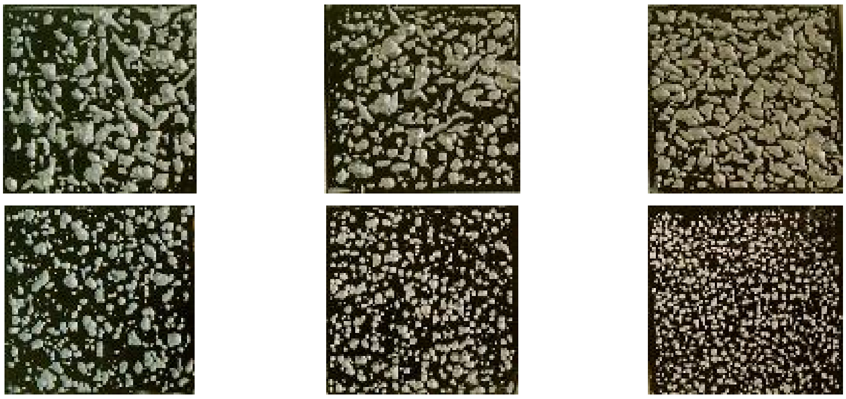


Figure 11. Hailpad examples

(source IASMA)

A hailfall is a complex phenomenon and one single event can be different from another in many factors, as:

- time of onset, duration;
- internal structure of hailstones;
- shape, size, hardness and density;
- terminal velocity.

According to Griffith & Morgan (1976), for the purpose of studying the relationship between hailfall measurements and crop damage, not all of these factors are available or even of interest. Many of the complications of hail measurement with hailpads are removed by making certain assumptions:

- all stones which dent hailpads are of equal but unknown hardness;
- all stones are spherical;
- all stones fall at their terminal velocities and move horizontally at the speed of wind;
- each stone strikes the hailpad once;
- timing (onset and duration) is unimportant to the damage process.

The main problem in this analysis is the determination of the dependence of crop damage on a function of the hailstone size distribution. Ordinarily, crop damage means the percent loss of yield.

4.2.2. Hailpad networks in Italy

Hailstorms are most common in middle latitudes during early summer where surface temperatures are warm enough to promote the instability associated with strong thunderstorms, but the upper atmosphere is still cool enough to sustain ice.

The most favourable hail period is when the storms are more frequent and can therefore be extended from March to November. However, the most intense hailstorms are typical of the summer, when the atmosphere, full of energy, can give rise to the phenomena of increased violence.

Unfortunately in Italy there are few hailpads networks, considering both the active and those already disposed and the information produced by them have different level of quality and spatial and time coverage various.

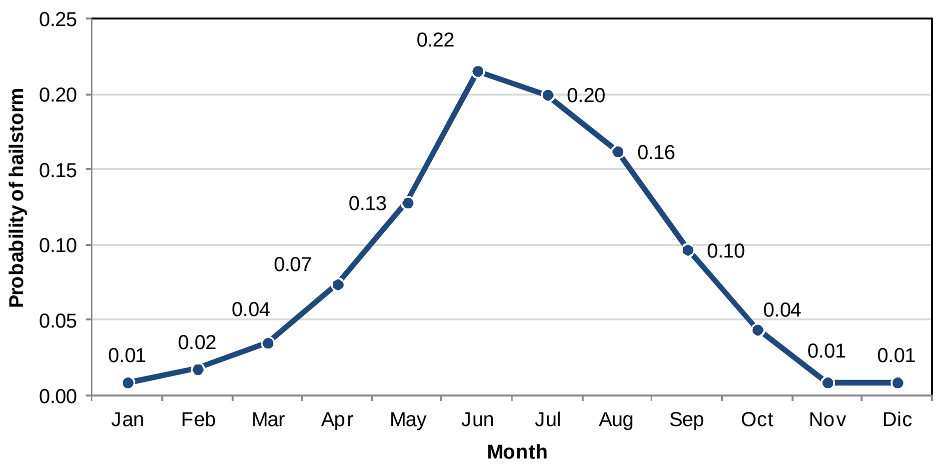
All networks belong to the north of Italy and their main features are presented in Table 4. There are currently no reliable hailstorms time series in Lombardy.

Table 4. Italian hailpads networks

Network	Operation period	Variables
Trento Province	Since 1974 274 active stations	number of hailstones for each size fraction; total kinetic energy for event; total number of hailstones;
Emilia-Romagna Region	1983-1998 427 disabled stations	number of hailstones for each size fraction; hailstone sizes; surface area affected
Friuli-Venezia-Giulia Region	Since 1989	Hailstone sizes; kinetic energy for event
Piedmont Province	Since 2003	No info available

From the analysis of information of these networks, the yearly distribution of hailstorms is presented in Figure 12.

Figure 12. Yearly probability of hailstorms in Northern Italy



This graph confirms that in the period from May to September are placed more than 80% of events in Northern Italy. June and July are the months with biggest probability, responding together to more than 40% of all yearly events.

4.2.3. Hail hazard maps in Lombardy

An exhaustive work been made to build a hazard map of hail events in Italy. According to Baldi, et al. (2011), information for different databases like Italian hailpads network, compensation claim reports, meteorological stations from Italian Air Force, regional hydrologic networks and ESSL hazard database are be acquired to realize the maps presented at Figure 13.

These maps are a representation of annual frequency of hailstorms divided by hailstones grain size. Figure 13.a is the frequency of events having hailstone between 5 and 10mm.

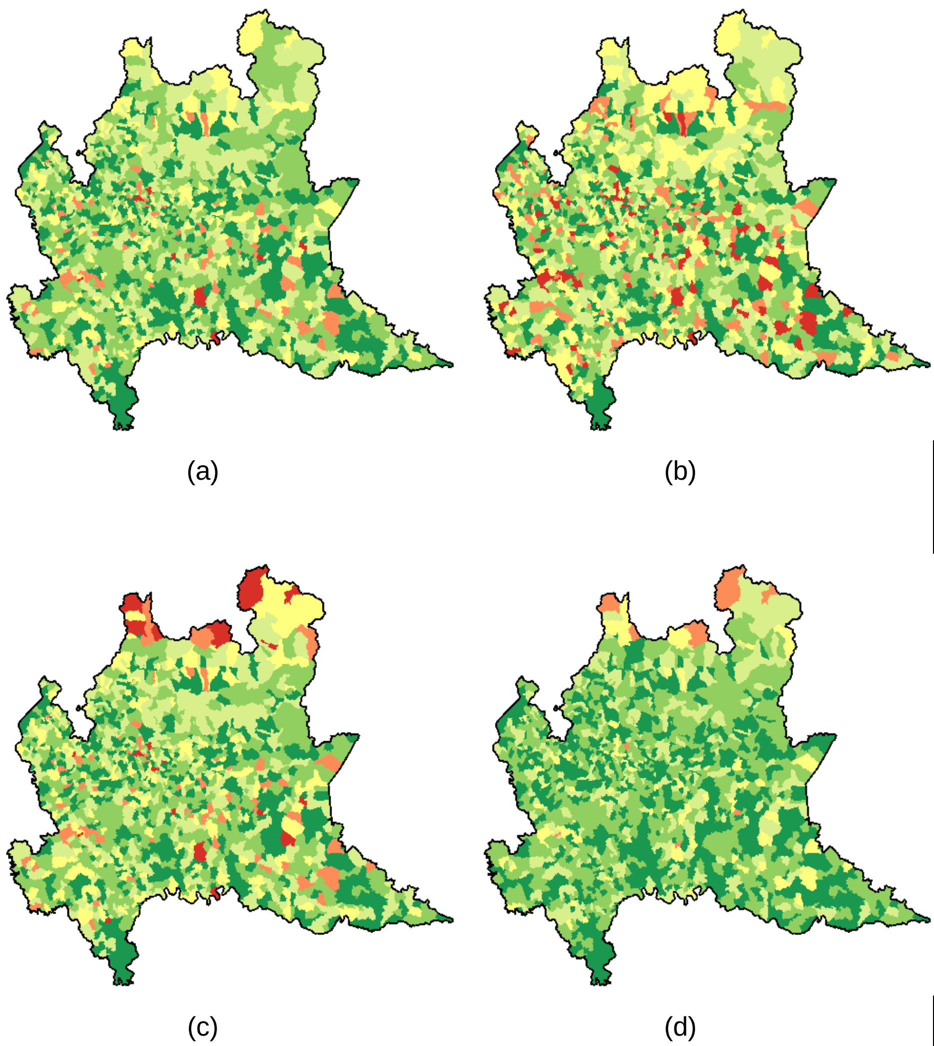


Figure 13. Annual hail frequency in Lombardy

(a) 5-10mm

Legend:

> 2.5
2.0 – 2.5
1.5 – 2.0
1.0 – 1.5
0.5 – 1.0
< 0.5

(b) 11-15mm

(c) 16-20mm

(d) > 20mm

Legend:

> 0.5
0.4 – 0.5
0.3 – 0.4
0.2 – 0.3
0.1 – 0.2
< 0.1

This is the most common event and, theoretically, the less dangerous to the crops due the small hailstone size. Classes intervals indicate the frequency of events of that magnitude in one year, for all municipalities in Lombardy region, calculated with a base data of 10 years information. In Figure 13.a, it is possible to note that there is a low correlation between frequencies and localization of municipalities, this fact is justified with a by the high spatial variability of hailstorms.

In the same way, Figure 13.b, Figure 13.c and Figure 13.d present frequency distributions to bigger hailstones, that from 11 to 15mm, from 16 to 20mm and more than 20mm, respectively. In these maps we can observe a trend to higher frequencies in municipalities located in mountain areas (northern region) and lower frequencies for Po valley region.

4.3. Freeze and Frost

Blanc *et al.* (1963) defines the word “frost”, technically, as a formation of ice crystals on surfaces, either by freezing of dew or a phase change from vapour to ice, however, the word is widely used by the public to describe a meteorological event when crops and other plants experience freezing injury.

Second Snyder & Melo-Abreu (2005) in their FAO report, a “frost” is the occurrence of an air temperature of 0°C or lower, measured at a height of between 1.25m and 2.0m above soil level, inside an appropriate weather shelter. Water within plants may or may not freeze during a frost event, depending on several avoidance factors. A “freeze” occurs when extracellular water within the plant freezes, changing from liquid to ice. This may or may not lead to damage of the plant tissue, depending on tolerance factors (e.g. solute content of the cells). A frost event becomes a freeze event when extracellular ice forms inside of the plants.

“Freeze” injury occurs when the plant tissue temperature falls below a critical value where there is an irreversible physiological condition that is conducive to death or malfunction of the plant cells. This damaging plant tissue temperature is correlated with air temperatures called “critical temperatures” measured in standard instrument shelters.

Subzero air temperatures are caused by reductions in sensible heat content of the air near the surface, mainly resulting from a net energy loss through radiation from the surface to the sky or a wind blowing in subzero air to replace warmer air, or even by some combination of the two processes.

Frost damage can occur in almost any location, outside of tropical zones, where the temperature dips below the melting point of water (0°C). The amount of injury depends on the crop's sensitivity to freezing at the time of the event and the length of time the temperature is below the "critical damage" temperature.

5. Agricultural concepts: the vulnerability

The second pillar of this study is the agriculture. It is important to know well the crops studied, the time of seeding, the dynamics of development and condition of ripening and harvest, as well as the final destination of the market that will.

According to Borin et al. (2003), phenology refers to the segment of Botany responsible for the study of the different stages of plant development such as germination, emergence, vegetative growth and development, flowering and fruiting, ripening, marking their times of occurrence, characteristics, the correlations between each other and with environmental factors, thus becomes an indispensable means to produce quality food and the environment.

Knowing phenological aspects of species with economic importance constitutes an effective tool in crop management. This knowledge allows identification, through observation of morphological characteristic of the plant, its actual physiological stage, which is linked to a series of needs from the plant. The satisfaction of these needs will allow the normal development of the crop and hence good yields.

The importance of the study on the phenology of a plant is explained in the following key facts:

- To identify and understand the relationships between plant and environment. The demands and responses of a plant to certain environmental factors may vary with the type of culture, however, the action of the environment is not the same during the various stages of plant development;
- Enables the identification and / or making decisions about the production system adopted, suitability climate, cultural practices, application of supplies, timing and methods for harvesting;
- Establishes relationships between climatic factors and physiological, and helps prevent plant diseases and evaluation of cultivation techniques, in order to maximize the performance of cultivated plants.

In this study, five different agricultural species are be considered – wheat and corn (cereals), soybean (oilseed), apple (pome fruit) and grapes (vine). – passing into major groups of cultivated crops in the area of study.

This chapter will describe the phases of the growth cycle and the phenomena observed on the plants, which may be relevant to the vulnerability of each species in each phase.

5.1. Wheat

The grain of wheat is destined for milling and production of flour, meal and bran. With durum wheat is produced semolina rough (pasta) and baking flour. Wheat life cycle is normally divided into the following phases:

- Germination, emergence, and establishment: Germination (Figure 14.a) begins with minimum temperatures of 2-4 ° C and optimum of 20-22°C, completed in 3-5 days. The process begins with the leakage of the radicle from the caryopsis. The first leaf (Figure 14.b) exit from the pericarp and the epicotyl increases a few days after. The end of the epicotyl consists of a node, called tillering or vegetation node. Then develop the next and leaves the plant strengthens against the rigors of winter;
- Tillering and dormant: the tillering (Figure 14.c and d), i.e. the development and increased of shoots starts after the output of the third leaf. In two or three winter months, many cultivars there is a stagnation of growth but not development, since there is a continuous progression of differentiation of the organs that will occur in spring, with the growth itself.
- Rising: begins with increasing temperature and when there is a gradual decrease in humidity (Figure 14.e). The first stages of rising are very slow, first is a straightening of the shoots that lasts 2-3 weeks. At the beginning of rising it has also the simultaneous differentiation of the ear. The rising is manifested by the elongation of the internodes which are pulling out gradually as the elements of a telescope;
- Heading emergence: by the gradual relaxing of the ear internode is pushed up and thickens (Figure 14.f). The output of the ear (Figure 14.g)occurs 10-20 days later;
- Flowering: The flowering period (Figure 14.h) is 1 week after earing. In the same plant anthesis takes 6-8 days, with stops in the middle of the day if the outside temperature exceeds 23°C;
- Maturation: the conclusion of the flowering plant reaches out to transfer into the caryopsis in formation all substances produced in various organs. The maturation phase (Figure 14.i) is usually divided into four parts: milky, waxy, full and of death, with an index humidity in relation to fresh weight of 70%, 40-50%, 15% and 12% respectively.

Were considered crops containing products intended for commercial purpose (processing of flour, semolina, etc.) intended for the human animal feed.

Figure 14. Wheat growth stages

(source Borin et al., 2003)

The damages can be divided into:

- Damages in vegetative stage: those that occur before the phase of heading emergence and cause nutritional deficiencies that have a negative impact on the production of grains. There are typical damages found in this period: decked leaves, the beatings and bending to the culm and the plants death from hard criticism at the base.
- Damages during reproductive stage: those that occur starting from heading emergence phase, like curl of the ears, loss of kernels, plants truncated or death.

The wheat base temperature is 2-4°C in seeding phase and optimal temperature is 18-22°C in rising.

5.2. Corn

The corn crop, when harvest in mature waxy phases, is destined to feed livestock. When the grain is mature can be used to manufacture flour, sweet biscuits.

Due to the similarity among these species, the following considerations are valid for corn grain, sweet corn and the corn for seed.

The growth cycle of corn takes place during the period between spring and autumn and there are the following steps:

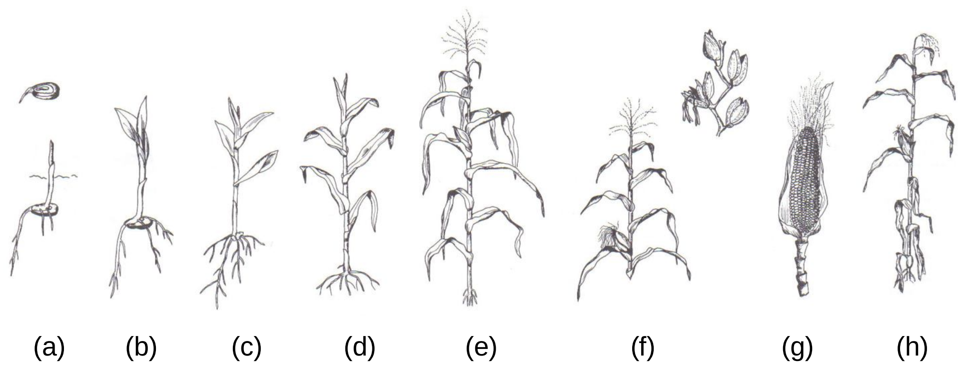
- Germination, emergence, establishment: the first organ to escape from the enclosures is the embryonic radicle (Figure 15.a), but later embryonic lateral roots, smaller than the primary. The duration of this period varies depending on the temperature: it is only 5-6 days with average temperatures around 21 ° C and 8-10 days at 17 ° C and rises to 18-20 days at 12 ° C. Subsequently other leaves and secondary roots permanent emerging in about 14-days Figure 15.b and c);
- Rising: differentiation starts from vegetative apex and then the subsequent development of the remaining leaves (Figure 15.d). This phase ends about 4-5 weeks after seeding and the plant reaches 40-50cm in height. At the end of this phase

starts the differentiation of the apex male inflorescence (Figure 15.e) and 8-10 days after the female one (Figure 15.f), placed below the male. The rising starts from 5-6 weeks after seeding and takes 4-6 weeks, with the emission of the plume;

- Flowering and fertilization: after a few weeks stigma-styles appear on the ear. Once the pollen grain has been retained by the stigma, within 24 hours emits a long pollen tube and fertilization occurs. The scaling of pollen maturation and stigmas issue can often lead to a lack of fertilization of ovules apical, resulting in a lack of grain (Figure 15.g).
- Filling the seed and maturation: after fertilization, within 10-12 days there are the differentiation embryonic organs followed by filling, the accumulation of starch in caryopsis, which has a white colour and become yellow, more intense (Figure 15.h).

Figure 15. Corn growth stages

(source Borin et al., 2003)



Crops containing products intended for commercial and animal feed purpose must be considered.

There are three types of damage to consider: damage to the foliage and to the culm: they can avoid the final development of the product; Loss of kernels, which is the direct damage on the ear. The corn base temperature is 8-10°C in seeding phase and optimal temperature is 23-25°C in flowering and seed filling.

5.3. Soybean

The interest in this crop is mainly due to the seed oil content (18-21%) and in crude protein (38-41%). The soybean flour is placed in strong competition with other protein concentrates for human consumption and livestock.

- Germination, emergence and establishment: The hypocotyl emerges from the seed that in 5-10 days stretches out, bringing the two cotyledons, still closed. When it opened its first leaves develop in a few days. The first ramification occurs when the radicle reached 2-3cm. The emergency is faster if the soil contains adequate water availability and temperature around 10 ° C. Soy may also emerge at lower temperatures, equal to about 4.5 ° C and 7-9 ° C, respectively, as a critical temperature day and night.

- Vegetative growth: The first trifoliate leaf, covered with hair, spread 15 days after emergence. Soybeans also formed branches, which may originate both from axillary buds of cotyledons, both from those of true leaves. The number of branches depends on genetic factors, the density of seeding and soil fertility.
- Flowering: The flowering period lasts about a month, depends from the time of seeding and variety, and begins when the plant has developed about 3-4 true leaves. In full bloom, there will be an opened flower on one of the nodes higher than the main culm. Not all fertilized ovules turn into seeds. Abortion, in fact, cause yield losses of 60% compared to the predicted flowering.
- Formation of the pod: small pods are formed in a month (50-60 days from emergence).
- Development and maturation of the seed: The beginning of seed formation occurs when seeds are found of 3 mm in diameter. At the approach of maturity, the leaves change colour to yellow and fall around the same time period, when the seeds are still more than 50-60% humidity. The full maturity occurs when nearly all pods are toned in colour and begin to lose turgor. After this stage, it takes 5-10 days to dry so that the seeds reach the 15% moisture.

The cycle length can vary from 75 to 200 days. To define the earliness of a cultivar of soy cannot be ignored the latitude of cultivation. With increasing latitude should be used with the shortest cycle types.

Harvesting takes place when the seed has a humidity of 12-14% in certain periods of maturation from the group cultivated by climate zone and on the performance (usually located in the north, in the month of September).

The soybean base temperature is 7°C in germination phase and optimal temperature is 24-25°C in vegetative growth.

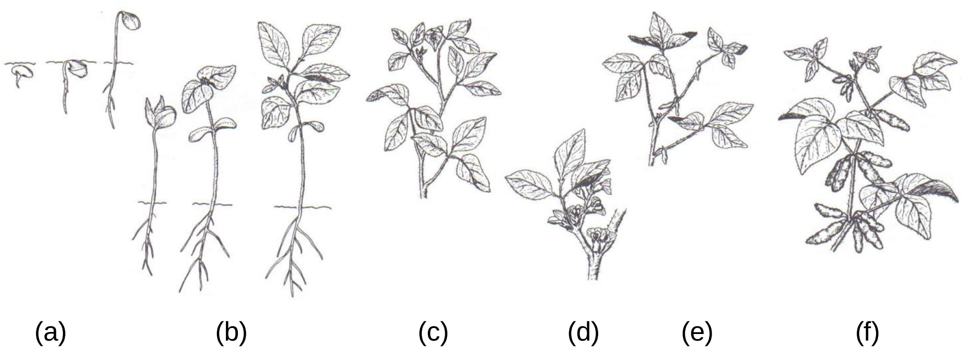


Figure 16. Soybean growth stages

(source Borin et al., 2003)

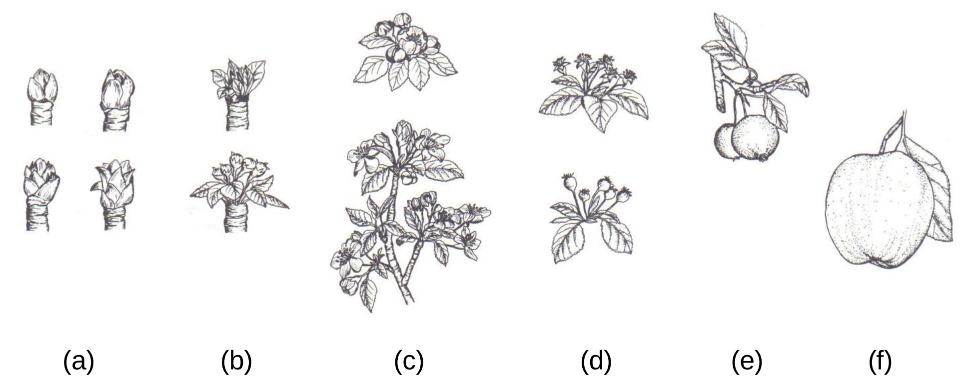
5.4. Apple

The apple has a multi-year life cycle and its vegetative growth is given with the following steps:

- Hatching gems: fruitful production is present in different percentages in the various cultivars on the basis of genetic characteristics, so the fruiting may be prevalent from time to time in different branches. The processes of induction and differentiation of the buds begin just over one month after flowering. The differentiation of floral organs and shuts down is very slowly in the colder winter months, to resume in early spring.
- Vegetative growth: The leaves normally appear alternately on the branches and very close to the limited size of the internodes. A mature tree can ragging medium high, up to 8-10 meters in height, the canopy in the wild adults have spherical shape up like an umbrella.
- Flowering and fruit set: The flowers are gathered in groups of 4-9 of a typical inflorescence. When the central flower opens it is between 5 and 15% of flowering. This phase passes quickly, especially if the temperature is high. The apple tree is self-incompatible and therefore it is essential the association of two or more varieties with contemporary flowering and cross-compatible.
- Fruit development and ripening: The fruit swells and reaches the central diameter of about 2.5 cm, when the seeds, cuneiform, are visible and remain unclear. Following a progressive enlargement of the fruit to reach the final size. During this phase occurs the arrest of the shoots. With the maturation of the fruit takes on final color with an increase of sugars and reduction of the consistency of the pulp.

Figure 17. Apple growth stages

(source Borin et al., 2003)



The destination is mainly eaten fresh, but apples can be kept for a long time in cold storage. Considerable interest to the industry for the production of jams, juices and cider.

The distribution of the apple of very different climatic zones shows the remarkable plasticity of this species in regard to environmental characteristics. The apple tree is a hardy plant and good resistance to winter cold, but is sensitive, however, the late frosts, more so the flowering is early.

Collier et al. (2008) describe as vulnerable stages for the apple bud break, flower initiation, flower development and fruit growth. His work defines that the high temperature in summer can be adverse especially in flowering stage. A winter not so cold, instead, can help an early bud break and increase the frost susceptibility.

According to Tartachnyk & Blanke (2008) The stomatal closure within 3 min after hail injury led to a 16% decline in evapotranspiration and a severe reduction of 33% in photosynthetic CO2 assimilation at the affected leaf area during the first 15min. Recovery in both transpiration and photosynthesis commenced after 3h.

The negative effects of hail on the first fruits are related at the time when the phenomenon occurs and its intensity. Hailstorms early, mild, affecting the fruit in the early stages of development can sometimes cause damage partially "absorbable" and that will not devalue the product completely, on the contrary, if the phenomena are very violent, the damages are likely to cause irrecoverable deformation in the fruit and, often, injuries to the vegetative parts of the canopy, which also have an impact on the future of the vegetative-reproductive plant. The hail early hardly leads to rotting of the fruit, as is the case. However, when hail strikes in the vicinity of the harvest and damage are most often compromising production (healing interventions have significant effects only in certain circumstances).

The hailstorms can determine, with the same severity of the event, different damage depending on the species and variety, even if it hardly induces targeted production choices. The varieties of apple with thin and delicate skin, such as Golden Delicious and Fuji, are damaged usually much larger than other cultivars that have a skin thicker and more resistant, such as Red Delicious.

The Italian insurance legislation provides that in the apple the only type of damage considered is direct damages relating to the fruit

The apple base temperature is 6°C regrowth and optimal temperatures are 20-24 ° C in vegetative growth stage.

5.5. Vine

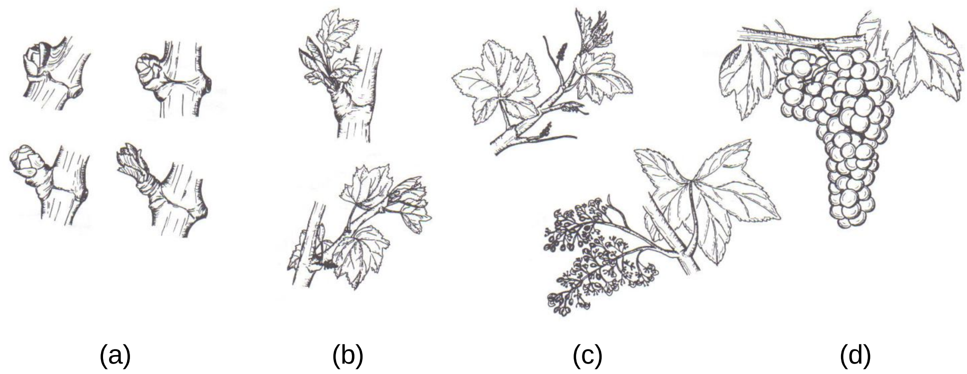
Vine has a multi-year life cycle and its vegetative growth is given with the following steps:

- Hatching gems: the grape brings mixed gems, whose differentiation is accomplished in the spring preceding the year of fruiting. Then enter into the bud dormancy. Germination begins when the temperature takes values around 7-12 ° C and lasts about 10 days;

- Vegetative growth: The growth of the buds reaches maximum intensity until 1-2 weeks before flowering in the early stages of the berry development and then decreased with advancing season. In late summer, the leaves turn yellowish in colour at white grape varieties in red and those at black grapes. The subsequent fall is generally from the base toward the apex, in the order of formation.
- Flowering: With leaves already well developed, the plant begins to make visible the small clusters, which, with the increase, they separate. So the buds appear. Inside the flower, there is a lag of one week between the maturation of the pollen and the hatching of the flower. The duration of flowering is quite variable and lasts for 4-8 days in the bunch and 9-21 days in the plant, in relation to the growing area and seasonal trends.
- Fruit maturation: The growth of the grapes is characterized by a series of chemical transformations, physics and anatomy. This period can be divided into four parts: herbaceous (lasts 25-50 days with an intense increase the berry), veraison (lasts 4-30 days with completion of the structure of seeds and the changing colour of grapes), the closure of grapes (after they have reached final size) and maturing (55-65 days after the onset in Northern Italy, so when the sugars increase and decrease of organic acids).
- The cultivation of grapes for winemaking has spread virtually throughout Italy, where the climatic conditions allow. The maturation process is strongly influenced by the climate: in fact, in northern Italy is conditioned not so much by the low temperatures, but the global radiation in the period from germination to veraison. In southern Italy, however, the limiting factor is water: in fact, a deficiency during growth can actually stop the ripening.

Figure 18. Grapes growth stages

(source Borin et al., 2003)



Grape base temperature is 4-5°C in *bud break* and optimal temperature is 18-26°C in maturation.

According to Vinet (2001), hail damages on grape crops appear on the most fragile cultivations starting with 10 J/m^2 and beyond 300 J/m^2 the crop loss is total. If hail occurs during fruit set, the grape, which is in the process of cell division, can heal the wound, while if it occurs during ripening, undergoing cell distension, the damage is more serious because the grape no longer heals. In addition, the damage can be aggravated because the wounds to increase the likelihood of attack by rot and gray mold.

6. Crops distribution: the exposure

This chapter will treat of last pillar of risk definition: the exposure.

In next paragraphs different points of view will be discussed. First, an analysis of the spatial distribution of crops and quantity of production for all cultures studied and then a temporal examination using growth calendars of each species are going to be done.

6.1. Cultivated area: spatial exposure

The first way to evaluate the exposition of a certain crop in a weather event is calculate the quantity of product subject to damages. This quantity can be express in products weight (or units) or cultivated area. Table 5 has the extent of cultivated area for three years in each of provinces of Lombardy for five crops analyzed (wheat, corn, soybean, apple and vine).

Table 5. Cultivated area in Lombardy region (2008 to 2010)

(source ISTAT)

values in km^2

bold rows represent the average to the available period

Crop	BG	BS	CO	CR	LC	LO	MB	MI	MN	PV	SO	VA
Wheat	**45.1**	**85.7**	**5.2**	**134.4**	**4.2**	**42.4**	**4.6**	**91.0**	**301.4**	**158.4**	**0.0**	**6.4**
2008	51.7	101.5	7.0	161.7	5.0	52.2	0.0	123.5	321.5	194.9	0.0	9.4
2009	42.6	81.6	3.6	124.2	3.5	39.7	0.0	92.1	302.9	150.2	0.0	5.3
2010	41.0	74.0	5.1	117.2	4.1	35.2	13.8	57.2	279.7	130.0	0.0	4.5
Corn	**128.3**	**493.2**	**22.6**	**577.7**	**11.2**	**224.0**	**9.5**	**203.0**	**466.3**	**225.3**	**1.3**	**12.9**
2008	140.4	511.0	24.7	610.0	11.1	237.0	0.0	224.0	505.0	260.3	1.3	12.8
2009	126.0	500.0	24.1	573.0	12.0	230.0	0.0	218.0	460.0	225.5	1.3	13.2
2010	118.6	468.5	19.0	550.0	10.5	205.0	28.5	167.0	434.0	190.0	1.3	12.5
Soybean	**4.4**	**12.5**	**3.1**	**33.5**	**0.2**	**16.3**	**1.2**	**15.3**	**78.6**	**36.7**	**0.0**	**1.2**
2008	2.3	5.9	1.2	15.2	0.0	6.9	0.0	6.3	50.4	28.5	0.0	0.9
2009	4.0	12.8	3.0	40.0	0.1	17.2	0.0	20.7	94.5	35.1	0.0	1.1
2010	7.0	18.6	5.1	45.3	0.4	24.8	3.5	19.0	90.8	46.6	0.0	1.7
Apple	**0.8**	**0.8**	**0.2**	**0.2**	**0.0**	**0.0**	**0.0**	**0.2**	**3.2**	**3.4**	**18.1**	**0.2**
2009	0.5	0.7	0.1	0.1	0.0	0.0	0.0	0.2	2.1	2.5	12.3	0.1
2010	1.0	1.0	0.2	0.3	0.0	0.0	0.1	0.2	4.3	4.4	24.0	0.2
Vine	**7.4**	**50.4**	**0.2**	**0.5**	**0.6**	**0.3**	**0.0**	**2.2**	**16.6**	**127.8**	**10.9**	**0.2**
2008	7.5	51.2	0.2	0.6	0.7	0.3	0.0	2.2	17.0	129.4	11.1	0.2
2009	7.3	49.6	0.2	0.5	0.6	0.3	0.0	2.3	17.2	127.7	11.0	0.2
2010	7.3	50.5	0.2	0.5	0.6	0.3	0.0	2.2	15.7	126.3	10.8	0.2

Table 5 values can be confirmed analyzing the map of Figure 19. This map was build using DUSAF data, interpretation of aerial photos made initially in 1998/1999 and updated in 2005, 2006 until to reach the actual version with a aerial photos campaign of 2007.

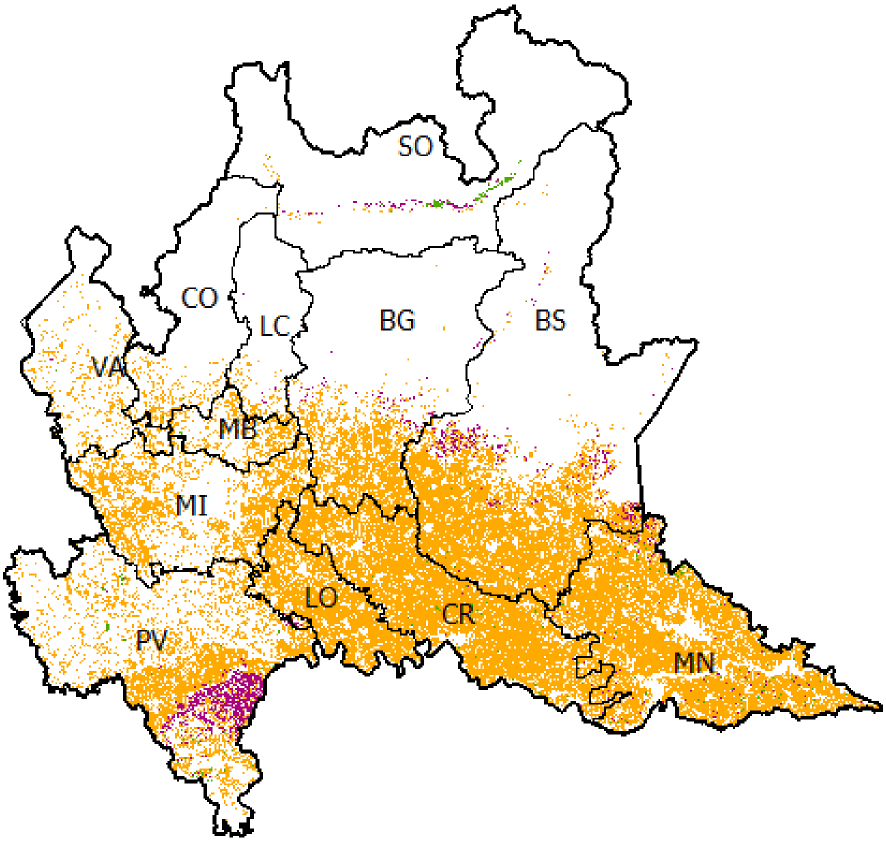


Figure 19. Crop areas in Lombardy

(source DUSAF)

Legend:

According to ERSAF (2007), “crops class” includes all arable crops (not only wheat, corn and soybeans). In an analogue way “fruits class” contain all kind of orchards (not only apples).

From the map of Figure 19, it is possible to note that the Po Valley zone has a higher concentration of arable crops in Lombardy, especially Cremona (CR) and Mantua (MN) provinces. The higher quantity of vine is placed in province of Pavia (PV). In Milan (MI), despite the extent urbanization, there is a considerable area used with agriculture sector. Northern provinces like Como (CO), Lecco (LC), Bergamo (BG) and Brescia (BS) have two different situations, with a south area where is present a relative agriculture and a north side occupied by other land uses (like pastures or vegetation). Province of Sondrio (SO) has a higher concentration of fruit cultivation, and, as shown in Table 5, there is a huge area used to apple culture, the biggest in entire Lombardy region.

Other approach to the exposure is thinking about the quantities of production. Table 6 presents the total production weight for five products analyzed (wheat, corn, soybean, apple and wine) for past three years in each of provinces of Lombardy region. Results of this table are in accordance with those of Table 5 because, respecting the tax of production, the weight following the same trend of surfaces table results, i.e. highest exposure of vine in Pavia (PV), for apples in Sondrio (SO) and the other cultures having an analogue behaviour.

Table 6. Production in Lombardy (2008 to 2010)

(source ISTAT)

values in tons

bold rows represent the average to the available period

Crop	BG	BS	CO	CR	LC	LO	MB	MI	MN	PV	SO	VA
Wheat	**272.9**	**497.5**	**25.0**	**835.8**	**20.0**	**274.9**	**25.6**	**504.4**	**1841.8**	**763.1**	**0.0**	**32.2**
2008	320.4	635.7	31.5	1006.8	22.5	356.8	0.0	695.8	2053.1	961.3	0.0	43.3
2009	253.6	435.3	18.2	773.2	17.3	275.4	0.0	470.6	1853.8	612.1	0.0	28.0
2010	244.8	421.3	25.3	727.4	20.4	192.6	76.7	346.8	1618.6	715.9	0.0	25.2
Corn	**1483.5**	**5393.4**	**172.4**	**6690.3**	**89.5**	**2807.7**	**72.0**	**2106.1**	**5125.3**	**2409.0**	**7.8**	**122.6**
2008	1955.0	6038.4	184.9	7015.0	88.4	3318.0	0.0	2352.0	5555.0	2808.6	7.8	125.1
2009	1316.7	4969.0	180.4	6618.3	95.9	2645.0	0.0	2186.6	4830.0	2305.5	7.8	121.0
2010	1178.8	5172.8	152.1	6437.6	84.2	2460.0	216.0	1779.8	4991.0	2113.0	7.8	121.8
Soybean	**15.8**	**41.4**	**13.7**	**147.4**	**0.6**	**73.4**	**3.0**	**45.9**	**314.3**	**120.7**	**0.0**	**4.4**
2008	8.5	21.5	4.6	66.8	0.1	31.1	0.0	18.7	201.6	77.2	0.0	2.3
2009	14.5	41.8	13.5	176.0	0.3	77.4	0.0	58.5	378.1	122.4	0.0	4.1
2010	24.5	60.9	23.0	199.3	1.2	111.6	8.9	60.4	363.2	162.5	0.0	6.7
Apple	**9.7**	**24.6**	**3.5**	**3.4**	**0.0**	**0.5**	**0.6**	**3.2**	**95.3**	**76.9**	**551.3**	**3.2**
2009	6.5	17.9	2.2	2.0	0.0	0.3	0.0	3.3	62.7	54.1	385.1	2.2
2010	13.0	31.4	4.8	4.8	0.0	0.6	1.2	3.2	127.8	99.6	717.4	4.3
Vine	**55.0**	**446.7**	**1.0**	**4.0**	**3.5**	**2.7**	**0.1**	**18.0**	**211.9**	**1016.4**	**67.6**	**1.0**
2008	54.3	411.0	0.8	3.4	3.4	2.7	0.0	15.7	220.4	1018.1	59.6	0.8
2009	55.3	410.5	1.0	3.6	3.5	2.6	0.0	19.9	211.3	1020.9	73.3	1.1
2010	55.3	518.6	1.0	5.1	3.5	2.6	0.2	18.4	204.1	1010.2	70.0	1.1

6.2. Phenologic calendars: temporal exposure

This chapter presents the phenogram, or diagrams in which individual phenological phases are placed in different periods of the year. This is a very delicate representation, because the phenological calendars may vary for the same species, with the environment of cultivation, the earliness of the cultivars, the adoption of specific techniques of cultivation, the destination of the product, which may anticipate or postpone phases of the cycle.

The determination of phenophase where a crop farm is located on a certain day of the year is a process that depends on various factors, including:

- The date of the cultivation;
- Variety of the species;
- Physiological condition of the plant (presence of a genetic problem);
- Characteristics of soil nutrients;
- Weather conditions in its growth (temperature and quantity of water appropriate to each stage);
- Existence of some type of diseases;
- Attack by predators.

To know and analyze all the special combinations that can be produced by these various factors can turn become this study of hard execution.

Surveys conducted Borin et al. (2003) respect these differences and represent the average situation of the growing areas most significant for each species, with reference to normal cultivation techniques. Thus, each time interval associated with a given phenophase indicates the most likely period when to find that particular stage of development, rather than the actual duration of the single stage.

The final graphs are presented in following Figure 20.

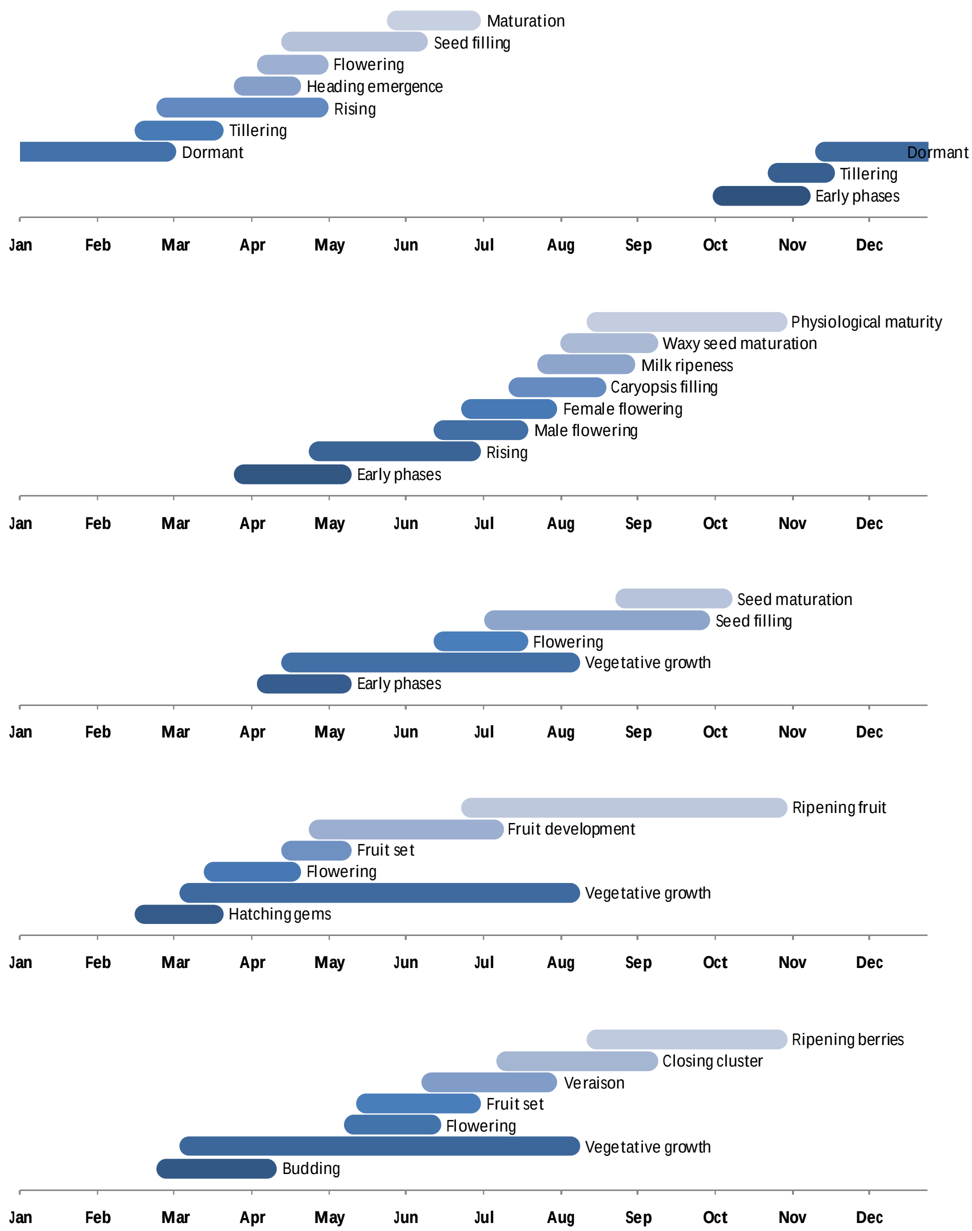


Figure 20. Phenologic calendars

(a) Wheat

(b) Corn

(c) Soybean

(d) Apple

(e) Vine

(source Borin et al., 2003)

In these graphs it possible to note suddenly a difference between the wheat cycle to the others. Cultivation of wheat starts in autumn and harvesting in early summer, while the other crops have germination at spring and maturation before the winter, in a same year. This difference could be an advantage to wheat for risk to hailstorms, because the most dangerous period is the summer, when, in normal conditions, the crop will not be in ground.

Very often there is overlap of individual phenological phases of the same species, even in the case of plants that grow in stages, because, at the same time it is possible to find the same species in different phenological moments, in relation to environmental conditions in which its cultivation occurs.

The information contained in this database involves:

- stages of growth of each plant analyzed;
- the probable date of beginning and end of each phase;
- the scope area of information;
- the minimum lethal temperature, under which the plant suffers irreversible damage to the death;
- the maximum lethal temperature, above which the plant suffers irreversible damage to the death.

7. Model calibration

Risk management was described in Chapter 2.1. In Figure 6 were presented the interlacing among hazard, vulnerability and exposure. Chapters 3, 4, 5 and 6 presented what is the behaviour of each one of these parameters and how can contribute to the risk formation.

The objective of this chapter is to quantify these parameters, sometimes expressed just in a qualitative way, and construct a risk map for the studied area showing, for each culture crop, where are the most dangerous municipalities.

7.1. Evaluation of hazard

From hazard maps presented in Chapter 4, estimate the hazard becomes a direct step. Those maps provide the values of frequency of a certain intensity of hazard, expressed in a percentage possibility to occurs in one year interval. Since the culture crops selected for this study have a maximum of one year vegetative growth cycle length, a value of possible bigger than 1 indicates a certainty of happening of 1 event with that magnitude.

7.2. Evaluation of exposure

For the analysis of the exposure, will be utilized information of the total agricultural area cultivated of determined crop in a certain municipality. In this way, the risk will be calculated related with a geographic parameter, to avoid to joining another parameter like productivity, to connect surface and weight of product.

It is important to make an assumption of the exposure will be consider directly proportional to total surface cultivated. So, a municipality with double of area of some product will have double chance to receive an event in the same period.

7.3. Evaluation of vulnerabiliy

This is the more subjective and qualitative parameter to estimate.

Define how is the susceptibility is not a simple operation. Each plant has different characteristics that are changeable on time and depending of a many environmental variables and cultivation method utilized.

To reduce this uncertainty, it is crucial to find a direct relation, where possible, between damages of a certain crop and the intensity of the weather event that suppose caused them.

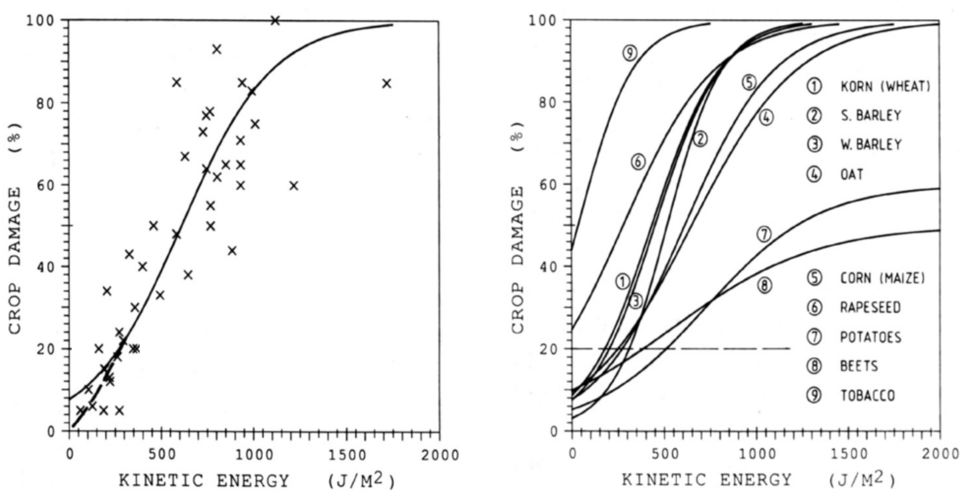
7.3.1. Kinetic energy as indicator of hailstorm intensity

Second Vinet (2001), kinetic energy of hail is the most commonly used indicator for measuring the intensity of hailstorms. Besides the ease of calculation, this indicator is favoured because it is synthetic: it integrates the number of hailstones per square meter, their diameter and their speed of fall proportional to the square root of the diameter. According to Schiesser (1990), there is good correspondence between hail kinetic energy and the amount of damage caused to agricultural crops. Beside, many studies – Changnon (1970), Vinet (2001) – have shown that among all the available indicators, kinetic energy is the one that has the closest correlation to hail damage to crops.

Figure 21 was taken from Hohl (2001) and presents a polynomial trend for the relationship between kinetic energy of a hail storm and damage caused to crops, in this case the wheat and corn, near to maturity. Crops least vulnerable, generally located in ground, have flat damage curves to hailfall, while steep damage curves indicate highest vulnerability to hailfall.

Figure 21. Damage curves on corn, wheat and other species

(source Hohl (2001)



Stanley & Changnon (1970) have studied damage in fields of wheat, soybeans and corn for a period of 3 years linking data from a network of registered hailpads to sinister within a distance of 200ft from the highlights in the hail.According them, wheat loss is well related to frequency of the larger hailstones but poorly related to the energy imparted by the hailfall, because in Illinois (area of study) the wheat is densely planted, resulting in a uniform distribution in a field, representing a substance crop compared with corn and soybeans crops. Since wheat is a relatively dense target for hail, it could be expected to experience greater loss as the volume of ice increases. Corn and soybeans losses are well relater to both energy and stone frequency, at least in their later growth stages.

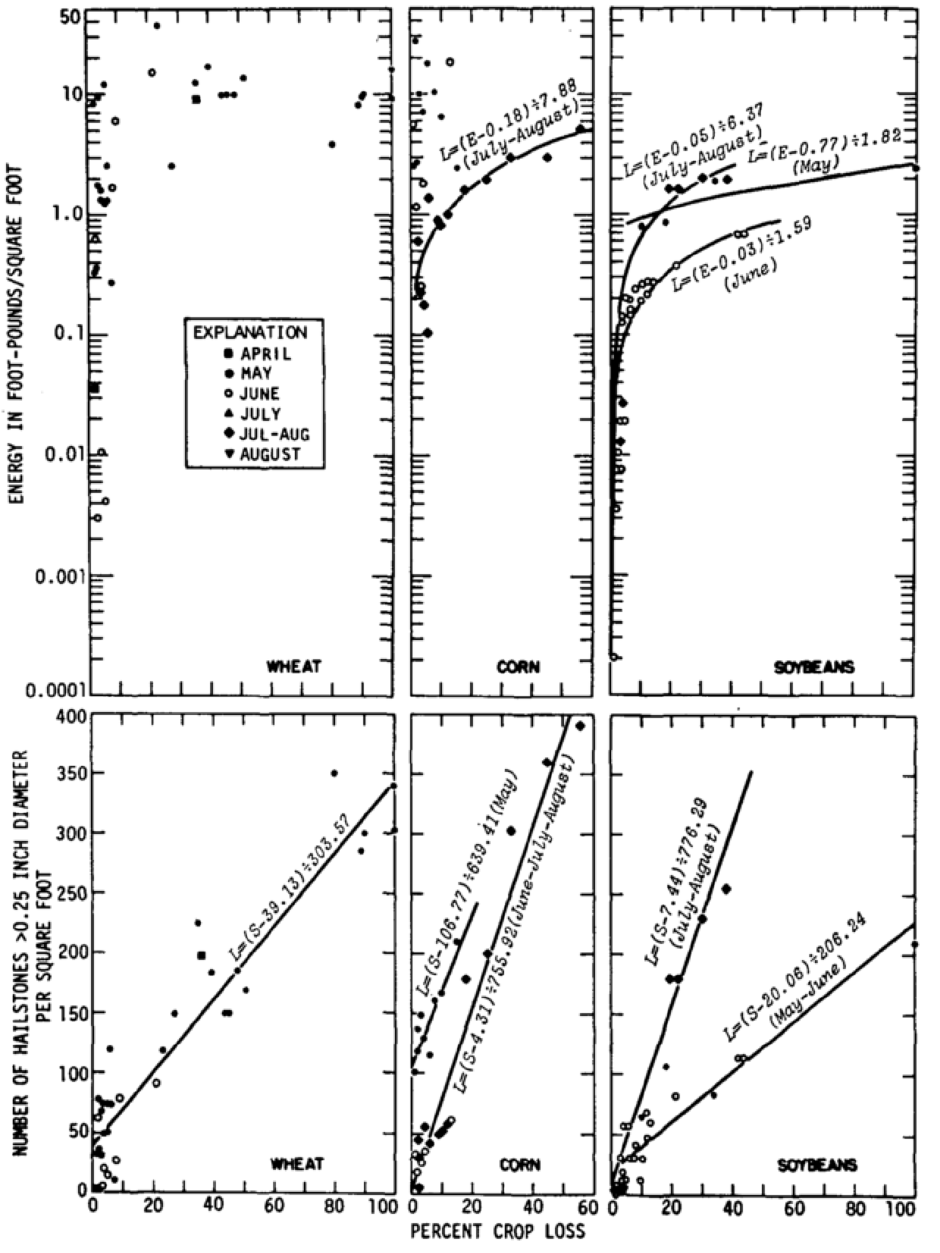


Figure 22. Damage curves on wheat, corn and soybeans

(source Stanley & Changnon, 1970)

The previous graph of Stanley & Changnon (1970), presented in Figure 22, shows that, for the corn, losses in May, when corn is emerging and quite small, show no relationship with energy, but they do correlate well with the frequency of hailstones. Furthermore, the vulnerability of corn to hail damage in June is bigger than May, because an identical storm causes three more loss in that month. Soybean susceptibility to loss in June is 30-100% greater than in July and August.

7.3.2. Crops damage investigation

Applying analogue methodology of Stanley & Changnon (1970) and Hohl (2001), in this chapter the relation between kinetic energy and crop damage will be calculated for apple and vine cultures. Data from Province of Trento are going to be used due to be a region with analogue physical, geographic and climatic characteristics with Lombardy, but mostly because Trento has a complete set of measuring stations, with a consistent and trust hailpad and meteorological networks.

The Province of Trento is known primarily by its production of fruits, especially apples and vine. In fact, according to ISTAT, in 2007 the production of apples and grapes occupied 7.1% and 6.7% of the total utilisable agricultural area respectively, and together reach almost 20.000 hectares and are the largest crops in the Trentino area (about 140.000 hectares). Not surprisingly, second ANIA, the crops that suffered the most damage for the period between 2007 and 2009 in Province of Trento are:

- different types of apples (61% of total complaints);
- different varieties of grapes (29%);
- cherries (3%);
- kiwi (1%);
- other crops representing the other 5%.

The initial step is to find the correlation between the kinetic energy of hail storms and the percentage damage caused on agricultural crops. To perform this analysis must be crossed data from hailpad network and insurance companies.

According to Eccel et al.(2002), the currently hailpad network of Province of Trento counts with 274 data points located in major agricultural areas, that can be viewed in **Errore. L'origine riferimento non è stata trovata.**.

The network is managed by a group of observers who collaborate with the institute. The panels used for the detection of hail are made from a square of side 15cm of polystyrene covered with a sheet of aluminium which is replaced after each event.

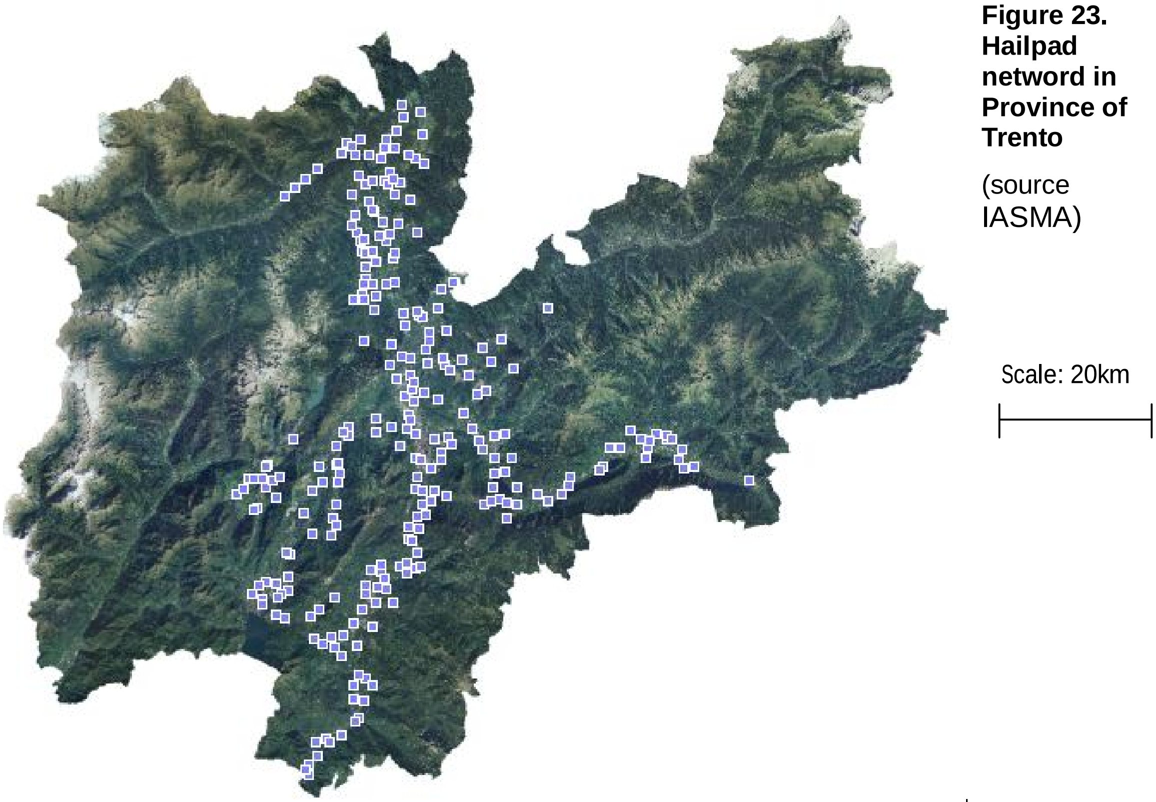


Figure 23. Hailpad netword in Province of Trento

(source IASMA)

Have been registered 836 hailpads affected for the period between 2007 and 2009, whose events are distributed between the months of May and September, with the period of greatest frequency in the month of July (40% of events).

Association between damage to crops and hailstorms is not an immediate activity because their databases are not linked. The main difference is that in damage database the only existing geographical reference is the municipality code where the sinister complaint has been made. Instead for the hail database, the exact coordinates where the hailpad is installed are known.

However, it is not possible to make a simple association and assume that a certain hailpad is representative for an entire municipality, because:

- many times there are several hailpads in the same municipality;
- many municipalities have no hailpads installed.

The following methodology has been adopted to guarantee a correct association of hailstone kinetic energy for each hailstorm event:

- the network of reference hailpads of a single municipality is composed of all hailpads placed inside an imaginary rectangle that circumscribes the administrative boundary of that municipality. In this way will be considered as a reference network also hailpads situated in neighbours municipalities close to the edge;

- for municipalities where there are no hailpads within the imaginary rectangle described in the previous paragraph, will be considered all hailpads within a 3km radius buffer outside of rectangle;
- municipalities still remains without any reference hailpad will be considered too much far and will not be taken for analysis. This decision has been taken to respect the spatial variability of hail events and reduce the uncertainties of the method.

Each hailstorm is associated with a value of kinetic energy which is calculated as the average of the energies detected at all points of the reference network.

$$E_k = \sum_{i=1}^{n} E_{ki}$$

where n is the number of hailpads in network reference to a single municipality and E_{ki} is kinetic energy calculate for a single hailstorm in a single hailpad, defined as:

$$E_{ki} = \frac{m_h v_t^2}{2}$$

Where $m_h$is the mass of a supposed spherical hailstone, v_t is the vertical fall velocity (terminal).

Crop damages are percentage values that are calculated based on percentage of damage estimated by expert on site survey after a complaint of damage by the insured. These values are found in campaign sheet (Figure 7), and are briefly described as:

- Pre-damage risk: any damage before the insurance coverage period;
- Previous damage: damage that has already been appraised before the current survey, but within the coverage period;
- Total damage: the damage report on the current visit (E_{ki}).

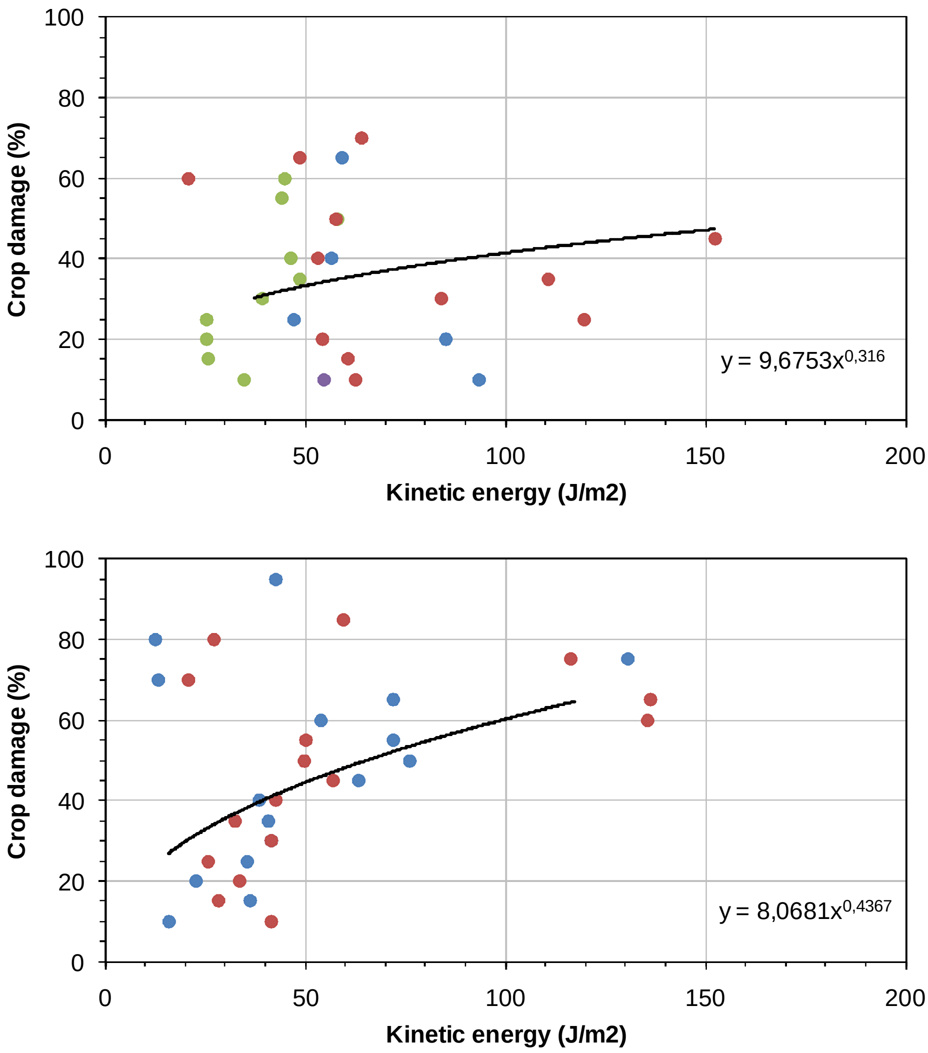
The damage data were divided into classes with interval of 5%. The results of crosses made for data acquired in the Province of Trento for the apple and vine crops existing in region are show in Figure 24. There are a trend line that was built using all available pairs of data. The division in class intervals indicates the plant growth stage in the day of hail event.

It is important to note that the graphs generated by this method respect a general indication that greater is the kinetic energy, greater will also be the damage to a crop.

Figure 24. Damage curves for vine and apple crops

(a) Vine

(b) Apple



Analyzing the graphs of Figure 24, it is possible to presume that:

- When two points have a same damage, the point which more kinetic energy indicates a possible phenological phase having more resistant.
- Phenological stage, and vegetative growth have important effects: early events that occur when the foliage and vegetation of the year are not yet fully formed, causing damage on the fruit more severe than situations where trees have a greater leaf area and a more advanced vegetative growth.

The next step is to find the correlation between the kinetic energy produced by a hailstorm and the meteorological variables at the time of the event.

According to WMO (2006), precipitation is defined as the liquid or solid products of the condensation of water vapour falling from clouds or deposited from air onto the ground. It includes rain, hail, snow, dew, rime, hoar frost and fog precipitation. The total amount of precipitation which reaches the ground in a stated period is expressed in terms of the vertical depth of water (or water equivalent in the case of solid forms) to which it would cover a horizontal projection of the Earth's surface.

The general problem of representativeness is particularly acute in the measurement of precipitation. It is particularly sensitive to exposure, wind and topography, and metadata describing the circumstances of the measurements are particularly important for users of the data.

The unit of precipitation adopted in Italian networks is linear depth, in millimetres (volume/area). The rate of rainfall (intensity) is similarly expressed in linear measures per unit time, usually millimetres per hour. A network generally has climatological and hydrological purposes and its observation times are hourly.

It is possible to define temperature, second WMO (2006), as a physical quantity characterizing the mean random motion of molecules in a physical body. Temperature is characterized by the behaviour whereby two bodies in thermal contact tend to an equal temperature. Thus, temperature represents the thermodynamic state of a body, and its value is determined by the direction of the net flow of heat between two bodies. In order to measure the temperature of an object (in this case the object is the air), a thermometer can be brought to the same temperature as the object (namely, into thermodynamic equilibrium with it), and the temperature of the thermometer itself can then be measured.

Wind velocity, always in agreement to WMO (2006) is a three-dimensional vector quantity with small-scale random fluctuations in space and time superimposed upon a larger-scale organized flow, however, in this study, surface wind will be considered mainly as a two-dimensional vector quantity specified by two numbers representing direction and speed and the wind direction will not be considered, because it does not affect the amount of damage in agricultural crops. Most of the wind measuring stations of a network provide average quantities information, that are averaged over a period of 60 minutes. Wind speed generally is reported to a resolution of 0.5 m/s to the nearest unit, and represents an average over 60 min.

Data from the meteorological monitoring network were acquired from IASMA, which manages a network of 107 automated stations with different types of sensors including temperature, humidity, precipitation, sell speed, solar radiation, barometric pressure, leaf wetness and temperature in the underground. The location of these stations is presented in Figure 25. To note that the central area of the province – where are positioned the hailpads, Figure 23 – is well served also of meteorological monitoring points.

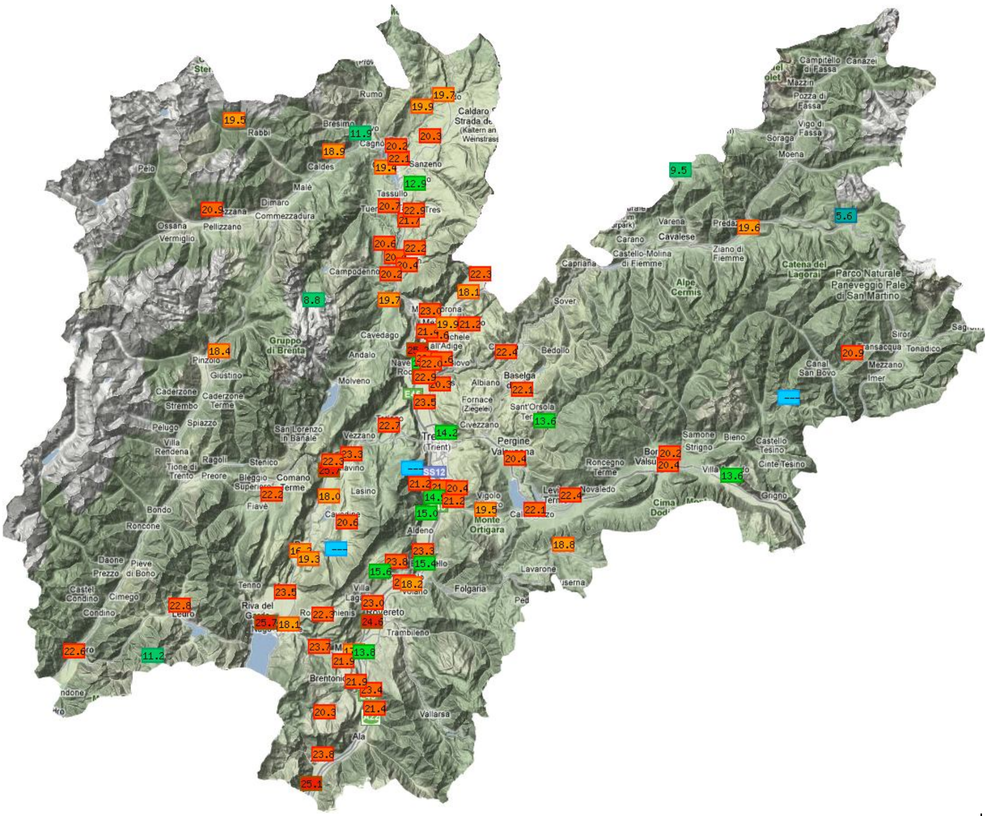


Figure 25. Weather stations network in Province of Trento

(source IASMA)

Scale: 20km

The procedure of correlation between atmospheric variables and hailstorms can be describes as follows:

- Each hailpad was given a reference weather station, usually within the same municipality and if that does not exist, the closest, but always in a region with the condition of mountains, vegetation, urbanization homogeneous;
- Extracting data of precipitation, temperature and wind speed in an hourly basis, for the hailstorm day;
- Getting start time and duration of event from hailstorm database;
- By comparing this information, verify the existence of a temporal correspondence between the hailstorm and peaks of precipitation or wind speed;
- Due to the possible distance between a hailpad weather station and its respective reference, a difference of plus or minus 2 hours will be considered valid.

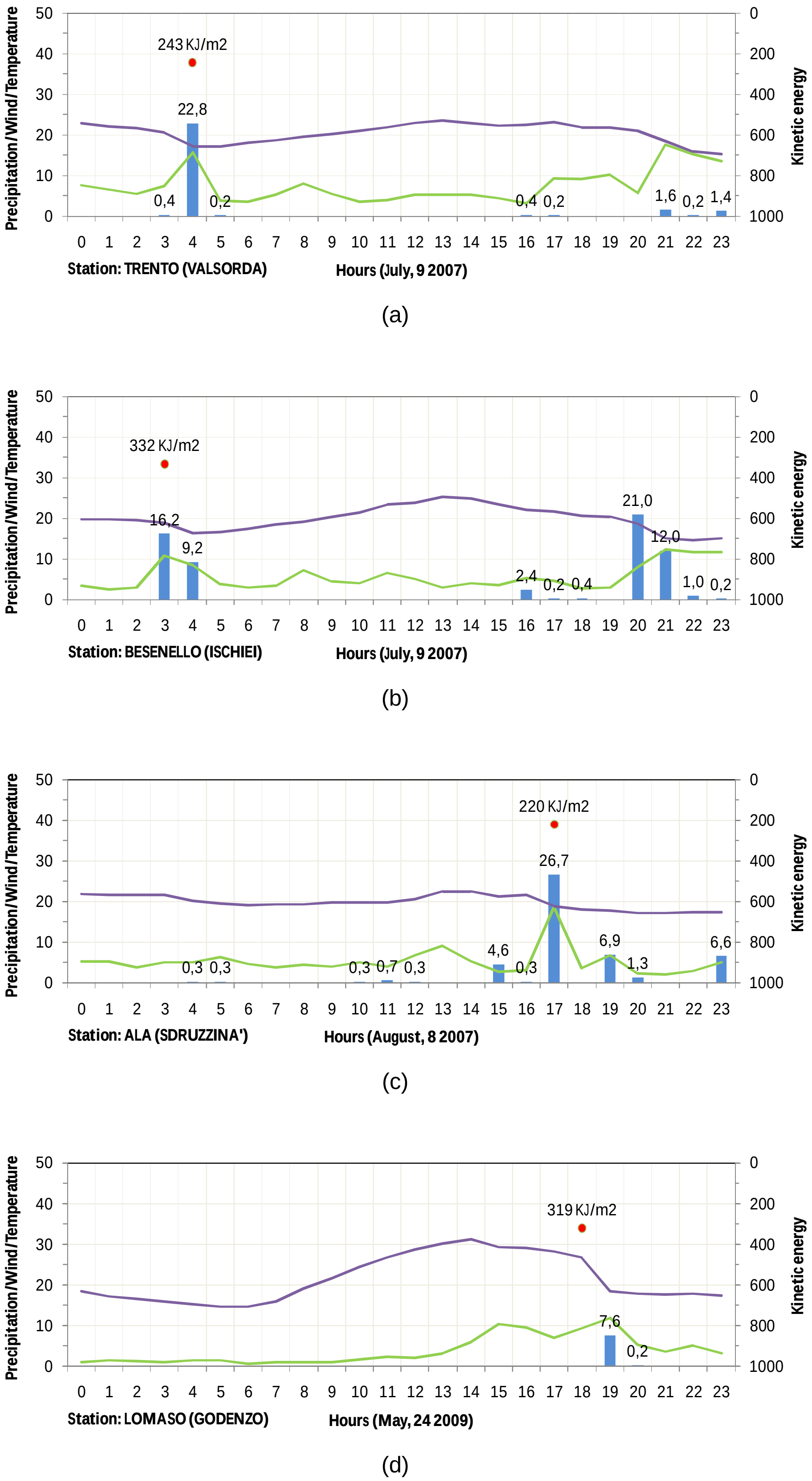
About 830 hailstorm compressed in the period between 2007 and 2009 that hit the province of Trento were analyzed.

Errore. L'origine riferimento non è stata trovata. shows four examples of the typical distribution of meteorological variables on a day where successful the event of hail. **Errore. L'origine riferimento non è stata trovata.**.a and **Errore. L'origine riferimento non è stata trovata.**.b are generated graphs for two hail events occurred in a same day, and therefore, are result of a same thunderstorm.

Figure 26. Samples of atmospheric conditions in a hailstorm day

Legend

- Precipitation (mm)
- Wind speed (m/s)
- Temperature (°C)
- Hailstorm kinetic energy (KJ/m²)



The day in question is July 9, 2007, and the distance between the two locations (*Valsorda* and *Besenello*) is about 8km as direct route. Despite the small distance between the two points, it is possible to observe that the hail came at 3 AM in the town of *Besenello* (southern) and arrived at 4 AM to *Valsorda*. Even the kinetic energy of hail reports a difference. The intensity in fact fell by 27% between the first and second survey.

Errore. L'origine riferimento non è stata trovata..c and **Errore. L'origine riferimento non è stata trovata.**.d are unrelated to each other, serving only as a comparison to show the average behaviour of climatic variables at the time of a hailstorm.

The main conclusions that can be made from this analysis are:

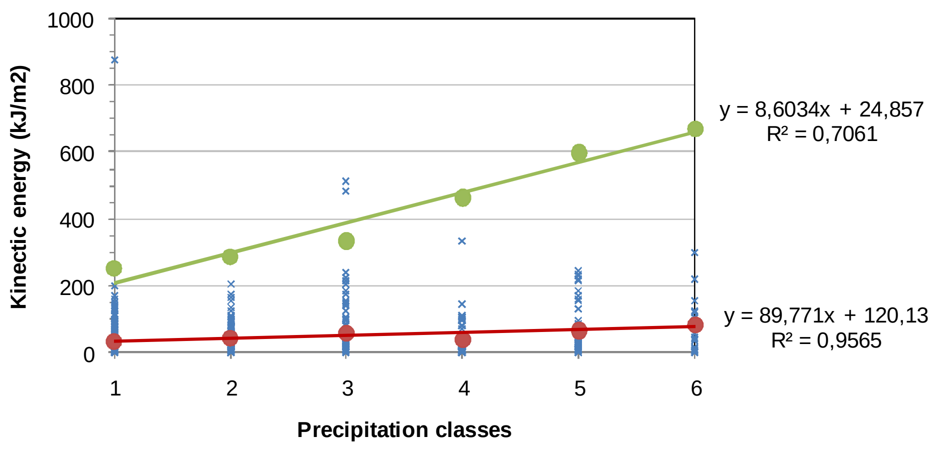
- At the time of the hailstorm, in general, there is also the rain;
- The rain that falls at the same time the hail is not necessarily the maximum hourly rainfall of that day;
- The rain is actually a precipitation that contains both water and the hailstones;
- When the hailstorm falls is common to have a strong gust of wind, identified by an abrupt rise of the green line in the graphs;
- At the time of the hailstorm also occurs a lower temperature of the air at surface, mainly due to the presence of ice grains;
- Lowering the temperature can exceed 10 ° C, depending on the time of the hailstorm, and for this reason, the temperature cannot recover after the event has ended.

The next tests to be done is to find the link between these weather variables (precipitation, wind speed and temperature) and the kinetic energy of hail. To do this, meteorological data were divided into intervals of classes, homogeneous, so that each class had approximately the same amount of items.

In Figure 27 is possible to analyze these associations, as well as the class interval adopted. The red lines indicate the average of all copies of data, while the green is the maximum value of kinetic energy found for the respective class, excluding items still more observations that are considered as outliers. Linear equations are also presented which give better adjust to these two lines.

Figure 27. Correlation between kinectic energy and meteorological variables

(a) Precipitation



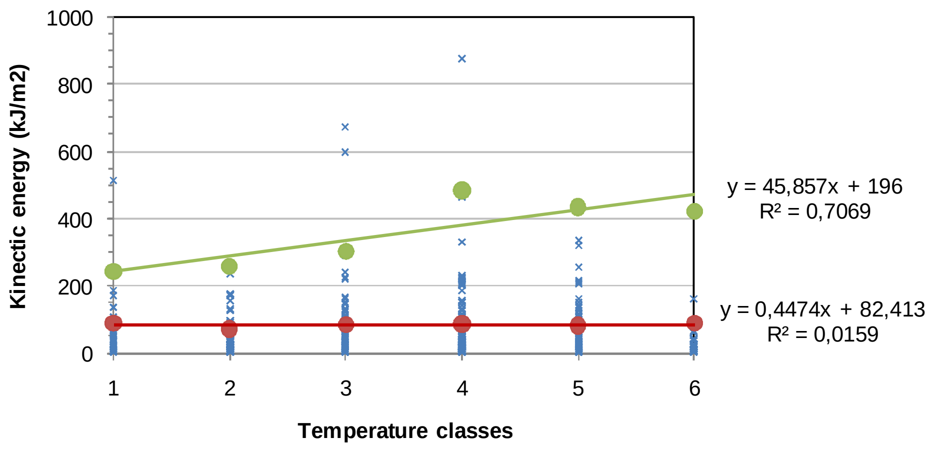
Classes	1	2	3	4	5	6
Precipitation (mm)	< 5	5-10	10-15	15-20	20-30	> 30

Legend

Mean

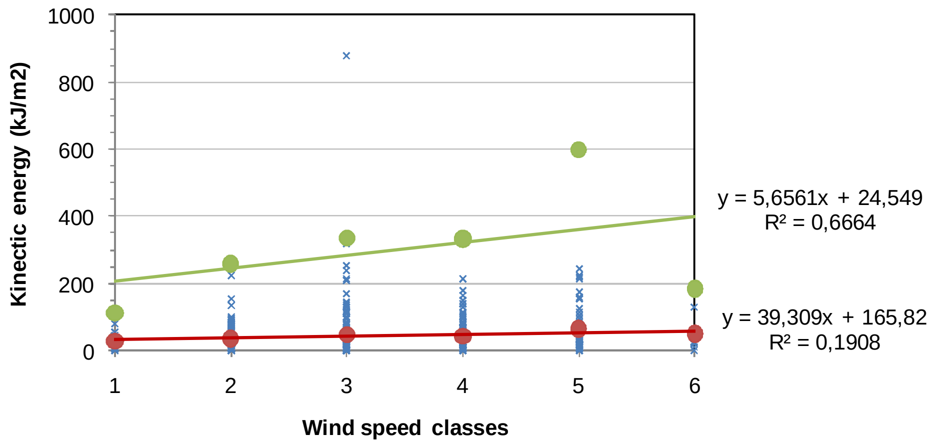
Maximum

(b) Temperature



Classes	1	2	3	4	5	6
Temperature (°C)	< 12.5	12.5-15	15-17.5	17.5-20	20-30	> 30

(c) Wind speed



Classes	1	2	3	4	5	6
Precipitation (mm)	< 2.5	2.5-5	5-10	10-15	15-20	> 20

7.3.3. Risk maps

The map of risk (Figure 28) is geographic representation of the equation presented in Chapter 2.

$$Risk = H \times V \times E$$

where:

H is the product of hazard maps (Figure 13) and a destructiveness parameter

V indicates the product of monthly probability to hail event (Figure 12) and susceptibility to have complete destruction of the plant

E is the percentage of cultivated area in the current municipality for the current crop.

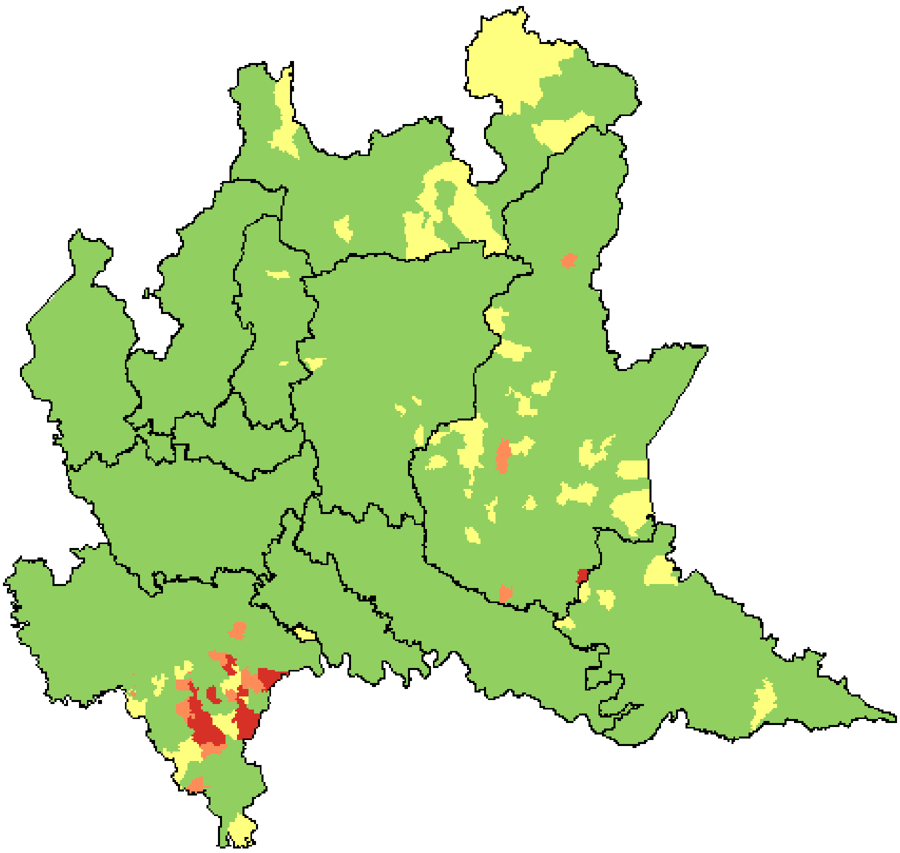


Figure 28. Risk map for vine crops

Legend:

- > 10%
- 5% - 10%
- 1% - 5%
- < 1%
- No risk

Conclusions

Northern Italy is the region that are more affected by hail, for reasons based on atmospheric circulation and topography. Consequently this is more subjected region to hail crop damages due the high exposition (large areas occupied by open field crops of diverse cultures).

On the other hand, the study of hailstorms behaviour is difficult, and its prediction and protection even more so. Hail is not a simple climate variable but the consequence of a combination of multiple factors.

To develop new analysis and develop improvements to the actual, is necessary:

- a continuous monitoring of hailstorms;
- extend on time the actual series;
- installing new panels to acquire information of new cultures;
- associate this data with meteorological information and crop damages.

Hail is an interesting subject that requires further studies for its total understanding. Agricultural associations, instigated by research institutions, can encourage farm operators to collaborate, adding new hailpads to the network, which are an efficient and economic way for monitoring hailstorms.

Beside, standardize the monitoring network of hail between the various operators and facilitate access to this information has crucial importance throughout the entire process.

Based on previous scientific studies, were acquired crop damages curves for wheat, corn and soybeans, and using Province of Trento as a calibration zone, it was possible to apply the analogue method to find two more relations for apple and vine crops.

Even if the correlations between hailstorm intensity and meteorological variables are relatively high, many pair of values are not particularly well associated, indicating low correlation between damages on both apples and vine crops and hailstorms. Possibly because minor damages are being associated with hailstorms but are actually caused by the wind gusts that occurred during a storm when some minor amount of hail fell.

The adjustments between the hailstones kinetic energy and weather variables taken individually have presented a satisfactory result. Find a relation that combine all the variables, however, is a challenging effort, and require more detailed information of how is the relationship between precipitation, wind speed and surface temperature, and what effects are attempt in presence of hail.

Finally, the risk maps produced are in accordance with the crops distribution and the hazards probabilities.

Appendix

A. Glossary of insurance terms

According ANIA, the insurance terms used in this text are defined as follows:

- **Insured value**: This is a measure of the interest subject to insurance: for example, the sum insured for your vehicle against theft. The insured value may not coincide with the insurable value, thus giving rise to the phenomena of underinsurance (or partial insurance) or over-insurance.
- **Premium**: The premium represents the price that the contractor pays to buy the warranty offered by the insurer. Payment of the premium is, as a rule, condition of effectiveness of the guarantee. Prizes can be: unique, periodicals, only applicants. The award, whether single or periodic, may be spread (or partial). The premium paid by the contractor consists of several components: the pure premium, uploads, taxes. Summing up the first two items then the premium rate, and even if you add the taxes you get the gross premium.
- **Sum insured**: Amount within the limits of which the insurer agrees to provide its service. In property insurance, the sum insured usually represents the value of insured property (insurable value).

B. Insurable crops list

According to the Legislative Decree no 102 (2004), the insurable agricultural crops in Italy, and the species scientific names, are listed below:

- **Cereals**: barley (*Hordeum vulgar*), buckwheat (*Fagopyrum esculentum*), corn (*Zea mays*), faro (*Triticum monococcum*, *Triticum dicocoum* or *Triticum spelta*), millet (*Panicum miliaceum*), oat (*Avena sativa*), rice (*Oryza sativa*), rye (*Secale cereal*), sorghum (*Sorghum vulgare*) and triticale[4] (x *Triticosecale*), wheat (*Triticum spp.*);

- **Oilseed**: rape (*Brassica napus*), soybean (*Glycine max*) sunflower (*Helianthis annuus*);

- **Horticultural**: garlic (*Allium sativum*), asparagus (*Asparagus officinalis*), chard (*Bieta vulgaris cycla-chenopodiacee*), broccoli (*Brassica oleracea*), artichoke (*Cynara cardunculus*), carduus (*Carduus defloratus*), carrot (*Daucus carota*), cauliflower and cabbage (*Brassica oleracea*), cucumber (*Cucumis sativus*), onion (*Allium cepa*), watermelon (*Citrullus lanatus*), fennel (*Foeniculum vulgare*), strawberry (*Fragaria spp.*), lettuce (*Lactuca sativa*), aubergine (*Solanum melongena*), melon (*Cucumis melo*), potato (*Solanum tuberosum*), sweet pepper (*Capsicum annuum*), tomato (*Lycopersicon esculentum*), leek (*Allium ampeloprasum*), chicory (*Cichorium intybus*), beetroot (*Beta vulgaris*), radish (*Raphanus sativus*), shallots (*Allum cepa var. aggregatum*), celery (*Apium graveolens*), spinach (*Spinacia oleracea*), pumpkin (*Cucurbita spp.*), zucchini (*Cucurbita pepo*);

- **Legumes**: peanut (*Arachis hypogaea*), chickpea (*Cicer arietinum*), cicerchia (*Lathyrus sativus*), bean (*Phaseolus vulgaris*), broad bean (*Vicia faba*), lentil (*Lens culinaris*), lupin (*Lupinus spp.*), peas (*Pisum sativum*);

- **Fodder**: alfafa (*Medicago sativa*), ryegrass (*Lolium multiflorum*), French honeysuckle (*Hedysarum coronarium*), clover (*Trifolium spp.*);

- **Industrial crops**: woody and herbaceous biomass, sugar beet (*Beta vulgaris var. saccharifera*), poplar (*Populus tremula*), tobacco (*nicotiana tabacum*), other sauces;

- **Textile**: hemp for fiber (*Cannabis sativa*), flax (*Linum usitatissimum*);

[4] Triticale is a hybrid of wheat and rye

- **Pomes**: apple (*Malus domestica*), pear (*Pyrus spp.*);

- **Stone fruits**: apricot (*Prunus armeniaca*), cherry (*Prunus avium*), peach and nectarine (*Prunus persica*), plums (*Prunus cultivar*);

- **Citrus**: orange (*Citrus sinensis*), bergamot (*Citrus bergamia*), citron (*Citrus medica*), kumquat (*Citrus japonica*), lemon (*Citrus limon*), Clementine and mandarin (*Citrus reticulata*), grapefruit (*Citrus paradisi*), satsumas (*Citrus unshiu*);

- **Olives**: table or oil olives (*Olea europaea*);

- **Vine**: table and wine grapes (*Vitis vinefera*);

- **Other fruits**: kiwifruit (*Actinidia deliciosa*), persimmon (*Diospyros kaki*), chesnut (*Castanea sativa*), fig (*Ficus carica*), prickly pear (*Opuntia littoralis*), mulberry (*Morus alba*), raspberry (*Rubus spp.*), blueberry (*Vaccinium corymbosum*), blackberry (*Rubus ulmifolius*), loquat (*Eriobotrya japonica*), ribes (*Ribes divaricatum*), gooseberry (*Ribes uva-crispa*);

- **Nuts**: almond (*Amygdalus spp.*), hazelnut (*Corylus avellana*), walnut (*Juglans regia*), pistachio (*Pistacia vera*);

- **Ornamental plants**: plants in full field or nursery;

- **Nurseries for tree or herbaceous**: fruit trees, rootstocks, vine, industrial plants;

- **Herbs**: anise (*Pimpinella anisum*), basil (*Ocimum basilicum*), coriander (*Coriandrum sativum*), chilli (*Capsicum annuum*), parsley (*Petroselinum crispum*);

- **Other crops**: myrtle (*Myrtus communis*), dog rose (*Rosa canina*), saffron (*Crocus sativus*), medical plants.

C. Beaufort wind scale

Beaufort Wind Force Scale is an empirical measure for describing wind speed based mainly on observed sea conditions created in 1805 by Sir Francis Beaufort and extended in 1946 for add Forces 13 to 17. The classes are presented in following table.

Beaufort scale number and description *		m/s	km/h	Specifications for estimating speed over land
0	Calm	0 – 0.2	< 1	Calm; smoke rises vertically
1	Light air	0.3 – 1.5	1 – 5	Direction of wind shown by smoke-drift but not by wind vanes
2	Light breeze	1.6 – 3.3	6 – 11	Wind felt on face; leaves rustle; ordinary vanes moved by wind
3	Gentle breeze	3.4 – 5.4	12 – 19	Leaves and small twigs in constant motion; wind extends light flag
4	Moderate breeze	5.5 – 7.9	20 – 28	Raises dust and loos paper; small branches are moved
5	Fresh breeze	8.0 – 10.7	29 – 38	Small trees in leaf begin to sway, crested wavelets form on inland waters
6	Strong breeze	10.8 – 13.8	39 – 49	Large branches in motion; whistling heard in telegraph wires; umbrellas user with difficulty
7	Near gale	13.9 – 17.1	50 – 61	Whole trees in motion; inconvenience felt when walking against the wind
8	Gale	17.2 – 20.7	62 – 74	Breaks twigs off trees; generally impedes progress
9	Strong gale	20.8 – 24.4	75 – 88	Slight structural damage occurs (chimmey-pots and slates removed)
10	Storm	24.5 – 28.4	89 – 102	Seldom experienced inland; trees uprooted: considerable structural damage occurs
11	Violent storm	28.5 – 32.6	103 – 117	Very rarely experienced; accompanied by widespread damage
12	Hurricane	32.7 and over	118 and over	

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