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Enhancing Crop Insurance Processes through Geospatial Technologies: A case study of Ticinum Aerospace

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Summary

Abstract

Especially in recent years, it is increasingly clear that climate change is having a significant impact on global agriculture, with increasingly frequent extreme weather events such as droughts, floods, and hailstorms threatening farmers food security and profitability. Agricultural insurance is a key tool to mitigate these risks by providing financial support for farmers to recover from natural disasters.

The agricultural insurance sector, particularly in Italy, should still be considered underdeveloped with a low participation rate among farmers. To help improve this situation, in recent years insurance companies are increasingly considering the use of satellite remote sensing, a technology that, by simplifying claims handling, reduces operating costs and increases transparency in the insurance system.

Finally, to highlight the practical applications of satellite technology for improving agricultural insurance and food safety, the case study on Ticinum Aerospace will be examined.

Introduction

Climate change is having a significant impact on global agriculture, with extreme weather events such as droughts, floods and hailstorms becoming increasingly frequent and unpredictable. These phenomena threaten food security, undermining farmers' ability to produce food sustainably and profitably. To face this situation, farmers have several risk management tools at their disposal; among them agricultural insurance plays a crucial role in protecting agricultural producers from economic damage resulting from natural disasters, providing financial support to mitigate losses and aid recovery.

To make agricultural insurance more efficient and cost-effective for both farmers and insurance companies, satellite remote sensing is proving to be an increasingly accurate and affordable tool for commercial purposes. This technology makes it possible to monitor the condition of agricultural fields in real time, providing historical and current data on the condition of fields affected by natural events. Using satellite imagery, it is possible to obtain a detailed and reliable view of crops, identify anomalies and damage, and improve the accuracy of appraisals. In this way, satellite remote sensing addresses several problems in the industry, making claims handling faster and more efficient, reducing operational costs, and increasing transparency and confidence in the agricultural insurance system.

For insurance companies, the use of satellite imagery can significantly reduce the cost and time associated with field inspections. This approach improves claims management, enabling a more efficient response and reducing the time it takes to settle claims. In addition, the availability of historical data enables analysis of long-term climate and agricultural trends, improving the ability to forecast and manage risk. Satellite remote sensing has the potential to revolutionize the agricultural insurance industry, promoting greater resilience and sustainability in global agriculture.

Finally, the third chapter reports a case study on the Pavia-based company Ticinum Aerospace. A company specialized in remote sensing and the use of satellite imagery that aims to give practical application to the advances being made in research in this area and seeks to make its own contribution in the evolution of the agricultural insurance and food security industry.

Chapter 1

Climate change and weather report

WMO estimates indicate that the average surface temperature in 2022 was 1.15 °C higher than it was during the pre-industrial era (1850–1900). Climate conditions are changing, and this is causing a shift in average temperature together with an increase in the number of extreme natural events.

It is now clear to scientist and meteorologist that climate change manifest with a higher frequency of violent events, seasonal shifts and significant temperature fluctuations that compromise field crops, resulting in losses in agricultural production and damage to rural structure and infrastructures.

In Europe extremely high temperatures have been measured with increased regularity since 1950s and since 2015 (except for 2016) summer heatwaves have been registered every year. Northern and western Europe have seen an increase of heavy precipitation, while Mediterranean countries have seen a decrease in precipitations, leading to an increase of agricultural droughts. Moreover, according to meteorologist's predictions of future trends, extreme precipitation events are expected to increase broadly across Europe, while droughts are expected to decrease in northern Europe but to increase in central Europe and to triplicate in magnitude across southern Europe. (Devot et al., 2023)

Agriculture is particularly susceptible to changes in temperature, precipitation patterns, and weather, and it is particularly vulnerable to extreme climatic events.

It is clear that these weather trends are going to have negative repercussions on agricultural systems, and it is worth noting that 60% of Europe's economic losses can be attributed to 3% of extreme natural events (Devot et al., 2023).

Definitions of extreme climate events

An extreme weather event is defined as ‘an event that is rare at a particular place and time of year’ (Seneviratne 2021). When a pattern of extreme weather persists for some time, it can be classified as an extreme climate event (Devot et al., 2023).

Typically, phenomena such as heatwaves, cold spells, heavy rains, storm surges; flooding, landslides, droughts, wildfires and intense storms (wind, hail) can be considered extreme events. (Bucheli et al., 2023)

Heat and drought.

Heat stress results from exposure to critically high temperatures and agricultural droughts from insufficient soil moisture content, both reducing yields with different mechanisms (Panu and Sharma 2002; Barnab´ as et al. 2008). Both events are major drivers of losses in agriculture, especially when they occur together (Haqiqi et al. 2021). For instance, the hot and dry summer of 2003 caused losses in agriculture of up to 4 billion Euros in France (van der Velde et al. 2012) and the one of 2018 up to 2.5 billion Euros in Germany (Axer et al. 2019).

Frequency and severity of drought and heat events are expected to increase especially in southern Europa and become the first weather risk in agriculture production (Webber et al. 2018).

Droughts are distinguished in hydrological, meteorological, and agricultural. In Europe more than 50% of economic losses are caused by agricultural droughts (Devot et al., 2023).

Hydrological droughts depend on how rainfall deficiencies affect groundwater stream flow, reservoir and lake levels, and other aspects of the water supply. They mostly decrease water resources for irrigation; Meteorological drought focuses on the extent of dryness or rainfall shortage and the duration of the dry spell. It's a crucial aspect of drought monitoring and assessment, helping to understand the immediate impacts of precipitation deficits on water resources, agriculture, and ecosystems; Agricultural droughts arise from deficiencies in rainfall, soil moisture, groundwater, or reservoir levels critical for irrigation. These shortages directly affect crop production, inhibiting crop growth and development. The consequences can be severe, leading to reduced yields, crop failures, and economic losses for farmers and communities reliant on agriculture (Devot et al., 2023).

Heavy precipitation and floods

Heavy precipitation events are short periods with intensive precipitation or longer periods with continuous precipitation and particularly affect plant growth after planting. Extremely heavy precipitations can result in flooding that can affect plants in any growth stage. Different parts of Europe are facing an increase in frequency and intensity of heavy precipitation events, particularly in central and northern Europe.

Heavy precipitations and floods can have substantial effects on agricultural crop losses, for example in 2013 a flood event occurred in central Europe caused a loss of approximately 570 million Euros in German agriculture and forestry (Thieken et al., 2016).

Frost

Frost events happens when the vegetation is exposed to critically cold temperatures. It can affect all types of plants, but they are particularly threatening to fruit and vegetables (Barlow et al. 2015; Lamichane 2021). According to Munich Re, in 2017 total economic losses for European fruit and wine growers caused by a late frost event amounted to 3.3 billion Euros.

Plants are particularly vulnerable to frost during reproductive growth stages. Global warming led to accelerated crop growth, shifting the reproductive growth stages to happen earlier in the season, increasing the risk of frost. This phenomenon happens in particular in more continental regions such as Austria, France and Switzerland (Eccel et al. 2009)

Hail

Hail events can cause extensive yield losses by damaging plants (Katz and Garcia 1981). For instance, it has been calculated that in 2016 in Germany, one fourth of economic losses due to extreme natural events were caused by hail and one single hail event caused losses of up to 45 million Euros (Vereinigte Hagel 2019).

In Europe the most exposed areas are the mediterranean region and the Alpine region (Punge et al. 2017; EEA 2021a). Due to the effects of climate change hail events are expected to increase, in particular in France, Germany and Switzerland, during spring and summer months (Kunz et al. 2009).

Storms and excessive snow pressure

Critical levels of wind speed caused by storms and excessive snow pressure are two additional weather risks that can hurt agricultural production. Storms can damage all type of plants and trees. A single storm in central Spain in 2017 led to a damage of 100 million Euros (Devot et al., 2023).

Excessive snow pressure causes plants to buckle a remain damaged under the weight of the snow. The weight of accumulated snow can bend or break plant stems, branches, and even whole trees, especially if the snow is wet and heavy. This damage can hinder plant growth, reduce crop yields, and impact the overall health of vegetation.

Economic impact of extreme natural events

The impact of extreme events is generally measured in yield losses translated to economics losses.

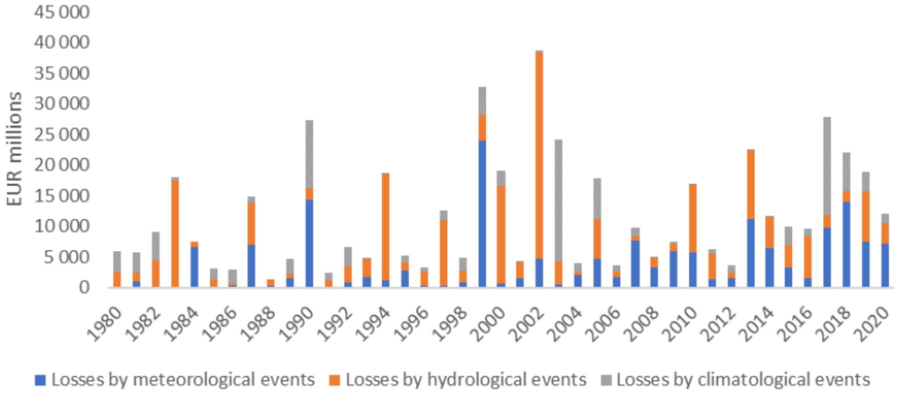


Figure 1: Climate related losses by type of event (Source: Eurostat 2022)

Droughts and heat waves have most significant effects on agricultural output. As seen before, heatwaves affect crop growth, especially when they occur around flowering time, they can lead to sterilization and yield losses.

Drought-related economic losses exceeded 150 billion USD globally between 1983 and 2009, impacting 75% of the world's arable land (Devot et al., 2023).

In addition, the forecast for the upcoming years is not at all encouraging. According to Garcia-Leon et al. 2021 the projected damage in Europe will increase five times by 2060, while a different study by Naumann et al. 2021 projects that the economic cost of the drought will rise for Europe from 4.8 billion euros in 2015 to 28.6 billion euros by 2100 (Devot et al., 2023).

Frost is cause of important economic losses, especially when they affect high value plantation such as grapevines or fruit trees.

A lower, but still relevant, cumulative impact is attributed to Hail, flood and heavy rainfall (Schmitt et al, 2022).

Examining individual crops, it has been found that some are more negatively impacted by intense events than others. Tuber crops like potatoes, onions, and sugar beet are more susceptible to extremely wet circumstances during the harvesting season, while maize, wheat, and soybeans are more susceptible to heat stress and droughts. Grapevines are susceptible to late spring frost, while olive trees are said to be incredibly resistant (Devot et al., 2023).

How climate is changing in Italy

In Italy, 2022 has been the hottest year registered since 1800, in particular in the northern regions the temperature has been 1,28C higher than the average. Since 1979 temperatures are increasing of 0.46 C each decade (ISMEA, 2023).

Regarding precipitations, 2022 has been characterized by the absence of rain, registering the lowest amount of rain since 1979.

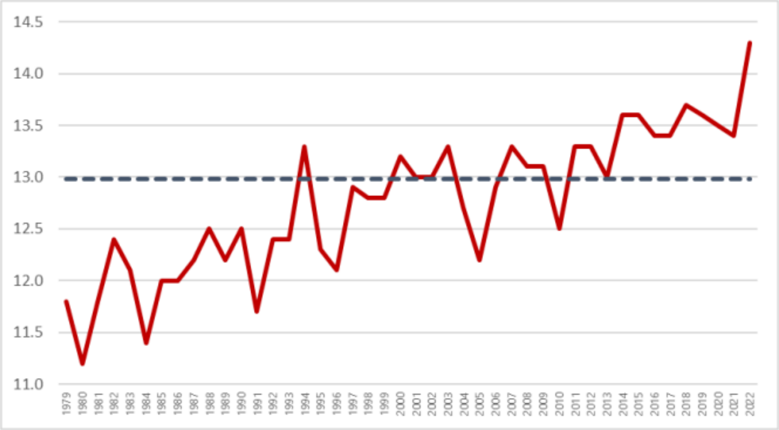


Figure 2: Average temperatures in Italy, historical series 1979-2022 (data in degree Celsius - comparison with the 1991-2020 average) (Source: Radarmeteo)

The particularly elevated temperatures and the absence of rain led to severe phenomena of draught, particularly in the northern regions, in Lombardy, Piedmont and Veneto and in the center. According to Coldiretti (Italy's biggest farmers association), the 2022 drought caused six billion Euro worth of damage to agricultural production.

In 30 years, Italy lost 13% of its water resources (19 billion m3 of water) (FAO, ISPRA & ISTAT, 2023)

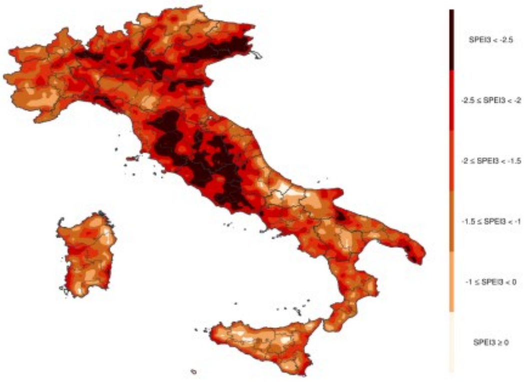


Figure 3: SPEI3 Index on 31/07/2022 (Source: Radarmeteo)

Despite the scarcity of precipitations, in 2022 and 2023 we assisted to severe floods, in particular the 15th and 16th of September 2022 in the Marche region, afflicting the provinces of Ancona, Pesaro e Urbino, causing damages for 2 billion euros (ISMEA, 2023); and in 2023 in Emilia Romagna causing 10 billion euro in damages (of which only 6% insured) (Swiss Re) the most expensive natural catastrophe ever registered in Italy.

Also, hail affects different parts of the Italian territory, in particular Veneto, Friuli Venezia Giulia, Emilia Romagna and Lombardia. Hail is the event most feared by producers during summer, because of the irreversible damages that it procures to plantations. It is an event the happens increasingly frequently but what determine the damages are the dimensions the of the hailstones that are increasing in the last years (Pappas, 2023).

Another phenomenon that affects Italian plantations are high winds. The areas typically more exposed are the Islands and the center and south regions. The northern area, in particular Pianura Padana, that is normally less exposed, in 2022 and 2023 has been affected by an increasing number of heavy storms (ISMEA, 2023).

Looking at latest trends it is clear that climate change is going to have an always bigger impact on the agricultural system, in Italy, in Europe and worldwide. Farmers must take action in order to keep their production sustainable.

The agricultural sector is already one of the most volatile sectors because of its high dependence on meteorological conditions, and in the next few years the instability is going to increase with increasingly extreme natural events that are going to negatively affect agricultural production.

To maintain alive and sustainable the agricultural sector it is always more important for farmers to give relevance to their systems of risk management. As we are going to see in detail, different tools are available, but in this research, we are going to focus on crop insurances and how they can benefit this sector.

Risk management in agriculture.

Climate predictions underline the fact that risk management in going to assume a critical role in the agricultural sector.

Risk management in agriculture is particularly important for the high exposure to risk that characterize the agricultural sector.

Reducing farming risk does not always improve farmers welfare, but the absence of risk management could be critical and have direct repercussion on farmers income, market stability and in some cases on food security (Schaffnit-Chatterjee, 2010).

Risks for agricultural producer, are expected to rise. On the one hand climate change will increase the frequency of extreme weather events, which will have a negative impact on production; on the other hand, long-term supply/demand imbalances are expected to increase globally because of a rising global demand (driven by several factors such as population growth) combined with shortages of raw materials, water, arable land, and energy. In addition to that, geopolitical developments influence price volatility and, consequently, on the welfare of farmers.

Researchers are also concerned with understanding producers’ behavior when confronted with risk and developing modelling tools to help farmers make decisions under risk (Barnett, 1999). Risk perception can vary from farmer to farmer, from sector to sector and from product to product; it depends on the farmer’s experience and on his degree of risk aversion.

Classification of risks in agriculture

Risk can be defined as the potential deviation between expected and real outcomes while risk management is the range of techniques and tools which can be applied to avoid or minimize losses and to utilize opportunities. (Schaffnit-Chatterjee, 2010).

Risks in agriculture are generally classified into 6 categories:

- Production or yield risks are risks associated to variations in crop yields and livestock production. Several factors can affect the severity of the risk: weather conditions, pests, diseases, technological change and the management of natural resources.
- Input and Output price risk mostly refers to the variability in input and output prices and the level of integration in the food supply chain (changes in transportation, storage, local price variability).
- Regulatory risks are risks related to the impact of recent changes in agricultural policies such as changing regulatory and government actions related to environmental concerns, business practices, financial issues, international trade relationships, and government support programs.
- Technological risks associated with the adoption of new technologies.
- Financial risks resulting from different methods of financing the farm activity, subject to credit availability, interest and exchange rates, etc. Financial risk management is particularly important for producers who acquire either short-term or long-term financing that requires scheduled interest and principal payments.
- Human resource risks associated with the availability of personnel. This includes the threat of injury, illness, or death among managers or employees.

Risks can also be classified according to the frequency of the occurrence of the events and the magnitude of the impact.

Risks associated with frequent events which do not result in large losses, are generally managed on the farm. On the other side, events which are not frequent but lead to severe damages to a whole region (such as floods, droughts or disease outbreaks) typically fall under the catastrophic risk layer, for which there usually is an involvement of public authorities.

It is also relevant, especially for insurance and policy purposes, whether it is an idiosyncratic risk, meaning that only a few farms are affected or whether it is a systemic risk where many farms are affected. Risks affecting a big region at the same time, like droughts or floods or price shocks, are more difficult to manage without an external intervention of public authorities.

Good practices for developing agricultural resilience.

The joint OECD-FAO project Building Agricultural Resilience to Natural Hazard-Induced Disasters: Insights from Country Case Studies identifies good practices for developing agricultural resilience at each stage of the disaster risk management cycle.

Principles for effective disaster risk management for resilience:

- An inclusive, holistic, multi-risk approach to disaster risk governance for resilience.
- A shared understanding of natural disaster risk based on the identification, assessment, and communication of risk, vulnerability, and resilience capacities.
- An ex-ante approach to natural disaster risk management.
- An approach that emphasizes preparedness and planning for effective crisis management, disaster response, and to "rebuild better" to increase resilience to future natural hazards.

Best practices include policy measures and governance arrangements that encourage public and private stakeholders to fill gaps in their resilience levels. This can be done by helping them understand the risks they face from natural hazards and their responsibilities in terms of managing the risks posed to their assets. For example, while rarer disaster risks such as a natural hazard-induced disaster may require public intervention, farm-level strategies, and the individual farmer's overall ability to manage risk play a critical role in reducing exposure to the risk of catastrophic events, particularly in the long run (OECD, 2009; OECD, 2020).

Specifically, best practices aimed at developing agricultural resilience to natural hazards are policies and governance arrangements that:

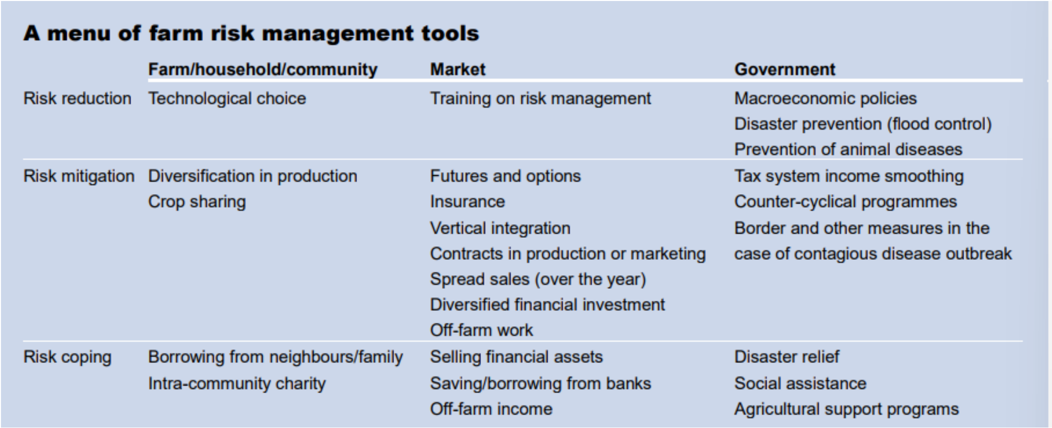
- Encourage public and private sector actors to consider the long-term risk landscape, including consideration of the potential future effects of climate change on the agricultural sector, and greater emphasis on what can be done ex ante to reduce risk exposure and increase preparedness. This may include investing in resilient infrastructure, promoting sustainable agricultural practices, diversifying crops, and enhancing early warning systems.
- Provide incentives and support farmers' capacity to prevent, mitigate, prepare and plan for, absorb, respond to, recover from, adapt to, and transform more effectively in response to natural hazards.
- Consider trade-offs related to natural disaster risk management, including measures to build sector capacity to absorb, adapt or transform in response to natural disaster risk, investments in ex ante risk prevention and mitigation, and ex post disaster assistance.
- Are developed with the participation of a wide range of stakeholders to ensure that all stakeholders are involved in the design, planning, implementation, monitoring, and evaluation of interventions; as well as share a mutual understanding of the risk landscape and their respective responsibilities in natural disaster risk management (OECD/FAO 2021).

Farm risk management tools

Farmers have at their disposal different strategies and different tools to manage the risks they face.

Generally, the risk management strategy starts with basic decisions at the farm level: how to allocate land, which output to produce, which techniques to use.

Farmers can either try to reduce the risk of an adverse event occurring (for example with the use of technology), mitigate it, reducing the potential impact of the adverse event (by reducing the farm exposure in advance), and when the first two option are not available they have to deal with the adverse event once it has occurred, supported for instance by insurances, government aid or public private partnership.



A menu of farm risk management tools

	Farm/household/community	Market	Government
Risk reduction	Technological choice	Training on risk management	Macroeconomic policies Disaster prevention (flood control) Prevention of animal diseases
Risk mitigation	Diversification in production Crop sharing	Futures and options Insurance Vertical integration Contracts in production or marketing Spread sales (over the year) Diversified financial investment Off-farm work	Tax system income smoothing Counter-cyclical programmes Border and other measures in the case of contagious disease outbreak
Risk coping	Borrowing from neighbours/family Intra-community charity	Selling financial assets Saving/borrowing from banks Off-farm income	Disaster relief Social assistance Agricultural support programs

Source: OECD (2009), DB Reasearch

It is important to notice that some strategies are mutually exclusive (for example insurances can reduce the need of crop diversification), while others are complementary.

The first step for developing a risk management strategy should be understanding the origin and nature of the risk. It is necessary to collect information on the risk: its cause, its features (distribution, frequency and correlation with one another), its consequences on farm income, and on the capacity of various strategies to reduce income risk (Hardaker et al.1997).

Once the risk has been assessed, different strategies can be used to manage the risk at the household and farm level. Two types of risk management strategies are normally identified (Bielza Diaz-Caneja et al., 2008):

- Strategies concerning on-farm measures: selection of products with low-risk exposure (e.g. those benefiting from public intervention), selection of products with short production cycles, diversification of production programs, vertical integration, self-insurance or individual stabilization accounts.

- Risk-sharing strategies: marketing contracts, production contracts, hedging on futures markets, participation in mutual funds and insurance.

These are some of the tools most used by farmers to manage risk (Bielza Diaz-Caneja et al., 2008):

Diversification

Crop and/or livestock production diversification suggests that a successful outcome in one business may assist offset a loss in another, lowering overall risk. The degree of risk exposure can decrease thanks to the variety of production activities and crops.

Farmers can also diversify their sources of incomes by engaging in other activities that can be a source of revenue for them such as agrotourism or recreational activity or events.

Vertical integration

Farmers can have more control on their products if they have control on two or more levels of the value chain. It helps in lowering the hazards associated with changes in the amount and quality of inputs (ahead integration) or outputs (reverse integration).

Stabilization accounts

Stabilization accounts are a form of self-insurance. They are accounts where farmers can put a predetermined sum of money every year that they can withdraw when they occur in significant losses.

Marketing and production contracts

A marketing contract is an agreement between a farmer and a buyer to sell a commodity at a certain price before the commodity is ready to be marketed (Schaffnit-Chatterjee, 2010). The farmer is responsible for all the decisions regarding the production process.

The contract can provide a fixed price, or the price can depend on the development of the commodity futures price.

Production contracts typically give the buyer of the commodity significant control over the production process. These contracts normally specify the production inputs, the quality and quantity of the product and the price that must be paid to the producer. This kind of contracts partially shift price risk to the buyer. On the downside, the farmer depends largely on only one buyer, therefore incurring a risk of losing his only client when the contract ends.

Futures contracts

A futures contract is an agreement to trade at a specified future time and price a specified commodity or other asset. The idea behind futures contracts is to protect the holder against adverse price changes before a cash sale or purchase of commodity in the future. They are essentially used for the purpose of managing price risks.

Mutual funds

Mutual funds, established on private initiative, are set up mainly at a sector-specific level, where producers share similar risks, or they can be set up at regional level. Mutual stabilization funds are often challenged with the problem of limited resources, especially in the first years after the creation of the fund. In some European countries the capital collected from the participants is supplemented by a public financial contribution.

The advantage of regionally organized mutual funds is that farmers generally know each other, reducing the problems related with moral hazard and adverse selection. The disadvantage of regionally organized mutual funds is the danger that many or even all farmers incur losses at the same time.

Public funds

In public funds, mostly called calamity funds, all aid is given by the national and/or provincial governments under the declaration of state of emergency.

Government Risk Management Programs

A range of government initiatives offer agricultural producers financial risk protection in many developed nations. Certain nations, like Japan, have policies in place that set minimum prices for agricultural goods. Producers in the US can receive countercyclical program payments to offset periods of low prices (Reusche et al., 2015).

Agricultural Price and Income Support Programs have a significant impact on producers' incentives to engage in agricultural insurance. Specifically, programs offering minimum price supports or countercyclical payments for certain commodities tend to mitigate financial risks by providing direct payments that bolster producers' financial reserves. However, such programs can inadvertently diminish producers' motivation to invest in crop insurance.

To sustain participation rates in agricultural insurance, some governments implement policies mandating that producers purchase crop insurance to qualify for income support benefits. This requirement ensures that producers maintain a level of risk management beyond what is provided by price and income support programs. By coupling income support with mandatory crop insurance, governments aim to encourage producers to actively manage their risk exposure while still benefiting from financial assistance during challenging periods.

This approach strikes a balance between providing financial stability to producers through support programs and promoting risk management practices that enhance resilience in the agricultural sector. It ensures that producers have access to a safety net while also incentivizing prudent risk mitigation strategies, ultimately contributing to the overall stability and sustainability of the agricultural industry.

Ad hoc Disaster Aid programs are offered by many nations to offset losses resulting from severe weather occurrences. Assistance from government emergency or disaster relief programs is given to farmers to recover from severe weather events like tornadoes, hurricanes, droughts, or widespread flooding. A great deal of research has been done on how farmers' willingness to buy crop insurance is affected by disaster relief initiatives. In general, farmers who are reasonably confident that their government will offer financial assistance following a natural disaster are less likely to buy crop insurance (Reusche et al., 2015).

Crop Insurances

Agricultural insurance aim to protect farm businesses from unforeseen losses after weather risk exposure. The idea behind insurance is that of risk pooling. Risk pooling involves combining the risks faced by many individuals who contribute through premiums to a common fund which is used to cover the losses incurred by any individual in the pool. Most insurance schemes in agriculture are provided under subsidized governmental schemes because the seen risks being covered a market determined premium would be too high.

Definitions

An Insurance Provider is an entity that is willing to provide insurance coverage in exchange for a fee (or premium); insurance providers can be issuing agencies or reinsurers. Issuing agencies, sometimes referred to as primary insurers, market and manage insurance contracts to the insured. Reinsurers are usually very large insurance companies (or is some cases, governments) that are well-diversified across space, sector, and types of insurance and that have substantial financial reserves that provide capacity to pay indemnities (Reusche et al., 2015).

The term premium indicates the price that an insurance purchaser pays to an issuing agency to obtain an insurance policy. The market transaction in which an insurance provider is willing to accept risk through the provision of an insurance contract (in exchange for a fee) is a risk transfer mechanism. Rating refers to the process of establishing actuarially sound insurance premiums. Actuarial soundness implies that, over time, the collection of premiums is sufficient to offset the provision of indemnities along with allowances for risk acceptance and insurance provider costs.

Deductibles are a proportion of a loss that is not covered by an insurance contract. In general, deductibles are established to reduce moral hazard behaviour. Coverage is one minus the deductible and moral hazard occurs when insurance purchasers increase risky behaviour simply because they have purchased insurance against losses. Indemnities are payments made by an insurance provider to an insurance purchaser to offset losses more than pre-determined deductibles due to insured perils (Reusche et al., 2015).

The procedures used to evaluate and quantify the risks in an insurance portfolio are known as underwriting. Quantifying risk involves developing risk measures for sub-populations or individuals. This value is then translated into premium rates for individual producers. Qualifying risk refers to identifying reasons for risk differences and assessing the accuracy of assigned risks.

Developing and writing policies with a high degree of accuracy is a complex and time-consuming process. Policies are binding contractual agreements. Therefore, they must necessarily be written in technical terms to reduce ambiguity (Reusche et al., 2015).

Risks are insurable if certain conditions are fulfilled (Skees, 1997; Skees and Barnett, 1999):

- The insurer and the insured have the same information as regards the probability of a bad outcome (symmetric information). This is normally not the case; the main problems are moral hazard and adverse selection.
- Risks should be independent across insured individuals. If risks are systemic (dependent), special measures have to be taken in order to make insurance solutions viable.
- Risks must be calculable. To fix the premium rates, the insurance company must be able to calculate the chance of loss, the average frequency and the average severity of loss. Actual losses occurring must be determinable and measurable.

- Premiums must be affordable. Insurance provision must be cost-efficient because insurance supply costs are added to the actuarially fair premium and an increasing premium reduces the attractiveness of insurance (Bucheli et al. 2021).

Several factors challenge the insurability of weather risks. (Bucheli et al. 2022)

- Firstly, accurate loss assessment must be feasible. A mismatch between the payout and weather-induced loss, referred to as basis risk, limits the risk-reducing capacity and hence the attractiveness of an insurance product (e. g., Woodard and Garcia 2008).
- Secondly, asymmetric information, comprising moral hazard and adverse selection, can result in a failure of the insurance market (e.g., Goodwin 2001). Moral hazard is a farmer's unobserved behavioural change that increases the probability of a payout. Adverse selection occurs if the premium reflects average risk exposure but farmers with above-average risk exposure take out insurance more often so that total payouts exceed total premium volume.
- The underlying risk exposure must be assessable to derive expected payouts and actuarially fair premiums.3 To this end, data on historical losses and risk exposure must be available and of sufficient length and quality (Gehrke 2014).
- The more systemic a weather risk (i.e., the more farmers affected simultaneously), the more resources are required for loss assessments (labour resources) and payouts (Miranda and Glauber 1997).

Different types of agricultural insurance schemes:

Several types of insurance products are now available on the market that can be classified in two macro categories: Indemnity insurance and Index insurance (Bucheli et al. 2022).

Indemnity insurances are the most used type of insurance Europe at the moment. They can cover one or more risks simultaneously and they require experts to inspect the insured fields and estimate the insured losses.

Basis risk in indemnity insurance might arise from the difficulty in estimating insured weather damage and differentiating it from losses attributable to management. Additionally, asymmetric information issues arise. Conventional approaches to address these, such field inspections requiring a network of knowledgeable loss adjusters, raise expenses and make insurance solutions less appealing (Vroege and Finger 2020). Most importantly, when systemic weather hazards arise, this network of loss adjusters may be overwhelmed (i.e., a risk affecting multiple farms simultaneously). For instance, it is extremely difficult and expensive to have simultaneous loss adjustments of many farms in one country or even on one continent after a large-scale drought (Vroege et al. 2021b).

Despite these problems, this is the most used type of insurance among insurance companies and farmers because they are familiar with this product, it is straightforward to understand, and can cover multiple weather risks simultaneously.

On the other hand, index insurance is an alternative, data-driven insurance type, in which the payout solely depends on the realization of an underlying index, such as cumulative precipitation (e.g., Turvey 2001), measured by a third party.

Index insurance products have several advantages. Firstly, given that the indemnities and the premiums do not depend on the individual risk of the insured group, they do not present adverse selection problems. In addition to that, the single farmer cannot influence the outcome that results in payments, therefore there are no moral hazard problems.

Another advantage of this type of insurance is that it can overcome asymmetric information problems since it ideally relies on a transparent, non-manipulable index, based on which payouts and actuarially fair premiums are calculated (Barnett and Mahul 2007). Automated insurance calibration and payout determination reduce the supply costs and payouts can be determined immediately after risk exposure (Bucheli et al. 2022).

Additionally, index insurance, has lower administrative costs since it does not require inspections of individual farms. It has a standardised and transparent structure.

Basis risk is also one of the issues with index insurance design. It can arise from an inaccurate loss estimation of the index (Clarke 2016; Dalhaus et al. 2018; Jensen et al. 2018). Basis risk can be decreased by carefully planning the index insurance policies cover period, trigger, measurement location, etc.

Another disadvantage is the need for the index to be precisely modelled, needing sufficient historical data, to have good statistical properties, being objectively and accurately measured, and then to be made broadly available in a well-timed way.

The last disadvantage is the absolute need of a strong reinsurance given that, in most cases, insurance companies do not have the financial resources to offer index insurance without adequate and affordable reinsurance. (Bielza Diaz-Caneja et al., 2008)

Three main categories of index insurance exist: area yield, vegetation health and weather indices.

- For area-yield index insurance, indices are usually regional average yield realizations in a specific year (Skees et al. 1997). Indemnities are computed from the decrease of the average yield in an area, where the area is some unit of geographical aggregation larger than the farm.
- Vegetation-health indices measure plant vigour, for example with a normalized difference vegetation index (NDVI) in a specific regional area (ranging from farm to region) (Bokusheva et al. 2016). Vegetation-health indices can reflect a range of weather risks (and other variables such as nutrient deficiency resulting from insufficient fertilization) that affect yields.
- In contrast to this, weather indices, that are the more commonly used, are more targeted (e.g., cumulative precipitation during vulnerable crop growth stages can cover drought risks (Bucheli et al. 2021)).

Setting index insurance parameters

The objective of index insurance product design is to develop an index that effectively captures the relationship between the indexed variable and the potential crop loss, and to then define the structure that is most effective in providing payouts when losses are experienced, reducing basis risk as far as possible (IFAD,2017).

To convert an index into an insurance structure, it is necessary to set rules regulating the provision of payouts. In particular, it is necessary to define:

- the maximum amount that the insured will be eligible to receive
- the point at which the contract should start paying out
- the point at which the maximum amount should be reached
- the payout rate per index unit between payout point and maximum amount.

In more technical terms, this means defining, respectively:

- the maximum payout: the highest payout the contract can provide
- the trigger (or strike): the threshold above or below which payouts are due
- the exit (or limit): the threshold above or below which no additional incremental payout will be applied
- the tick (or tick size): the incremental payout value per unit deviation from the trigger.

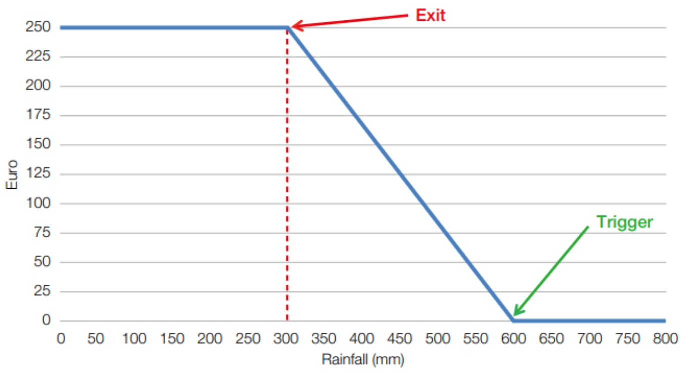


Figure 3: Example of index insurance payout structure (Source: IFAD, 2017)

Agricultural insurance schemes can be classified also based on the risk covered (Bielza Diaz-Caneja et al., 2008):

Single-risk insurance

Single-risk insurance covers against one specific peril or risk, or even two but of a nonsystemic nature, usually hail, or hail and fire). Single risk insurance for hail is the most developed insurance product with a long history and it is available in all European countries. For several countries, in particular Belgium, Germany, Ireland, the

Netherlands and the UK, hail insurance or single risk insurance are the main insurance products available (Bielza Diaz-Caneja et al., 2008)

Combined peril insurance

Combined insurance covers a combination of several risks (two or more risks, mostly with hail as basic cover). This type of insurance is also referred to as multi-risk insurance.

Yield insurance

Yield insurance guarantees the main risks affecting production. So, in the case of crops, the main risks comprise those affecting the yield (e.g. drought). Premiums can be calculated from individual historical data on yield or from regional average yield when individual yield records are not available. Losses (and premiums) can be calculated either by quantifying the losses due to each individual risk separately, or as the difference between the guaranteed yield and the insured yield. In some countries (e.g. the USA) this type is also called combined or multi-peril insurance.

Price insurance

This covers an insured amount of production against price decreases below a certain threshold. Price should be transparent and, to avoid moral hazard and adverse selection problems, loss assessment should be based on a price that cannot be influenced by the insured (futures price, spot market price).

Revenue insurance

Revenue insurance combines yield and price risks cover in a single insurance product. It can be product specific or for the whole farm. Potentially it has the advantage of being cheaper than insuring price and yield independently, as the risk of a bad outcome is smaller (low yields may be compensated by high prices and the contrary).

Whole-farm insurance

This type of insurance consists of a combination of guarantees for the different agricultural products of a farm. Depending on the cover of the guarantees, it can be whole-farm yield insurance or whole-farm revenue insurance.

Income insurance

Income insurance covers the income, so it covers yield and price risks, as well as the costs of production. Usually, this type of insurance is not product specific but covers whole-farm income. Income insurance is potentially more attractive to farmers than other forms of insurance (e.g. yield, price), because it deals with losses affecting farmers' welfare more directly (Meuwissen 2000). At the same time, it is also less attractive for insurance companies. Farmers can in fact easily manipulate certain elements influencing their income (e.g. compensation of employees, operating costs and inventories), making it quite hard for insurance companies to have access to trustworthy data to calculate the right premium.

Advantages and Disadvantages of Claim and Index-Insurance

The two types of insurance each have their own pros and cons. Index insurance offers the potential for lower delivery costs, which is a clear advantage. On the other hand, claim-based insurance faces a significant hurdle due to its high transaction costs involved in finding potential policyholders, negotiating contracts, verifying losses, and issuing payouts (De Leeuw et al, 2014).

Index insurance, however, sidesteps the need for loss verification, thereby reducing a major transaction cost. Nonetheless, the administrative tasks, contract structuring, client outreach, premium collection, and claims processing in index insurance still demand significant labor and resources. Additionally, there are initial costs associated with developing an index that accurately reflects insured losses, as well as ongoing expenses for acquiring and processing information related to the index's status.

Another advantage of index insurance is its ability to mitigate common issues such as fraud, moral hazard, and adverse selection, which are prevalent in traditional claim-based insurance.

Moral hazard arises when policyholders engage in risky behaviour, therefore increasing their actual risk beyond what was initially assessed by the insurer. Adverse selection occurs when individuals with higher risks are more inclined to seek insurance compared to those with lower risks, often due to information imbalances between the insured and the insurer.

These factors typically lead to increased premiums in conventional insurance schemes. However, index insurance circumvents these challenges by basing indemnity payments on index readings rather than individual losses or risk profiles. This approach significantly reduces the potential for fraud, moral hazard, and adverse selection.

Moreover, using a standardized and indisputable index enables rapid and possibly automated indemnity payments, further diminishing transaction costs associated with claim processing.

A significant drawback of index insurance is basis risk, which occurs when an individual suffers a loss but doesn't receive compensation, or conversely, receives payment without experiencing a loss. This risk stems from the correlation between the index used to estimate average losses for the insured group and the losses incurred by an individual. The weaker this correlation, the greater the basis risk. High basis risk reduces the attractiveness of insurance for potential clients and presents a challenge for insurance companies to design policies that minimize this risk.

The mentioned benefits enable index insurance to be delivered at a reduced cost compared to traditional claim-based insurance. This affordability extends its reach to remote regions, unlocking previously untapped insurance markets. For instance, in arid areas where the expenses associated with drafting individual insurance contracts and validating specific claims would be exorbitant, index insurance becomes a viable option. This includes coverage for agricultural assets like crops and livestock. By avoiding the complexities of individual assessments and claims processing, index insurance becomes financially feasible in such regions, providing much-needed protection against various risks.

Lower costs also make index insurance more accessible to smallholder farmers in developing countries. These farmers heavily depend on their agricultural yields for sustenance, yet they confront significant risks that can severely impact their livelihoods, such as crop failure or livestock loss due to drought.

Historically, insurance companies have refrained from providing agricultural insurance products to smallholder farmers in these regions due to the associated expenses. Consequently, smallholder farmers have traditionally managed risks by transferring them within their communities to mitigate adverse effects.

This approach is particularly efficient in addressing idiosyncratic risk, where the unaffected members of a community can still manage to cover and absorb the losses incurred by those affected. However, traditional arrangements are less effective when it comes to insuring against covariate risk.

Covariate hazards, such as widespread damage caused by droughts or floods, diminish the capacity of individual community members to cover the losses of others. Consequently, traditional arrangements lack the resilience needed to protect people against systemic risks posed by such events. Insurers capable of spreading risk beyond the geographical area impacted by these covariate shocks may, however, offer coverage against this type of risk. This realization has sparked a recent interest in the potential of index-based micro-insurance for smallholder farmers in the developing world (De Leeuw et al, 2014).

Overview of the insurance market in Europe

European farmers increasingly suffer from extreme weather risks. In the last years they have experienced substantial crop yield losses, and they will face even higher yield volatility in the future (Trnka et al. 2014; Webber et al. 2020; Bras ′ et al. 2021).

In Europe every country has a different agricultural insurance market structure and shows diversity in terms of agricultural production, exposure to weather risk, insurance market structures, and forms and depths of political market interventions (France has a 65% premium subsidy and Germany does not provide premium subsidies at the national level at present).

Since there is not a common framework, every European member states have autonomously adopted national policies for assisting farmers in dealing with production risks and natural disasters. These policy interventions, typically in the form of subsidies on crop insurance or agricultural solidarity funds, have been primarily adopted in the southern EU countries (France, Greece, Italy, and Spain). In contrast, public intervention in the United States and Canada aims at supporting farmers' management activities in a very broad sense by supporting farmers' revenue through hedge funds, revenue insurance programmes, mutual funds, and weather indices. (Bucheli et al., 2023)

Private crop insurance markets have a long tradition in Europe. The globally first documented crop insurance market was created in Germany in the late 18th century after the government cut off compensation payments for hail damage. In response, farmers founded a mutual hail insurance with yearly premium payments and payouts in case hail damage in their cereal production is observed. For this reason, the growth of private crop insurance, at first organized in form of mutual funds, is closely linked to the abandonment of governmental support for extreme weather damages (Koch 2012).

Private insurance markets have evolved since then. Many countries introduced and developed legal frameworks and different forms of political market interventions such as value-added tax deductions, premium subsidies, governmental loss participation or public–private partnerships to design insurances and define (subsidized) premium rates. Especially premium subsidies have gained in importance in many countries of the world (Glauber 2015).

In 1995 states member of the WTO signed the Agreement on Agriculture that classifies premium subsidies as Green Box subsidies, with no or at most minimal effects on production or trade distorting effects. The Agreement on Agriculture sets the boundary condition for the Common Agricultural Policy of the EU, which provides the boundary conditions for national policies of European member states.

The Common Agricultural Policy (CAP) in 2009 allowed for premium subsidies of up to 10% (European Commission 2017a), in 2013 it explicitly allowed premium subsidies for animal and plant insurance, mutual funds and income stabilization tools. (Meuwissen et al. 2013; El Benni et al. 2016; European Commission 2016; Severini et al. 2019). In 2018 the CAP allowed premium subsidies of up to 70% (European Commission, 2017b). Currently, every country has its own level of premium subsidies (Austria subsidies premiums up to 55%, France and Italy up to 70%, Spain around 40%, while Germany does not provide premium subsidies at the national level for the moment, but several federal states subsidize premium by up to 50%). Despite these large subsidies, participation has historically been low in many countries, with participation in Italy around 15% (Bielza Diaz-Caneja et al., 2008)

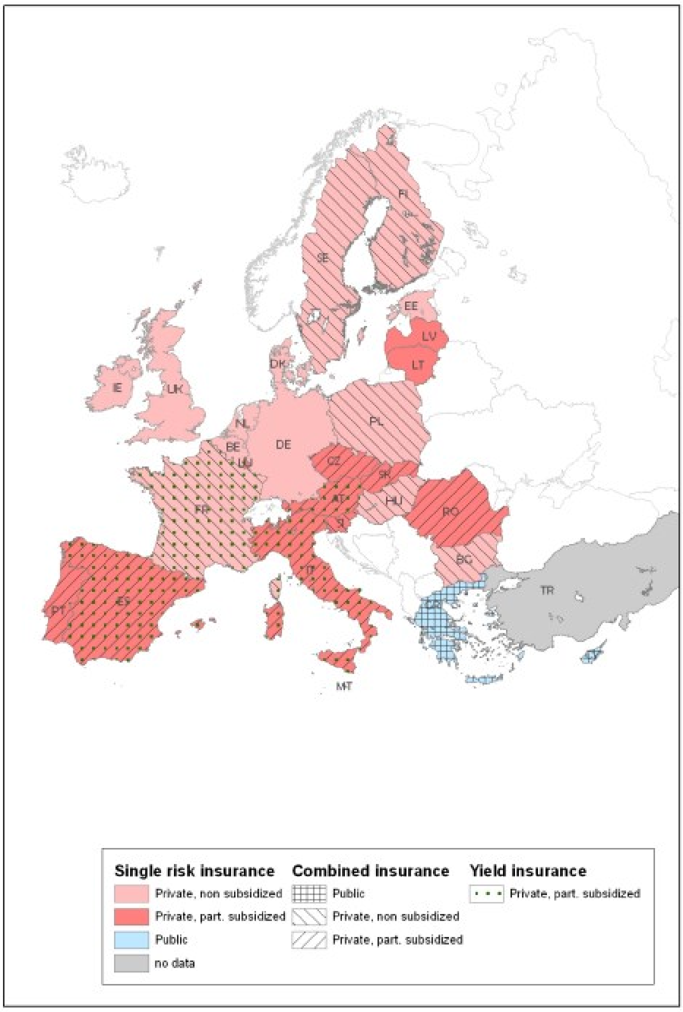


Figure 4 : Single, combined and yield insurance schemes in Europe (Source : Bielza Diaz-Caneja et al., 2008)

The Common Agricultural Policy continues to be very dynamic. In the CAP 2023–2027, the EU Regulation 2021/2115 provides the legal basis for insurance premium subsidization, which can be implemented in the member states' national support strategies. In addition to standard single and multi-peril insurance programs, this regulation now explicitly allows index-based insurance.

Not all countries in the European Union only rely on subsidies as an instrument for insurance support. Spain for example provides an expanded public-private partnership. In fact, the State Agency of Agricultural Insurance coordinates the design of insurance products that involves the participation of the public administration, private insurance providers and farmers.

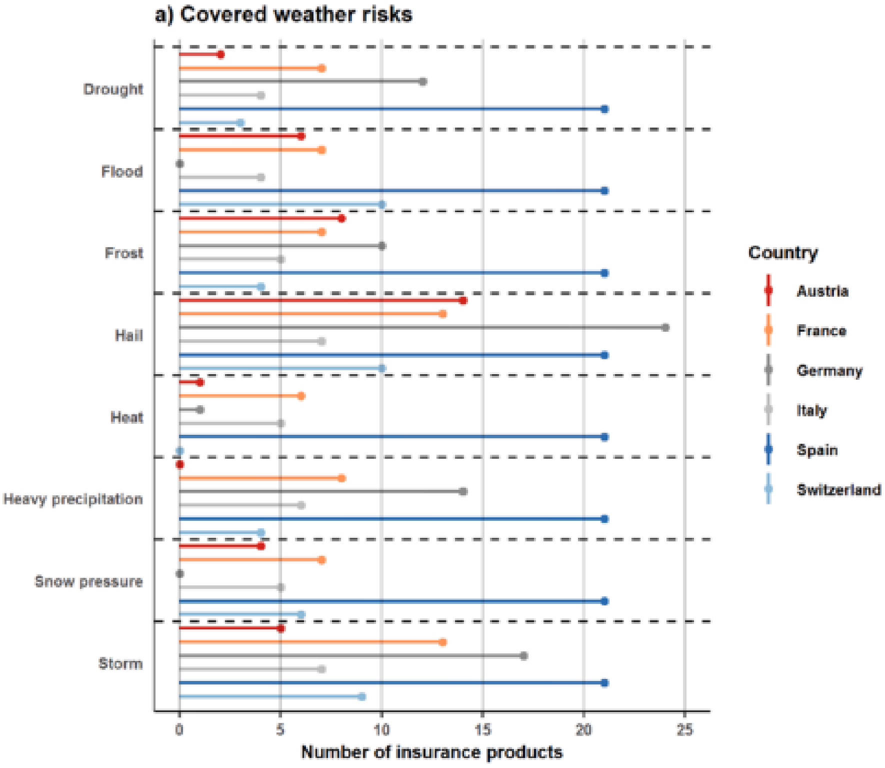
Other less expensive alternative forms of political intervention to costly premium subsidies exists. This includes the public provision of high-quality data collected by governmental institutes, such as meteorological offices or the development of software for secure data exchange (farm level yield data to tailor payout schedules to underlying risk exposure) between farmers, insurance provider and other actors. Such interventions can contribute to reducing transaction costs, improve accurate underwriting and reduce basis risk (Dalhaus et al. 2018; Bucheli et al. 2022).

In European countries there is now a general trend towards a convergence of the level of premium subsidies across countries that aim to increase the use of crop insurances to decrease the more expensive governmental disaster relief.

Even if premium subsidies are likely to become or remain an important political tool in European insurance markets Bucheli et al., (2023) observe that markets with comparatively little political intervention tend to be rather more innovative in terms of index-based insurance designs (e.g., Austria, Germany and Switzerland), suggesting that political interventions may disincentive innovation (e.g., weather index insurances for systemic risks).

Bucheli et al., (2023) in their research identified 107 different agricultural insurance products offered by forty-eight insurance providers in Austria, France, Germany, Italy, Spain and Switzerland. The largest number of insurance products is offered in Germany, while Spain has the largest number of insurance providers.

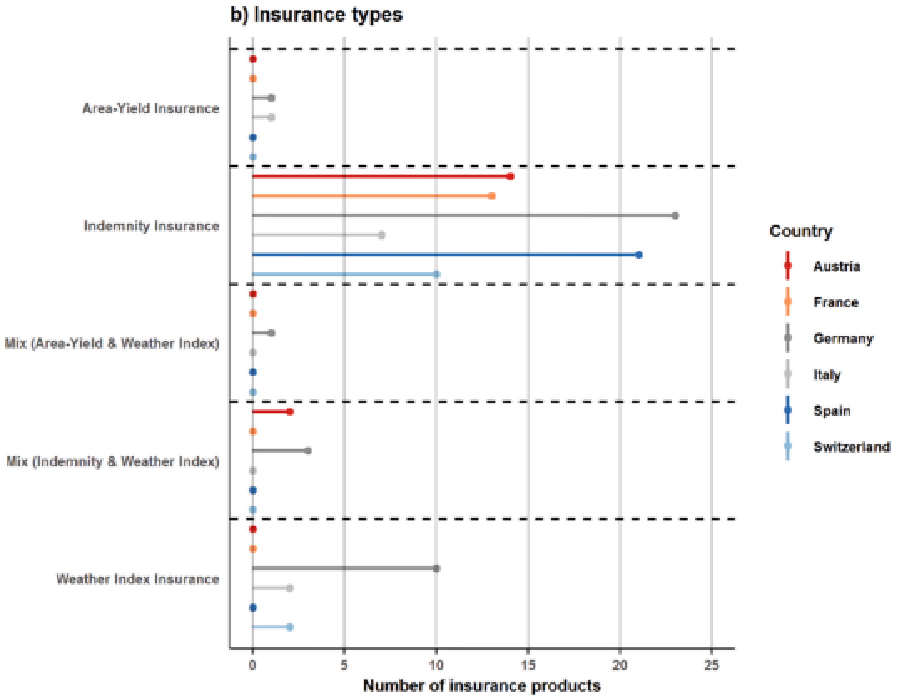
Panel a) shows on the x axis the number of insurance products that cover different types of risks on the y axis (Note that some of the identified insurance products cover multiple weather risks). The risk covered the most is hail, while only a few products cover drought and heat risks. Some gaps were also fund in this reasearch: in Germany there are no insurance products that explicitly cover flood events and the risk of high snow pressure, in switzerland there is no protection against heat and in Austria against heavy precipitation.



Panel 1a) (Source: Bucheli et al. (2023))

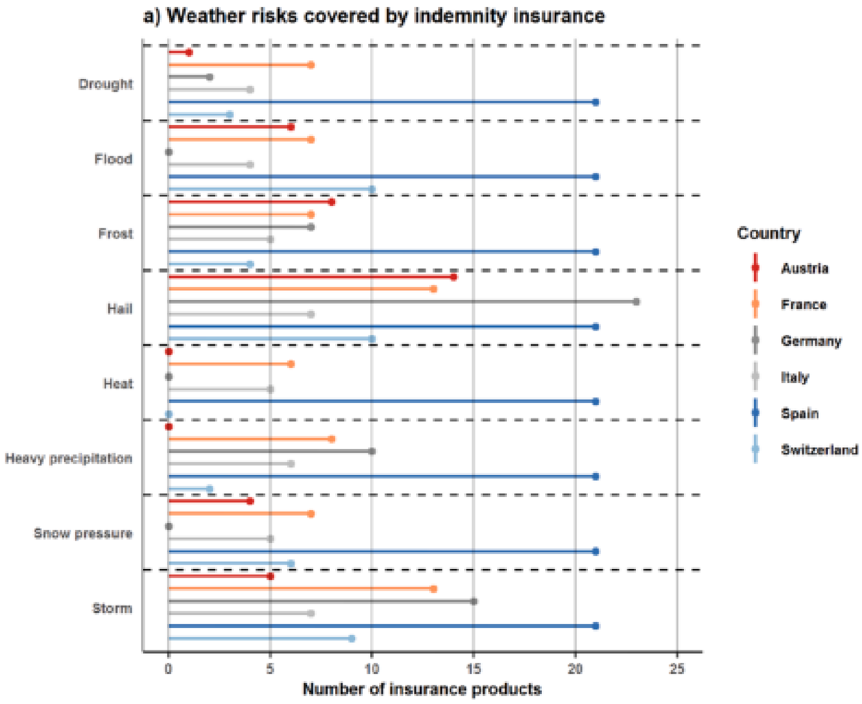
Panel b) on the other hand shows on the x axis the number of insurance products while on the y axis the type of insurance products per country that cover the weather risks displayed in panel a).

Indemnity insurances are the most commonly used, while between index based insurances, weather index insurances are the most used. Area-yield index insurance is less common and only available in Germany and Italy, while vegetation-health index insurances were not found in any of these six countries.



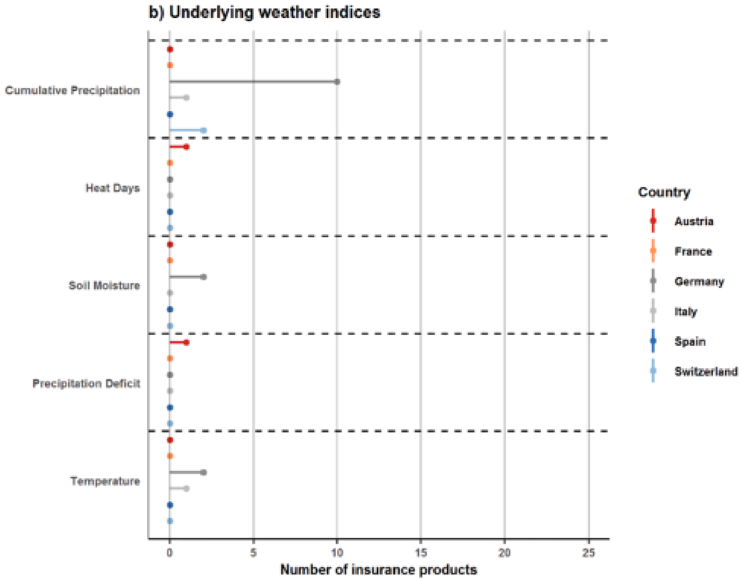
Panel 1b) (Source: Bucheli et al. (2023))

Panel 2 a) shows on the x axis the number of indemnity insurance products that cover a specific risk (y axis). It is possible to see that most of the insurable weather risks are covered by indemnity insurance.



Panel 2a) (Source: Bucheli et al. (2023))

Panel 2 b) focus only on weather index insurance products and shows on the x axis the number of weather index insurance products while on the y axis displays the indexes most used in the different countries. Contrary to indemnity insurance, weather index insurances cover only a subset of insurable weather risks in the considered countries, namely drought, heavy precipitation, heat and frost events. In particular "Cumulative precipitation" is the index most frequently used and covers drought and heavy precipitation events in Germany, Italy and Switzerland.



Panel 2b) (Source: Bucheli et al. (2023))

Even if at the moment indemnity insurance is the most used, there is a trend towards the use of weather index insurance, for the moment just to complement indemnity insurance by covering systemic risks such as droughts and heat, but there are already cases where they cover rather idiosyncratic risks such as heavy precipitation, indicating that in the future they may be used to cover an higher number of risks.

The inclusion of weather index insurance products in the insurance product mix will also depend on how farmers view the advantages of weather index insurance over indemnity insurance, including lower premiums, faster payouts following risk exposure, coverage of additional costs resulting from climate extremes like irrigation, basis risk, and product complexity (see also Patt et al. 2009).

Insurance companies are attempting to educate farmers about weather index insurances and discourage them from using indemnity insurance to cover heatwaves and droughts because they find that in some cases indemnity insurances can be problematic.

The markets in which area-yield index insurance is currently available (such as in Germany) are characterized by heterogeneous production conditions within the area that is relevant to calculate regional yield indices, increasing basis risk for farmers. As a result, area-yield index insurance is currently underutilized and is predicted to play a minor role in the European insurance markets.

Similarly, vegetation-health indices are unlikely to play a role in European insurance markets for crop and horticulture production, but they are currently used to cover grasslands (Vroege et al. 2019).

Crop insurance market in Italy.

Italy is one of the most affected places in the world in terms of exposure to severe natural hazards, such as earthquakes, floods, landslides and volcanic eruptions. On average, there are about four major catastrophic events per year in Italy, the damages of which exceed US$1 billion for each event (CRED, 2021). Since agriculture is practiced over the entire Italian territory, the sector is exposed to such risks and has recently suffered severe losses particularly from floods, droughts and storms. In addition to losses on farms in terms of assets, agricultural production or production capacity, these events also result in large public costs in the form of disaster assistance, as well as indirect losses caused by supply chain disruptions.

Country Background

Italy is a major producer and exporter of agricultural goods, leading the European Union in terms of gross value added in agriculture, as well as one of the world's leading exporters of a wide range of products, including apples, lard and ham, cheese, grapes, olive oil, tomato puree and wine (Eurostat, 2020; FAO, 2020).

The agricultural sector accounts for 2 percent of the country's GDP and nearly 4 percent of its employment (OECD, 2020).

In 2018, the country's agribusiness system (including agricultural production, forestry and fishing; food and beverage industry; and food and retail services) accounted for 15 percent of GDP (CREA, 2020). Therefore, natural hazards that directly affect agricultural production can have major cascading effects on both the rest of the sector and the entire economy, with severe economic impacts located in remote rural areas that are more dependent on agricultural activity.

Along with the economic importance of the sector, a key characteristic of the Italian agricultural sector is diversity. Agriculture is practiced throughout Italy in a variety of landscapes, including the Alps in the north, the Po River Basin, the central Apennines, and the south and islands washed by the Mediterranean. The difference in landscapes and climatic characteristics contributes to the variety of agricultural production and shapes the types of natural hazards typical of different regions. In fact, while the National Risk Assessment analyses seismic events, volcanic eruptions, tsunamis, geological and hydraulic hazards, extreme weather events, droughts and water crises/risk of water shortages, and forest fires, the level of exposure to these hazards varies by region (DPC, 2018). Although the type of hazards experienced varies from year to year, storms and floods have been the most frequent events in recent decades.

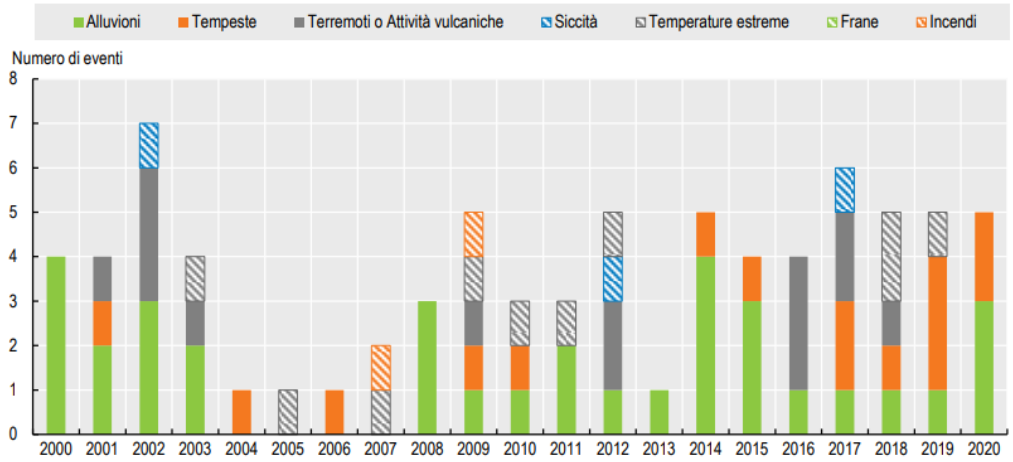


Figure 4: Frequency of disaster events (Source: CRED, 2021, EM-DAT Database)

Despite the different exposure to natural hazards, drought has become an increasingly pressing risk for the Italian agricultural sector. Since the last two decades, droughts have been increasingly frequent in Italy and have led to growing expenditures for the agricultural sector (AGEA, 2020; DPC, 2018). Although typically attributable to weather conditions, water crises are exacerbated by the poor condition of the country's water distribution network.

Most Italian farms are small, more than 50 percent of farms had a turnover of less than EUR 8,000 in 2016, and more than 20 percent of them allocate more than half of their production to their own consumption (Buglione et al., 2018; CREA, 2020). Farms oriented toward own consumption are often not well integrated into commercial value chains and, therefore, may be less prone to innovation and growth, less responsive to market incentives, less motivated to purchase ex ante risk management tools, and less likely to invest in risk reduction or adopt risk reduction management strategies.

In addition to that, Italian farmers on average are also much older than their counterparts in other European countries. In 2016, 41 percent of farm managers were over the age of 65, well above the EU average of 33 percent (Eurostat, 2019). Despite their experience, these farmers are often not open to introduce new technologies and innovations to their operations (Genius et al., 2014), and may be even less likely to make significant new investments in the long-term profitability of their farms.

Agricultural risk management in Italy

Agriculture's risk management practices in Italy have changed dramatically during the past few decades. In the 1970s was established the Fondo di Solidarietà Nazionale (FSN), created with the goal of providing compensation to farmers who had been impacted by natural disasters.

Decree No. 102/2004 marked a historic paradigm shift in public intervention for income stabilization in agriculture, starting the transition from an ex-post National Solidarity Fund (FSN) type of intervention system against natural disaster damage, to a mixed system, and ordering the start of a path of progressive increase in risk prevention tools (ex-ante) and the associated spread of subsidized agricultural policies (Santeramo et al., 2016)

This new mix of interventions, accompanied by a process of innovation, promoted and supported by the public and private reinsurance system, which led to the abandonment of single-hazard hail policies and the affirmation of multi-hazard and multi-risk policies, fostered the diffusion in agriculture of risk management tools that, starting in 2009, were also able to benefit from EU funding, through the resources of Pillar I of the CAP.

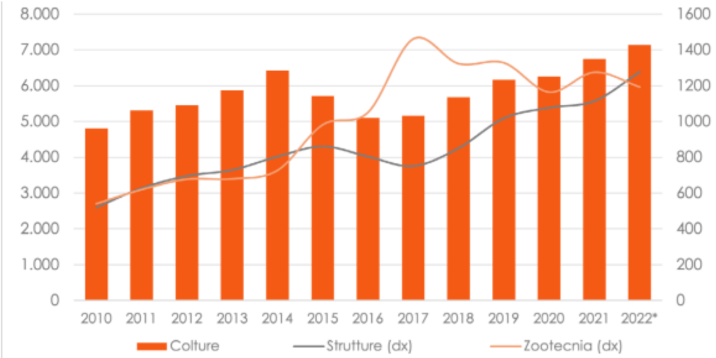
Since 2014, with the transfer to Pillar II, through Measure 17 of the 2014-2020 National Rural Development Program (NRDP), the toolkit of risk management in agriculture has been further improved, specially thanks to the possibility of financing a wider range of instruments alongside insurance offered by the introduction of mutual funds and the Income Stabilization Tool (IST). This further development has led to a new approach to risk management, no longer focused on the traditional insurance policy, but based on a broader and more articulated system of tools regulated by the Agricultural Risk Management Plans, approved annually by the Ministry of Agricultural Food and Forestry Policies and shared with the Autonomous Regions and Provinces

However, the slow process of transition to the new integrated risk management system (SGR) model (Decree 162/2015) eroded, particularly in the first phase of the 2014-2020 programming, the attractiveness of these instruments, which only recovered the ground lost in the first years of NRDP management at the end of the programming. In addition, some structural and economic criticalities prevented the development of subsidized policies and the spread of insurance culture among farms. In particular, high anti-selection, an equally pronounced asymmetry at the territorial level and between production chains, and a tendency to increase insurance costs still emerge among the hindering factors.

In Italy most contracts are purchased by farms located in Northern Italy rather than in other parts of the country (European Commission, 2009; Enjolras et al., 2012). This is a consequence of the structure of insurance premium rates in the north, where the typical loss ratio (the ratio of indemnity payments to premiums) is closer to unity. In contrast, the south of Italy has a loss ratio of about one half. Although greater insurance returns to farmers may well explain greater participation in the north than in other regions, farmers in different regions also face different sources of risk.

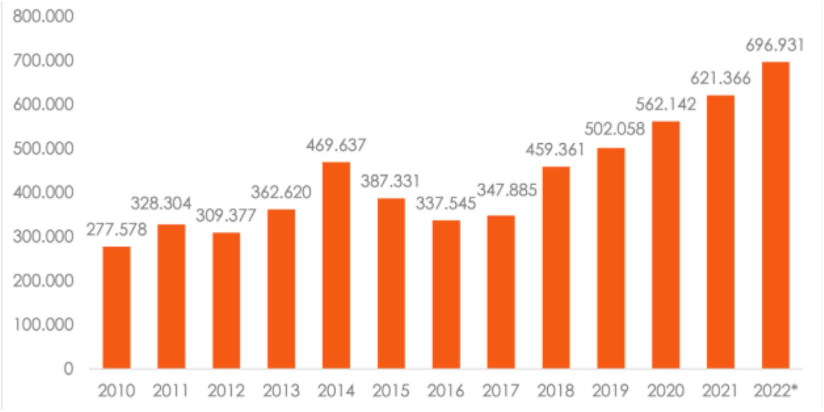
Insured values in Italy are increasing in the last years, putting up +7.4% in 2021 and another +5.2% in the 2022 campaign, reaching a total insured value of just over 9.6 billion euros (ISMEA, 2023).

In terms of insurance costs, 2022 confirms the previous trend. For vegetable crops, premiums grew again, touching the 700 million Euro level and reaching a new peak. At the same pace, the average tariff grew, which in 2022 came very close to the 10 percent threshold, registering an increase of 0.6 percentage points.



(*) Stime

Figure 5: Evolution of insured values by sector (Source: ISMEA, 2023)



(*) Stime

Figure 6: Evolution of premiums (.000 Euros), Crops sector (Source: ISMEA, 2023)

The increase in average rates for vegetable crops, which has been in place for at least six years, can be justified, in part, by the worsening levels of claims. Available data, but also information gathered from ISMEA surveys on the sector, show that over the past 5-6 years the loss ratio of subsidized insurance covering vegetable crops has averaged more than 80 percent, with the negative record reached in 2017, when it stood at 115 percent (at 120 percent the combined ratio). Moreover, broadening the analysis to a wider time span (average of the decade 2012-2021) the combined ratio stood at 113%.

Referring to the number of insured farms, there was a slight increase (+1.7%) in 2022, with a total of 65,665 farms insured. With the number of insured farms appearing to increase slightly, it is estimated that insured area in 2022 will amount to more than 1.24 million hectares, a decrease of less than one percentage point over 2021. Consequently, insured hectares per farm (18.8) are down from 2021 by about 2.5 percent but are still up from 2017 (up about 8 percent).

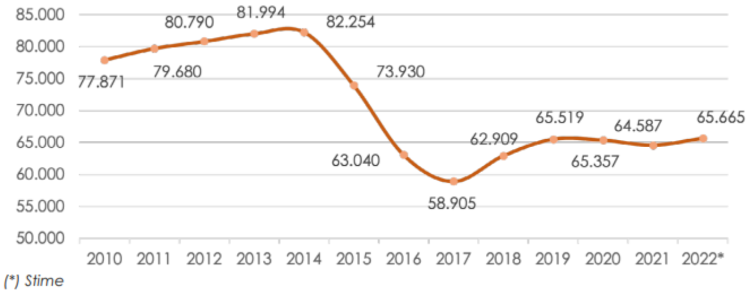
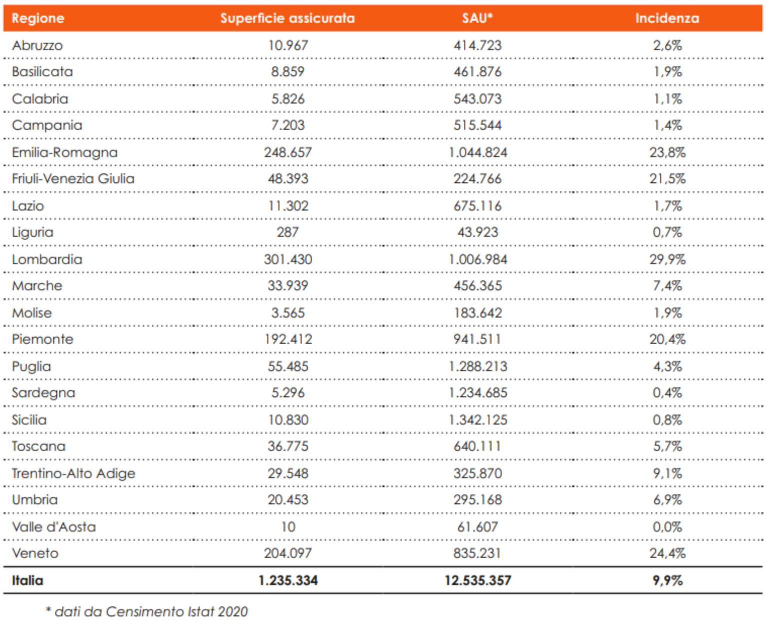


Figure 7: Evolution of the number of insured companies, Crops sector (Source: ISMEA, 2023)

Geographically, ISMEA's elaborations confirm the primacy of the northern regions, which by insured values (limited to vegetable crop policies) concentrate 78.5 percent of the national total, a share similar to that of the previous year. The incidences of the other two macro-areas also remain stable (12.3 percent in the South, 9.2 percent the Centre). Thus, the gradual rise of the South along with the Islands is halted for the time being, while the Centre has been maintaining the same market share for at least four years.

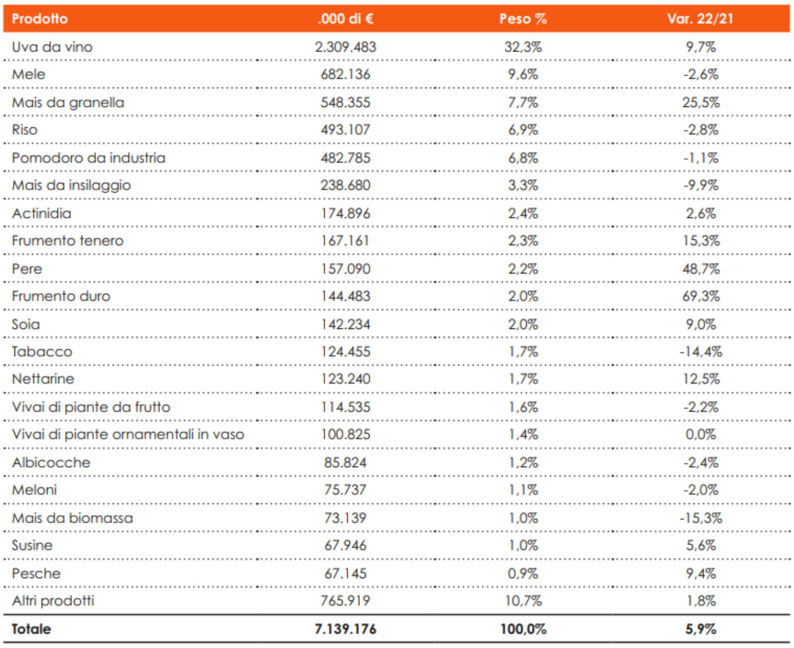


Regione	Superficie assicurata	SAU*	Incidenza
Abruzzo	10.967	414.723	2,6%
Basilicata	8.859	461.876	1,9%
Calabria	5.826	543.073	1,1%
Campania	7.203	515.544	1,4%
Emilia-Romagna	248.657	1.044.824	23,8%
Friuli-Venezia Giulia	48.393	224.766	21,5%
Lazio	11.302	675.116	1,7%
Liguria	287	43.923	0,7%
Lombardia	301.430	1.006.984	29,9%
Marche	33.939	456.365	7,4%
Molise	3.565	183.642	1,9%
Piemonte	192.412	941.511	20,4%
Puglia	55.485	1.288.213	4,3%
Sardegna	5.296	1.234.685	0,4%
Sicilia	10.830	1.342.125	0,8%
Toscana	36.775	640.111	5,7%
Trentino-Alto Adige	29.548	325.870	9,1%
Umbria	20.453	295.168	6,9%
Valle d'Aosta	10	61.607	0,0%
Veneto	204.097	835.231	24,4%
Italia	**1.235.334**	**12.535.357**	**9,9%**

** dati da Censimento Istat 2020*

Figure 8: Insured surface over total agricultural surface in 2022, in hectares (Source: ISMEA 2023)

Looking at the most recent data by crop, the primacy of products with a strong export propensity is confirmed, a phenomenon that proves the importance and selectivity of the insurance tool to protect and strengthen "made in Italy." Mention has already been made of wine grapes, a sector that reached 2.3 billion in insured value in 2022, with a growth of nearly 10 percent. Apples maintain the second position in the ranking by products, with more than 682 million euros (although with a decrease of 2.6 percent compared to 2021), followed by grain corn with more than 548 million, which rises two positions in the ranking thanks to the strong increase (+25.5 percent) in the relative insured values (the phenomenon incorporates the strong increase in prices recorded for all cereals and oilseeds in 2022). High values are also recorded for rice, processing tomatoes, and silage corn.



Prodotto	.000 di €	Peso %	Var. 22/21
Uva da vino	2.309.483	32,3%	9,7%
Mele	682.136	9,6%	-2,6%
Mais da granella	548.355	7,7%	25,5%
Riso	493.107	6,9%	-2,8%
Pomodoro da industria	482.785	6,8%	-1,1%
Mais da insilaggio	238.680	3,3%	-9,9%
Actinidia	174.896	2,4%	2,6%
Frumento tenero	167.161	2,3%	15,3%
Pere	157.090	2,2%	48,7%
Frumento duro	144.483	2,0%	69,3%
Soia	142.234	2,0%	9,0%
Tabacco	124.455	1,7%	-14,4%
Nettarine	123.240	1,7%	12,5%
Vivai di piante da frutto	114.535	1,6%	-2,2%
Vivai di piante ornamentali in vaso	100.825	1,4%	0,0%
Albicocche	85.824	1,2%	-2,4%
Meloni	75.737	1,1%	-2,0%
Mais da biomassa	73.139	1,0%	-15,3%
Susine	67.946	1,0%	5,6%
Pesche	67.145	0,9%	9,4%
Altri prodotti	765.919	10,7%	1,8%
Totale	**7.139.176**	**100,0%**	**5,9%**

Figure 9: Main insured products in 2022 (Source: ISMEA,2023)

Natural disaster risk management in Italy

Resilience to natural hazards is the result of measures implemented before, during, and after an extreme event. Different measures are established by different actors, with some measures being more effective in managing the impacts of risks of different magnitudes, while others are more effective in developing and extending resilience to all events (OECD, 2020).

Depending on the temporal and spatial structure in question and the severity of the event, disaster risk management in Italy's agricultural sector involves a variety of ministries and actors at the local and national levels. These activities include emergency management frameworks for immediate and disaster events, agricultural policies that aim to balance short and long term planning and risk management, and longer-term natural resource planning (particularly in the context of climate change).

Institutions and policy frameworks influence the decisions of farmers, government agencies, and other stakeholders about whether to invest in resilience building by defining the roles and responsibilities of stakeholders in natural disaster risk management and providing incentives to invest in risk prevention and mitigation, including following a disaster (OECD, 2014; UNISDR, 2015). The different types and severity of risks affecting agriculture in Italy fall mainly under four different governmental frameworks involving a range of stakeholders, including emergency management, agricultural risk management, agricultural policies related to investment and sector development.

Regarding hazards that endanger human and animal life as well as public safety (including drought and extreme weather events), activities such as hazard forecasting, prevention, warning, and crisis response are under the jurisdiction of the Department of Civil Protection.

Resilience of the agricultural sector is more directly defined by the various policy frameworks administered by the Ministry of Agriculture, Food and Forestry (MiPAAF), which individually addresses different aspects related to risk management albeit without an overall medium- or long-term resilience strategy for the sector.

The National Risk Management Plan, which outlines all the risk management instruments available to farmers for a specific year, is the policy framework most closely associated with risk management (MiPAAF, 2020). The tools outlined in the plan to assist farmers in mitigating the effects of natural hazards include those financed by the National Solidarity Fund (NSSF) and those partially subsidized through funds allotted by the second pillar of the European Union's Common Agricultural Policy (CAP) (animal and plant crop insurance, mutual funds, and income stabilization tool).

Instruments available through the NSSF include:

- Insurance against destruction of animals in response to disease
- Insurance of agricultural facilities
- Indexed insurance policies
- Income-based insurance policies for durum and soft wheat
- Ad hoc ex-post compensation for expenses incurred by farms to restore production activity following damage to production, facilities, or infrastructure, only available in cases where the damage is caused by an event not included in the National Risk Management Plan.

The agricultural policy context, which can impact risk management decisions at the farm level (e.g., through investments in risk reduction, or through direct support that can influence market incentives or resource allocation decisions) or have a direct impact on the overall risk landscape (e.g., through investments in irrigation facilities that can reduce the impact of drought), defines the sector's resilience to natural hazards in addition to the tools specifically designed for that purpose.

In Italy, the CAP provides the policy framework within which generic support and specific support on risk management is offered to the sector. The CAP is composed of two pillars: the first pillar provides funds for direct payments and the Common Market Organization (CMO), while the second pillar finances the Rural Development Program, through which countries develop rural development objectives in six priority areas to be chosen from a list of 20 predefined policy measures.

Italy distributes its rural development spending through 21 Regional Rural Development Programs (RDPs) and two programs at the national level (the National Rural Development Program and the National Rural Network, a body whose objectives include improving regional rural development programming by providing a forum for the exchange of best practices and supporting innovation).

In addition to risk management tools (previously described), rural development funds are used to restore agricultural production potential damaged by natural disasters, implement preventive measures, and invest in physical assets such as irrigation and water management infrastructure to reduce the impact of adverse events.

Indirectly, rural development also supports a more general improvement in farm resilience through programs for knowledge transfer, research, advisory services, farm business development, cooperation, and agri-environmental and climate measures.

Risk identification, assessment and awareness

Managing risks from natural events begins with a shared understanding of natural disaster risk aimed at encouraging investments in risk prevention and mitigation by all stakeholders (OECD, 2020). Fundamentally, this requires knowledge of the risk environment currently faced by producers through risk identification and assessment.

All local and territorial authorities are encouraged to have Civil Protection Plans to deal with non-epidemic emergencies; these plans are mandatory for municipalities. Therefore, throughout Italy, local authorities are required to get a general idea of the environmental risk they are exposed to and how they intend to intervene in case of adverse events.

An assessment of longer-term risks and vulnerabilities to climate change has also been carried out to support the development of a national adaptation strategy, including information on the likely impact of future conditions on crop or livestock production activities (Castellari et al., 2014; MATTM, 2015).

Other public agencies are also concerned with conducting risk assessments that focus more on the agricultural sector. For example, the Istituto di Servizi per il Mercato Agricolo Alimentare (ISMEA) is working, as part of its support activities to the MiPAAF, to analyse and revise the definitions of catastrophic events (particularly drought, floods, and frost) provided by the agricultural risk management plan to identify the most appropriate damage thresholds for such events based on the meteorological characteristics of Italy's rural areas.

Although these activities indicate awareness and experience about the main risks facing the country, an informed risk assessment needs good quality data on the impact of the risks to identify the most vulnerable and exposed actors and determine where resources are needed to prevent or mitigate future impacts. In Italy, there is still no systematic, uniform, and comparable data collection and analysis on the impacts of adverse events on agriculture, and there is still no concerted effort to regularly monitor the costs and benefits of risk reduction interventions in terms of avoided losses.

ISMEA collects and publishes data on the extent of the impacts of adverse events on agriculture for producers who have taken out insurance policies. However, given that only 9 percent of Italian producers are insured, these estimates offer only a partial overview of current losses, especially in regions with limited insurance coverage, or among certain groups of producers (Zaccarini Bonelli and Lasorsa, 2020)

While work is still being done to estimate direct agricultural losses, other initiatives are emerging to develop data sources that can demonstrate the costs and benefits of specific ex ante interventions, or even consequences related to new management practices.

Research indicates that Italian growers are aware of climate change but may have different perceptions of what it implies for their future business activities. One study found that apple and grape growers in the North believe that they will experience greater crop losses in the future (Menapace, Colson, and Raffaelli, 2015), while producers in Sardinia, although acknowledging climate change, they feel an increase in rainfall and, therefore, do not believe they need to change their water management regime despite climate change projections indicating increased pressure on water resources (Nguyen et al, 2016) As a result, although Italian producers are aware of climate change, their perception of environmental risks does not always reflect the scientific consensus and could therefore be an obstacle to adopting risk mitigation measures (OECD, 2012)

Ex ante investments in measures to prevent or mitigate disaster risk can reduce the cost of disaster response and recovery by addressing underlying vulnerabilities and mitigating impacts.

Hazard monitoring systems are generally included within the DPC, which undertakes, in coordination with regional grid centres, continuous monitoring and forecasting activities for a range of hazards (including weather forecasts, along with indicator data from rain, river, snow, and soil moisture sensors). DPC formulates daily hazard forecasts, summarized in publicly available national watch bulletins, and synthesizes alerts from regional centres into a national bulletin for geological and hydrological weather hazards that are distributed to Italy's 8,000 municipalities (DPC, 2020). Meteorological and climatic monitoring of the most relevant indicators for the agricultural sector is carried out by regional authorities through weekly and monthly "Agrometeo" bulletins and forecasts. At the national level, the partnership between CREA's Agriculture and Environment Department and the National Rural Network gives rise to a phenological bulletin that reports weather conditions and the state of development of vine, olive, chestnut, and locust crops (CREA-AA/RRN, 2020)

Disaster response and crisis management

Effective crisis management and disaster response depend on all actors being aware of their responsibilities in an emergency and communicating effectively with each other, with the public sector taking a leadership role when the private sector is unable to cope. In crisis situations in Italy, public sector actors play an active role, from risk notification to response and coordination.

Risk alerts are generated by the national DPC, but they are disseminated to the public by regional authorities via TV or radio, and soon by direct SMS notification systems.

Agricultural system organizations, however, indicate that these alerts often do not reach rural areas in an effective and timely manner, due to fragmented technological availability and poor connectivity infrastructure.

Risk governance in Italian agriculture could also benefit from more explicit thresholds defining when natural hazards are too great for farmers and individuals, requiring government intervention.

Currently, the criteria required to trigger government intervention are not adequately defined and do not provide a clear incentive for regions, provinces, or farmers to invest in risk reduction because of the likelihood of ad hoc public assistance being provided in the event of a disaster. In addition to financial responsibility for risk intervention and coping, personal responsibility for preventing, preparing for, and intervening in the event of risk is unclear, as there is currently only limited interaction between agricultural stakeholders and emergency management authorities in the absence of a crisis.

Chapter 2

Geospatial data

Geospatial technologies refer to a range of systems, equipment, and applications for geographic positioning and studying the planet and people on it. In the later 19th and through the first part of the 20th century, traditional large-scale cartography was complemented with new methods such as aerial photography initially with balloons and pigeons and later airplanes (American Association for the Advancement of Science, 2024).

Photographical analysis as well as cartographical knowledge was approached in the context of the Second World War, continuing to develop with the use of satellites and computers in the period of the Cold War. Spacecrafts offered pictures of the earth, and its events while vessels offered pictures depicting human activities and computers offered storage and transfer of the pictures. This age also birthed digital software, maps and data pertinent to the social and physical context of our world called Geographic Information System (GIS). Another distinctive characteristic of GIS is its capacity to build different data on a map that are divided by layers, which allows analysing and presenting themes. Such a layering is possible because all geospatial data is positioned on the Earth’s surface and, therefore, the term ‘geospatial’ (Henrikson and Alan, 2013)

As stated by the American Association for the Advancement of Science (AAAS), in the last decade, geospatial technologies have grown from a series of satellites with a primary application in the national security to a wide array of source of data for scientific and commercial uses. The quality of the hardware and data are still high but is now available to many other users such as universities, companies and nongovernmental organizations. Due to advancements of these technologies in several domains, decision makers in fields such as industrial engineering, conservation of the biological diversity, fire management in forests, crop managing, and humanitarian crises and disasters and the likes are helped.

The term ‘geospatial technology’ is a broad term and includes different technologies. The most used according to the AAAS are:

- Remote Sensing: imagery and data collected from space or airborne camera and sensor platforms. Different types of remote sensing technologies exist that use different types of images as input, such as filmed or digital areal images from airplanes and drones, electromagnetic impulses (visible, infrared, and microwave channels), Radio Detection and Ranging (Radar) and Light Detection and Ranging (Lidar) to calculate the distance using radio or light signals.
- GPS: The global positioning system (GPS) is a common type of geospatial technology. It is used for global navigation and glocalization. Global positioning systems have been fully operational since 1993 and are now contained in all modern smartphones.
- GIS: Geographic Information Systems (GIS) combine maps with a database of other descriptive information. GIS allow the management and analysis of location information. By relating seemingly unrelated data, GIS can help individuals and organizations better understand spatial patterns and relationships (National Geographic, 2024).
- Internet Mapping Technologies: software programs like Google Earth are changing the way geospatial data is viewed and shared with the general audience.

Geospatial data can be utilized in several disciplines or industry where the geographical position of the subject is relevant such as: geography, ecology, tourism, marine sciences, agriculture, forestry, marketing and advertising, military forces, logistics and transportation, demography, healthcare, meteorology, and many others (AAAS, 2024).

Here are some possible applications in these fields mentioned by the India Science, Technology and Innovation Portal:

- Climate Change and Disaster Management: GIS technologies play a significant role in bringing together multi-disciplinary subjects to enhance situational awareness and provide actionable intelligence for decision support in mitigating, preparing, and responding to natural disasters.

- Earth Observation Capabilities: Earth observing satellites are used to conduct earth observational studies thanks to remote sensing. Remote sensing is a great instrument to monitor a wide range of processes like vegetation biomass, phenology, water quality, land and sea surface temperature, ocean salinity, and many more.
- Healthcare: Recently, the healthcare sector has extensively needed geospatial tools and dashboards to deal with the pandemic. During the COVID-19 pandemic, geospatial technology supported healthcare professionals in numerous ways, including monitoring, contact tracing, identifying and managing containment zones and coordinating efforts to fight the pandemics.
- Land and Forest Resource Management: GIS technologies are frequently employed to establish survey infrastructure in villages, develop detailed maps, and produce accurate land records essential for rural planning. Similarly, forest departments utilize remote sensing and GIS technologies to map forest cover, assess carbon stock, and detect forest fires and deforestation.
- Logistics: Geospatial technological tools can help in tracking goods and ensuring their quality.
- Meteorology: Geospatial technologies con used for weather forecasts of territories.
- Agriculture: As we are going to see in the next paragraphs GIS technologies have several applications in the agricultural sector for assessing the vegetational state of a selected area.
- Marketing and advertising: With the help of Geospatial tools, advertising agencies can target their ads for relevant regions.
- Real estate: Remote sensing technologies are used for visualizing and analysing real estate objects remotely.
- Insurance - It is also helpful in managing risks for some specific areas (e.g., via historical georeferenced data analysis). Insurance companies rely on predictive models to detect risk and identify where maximum risk is expected. Geospatial technology also proves useful in providing accurate data on how exposed a particular region or area is to natural disasters or social factors that pose a danger.

Experts in this sector expect that geospatial technology will become increasingly sophisticated, especially through its increasingly close contact with machine learning and AI.

For our purpose we are going to focus our attention specially on remote sensing technology and how its use can be central for the insurance industry in improving insurance processes for agriculture.

Remote sensing

Remote sensing is a technique to observe the earth surface or the atmosphere from out of space using satellites (space borne) or from the air using aircrafts (Aggarwal, 2004). It is used to obtain information about objects or areas on the Earth's surface without being in direct contact with the object or the area.

Remote sensing allows to be able to acquire pictures of the surface of the earth at various wavelength in the electromagnetic spectrum. The spectral band within the electromagnetic spectrum the image is acquired in represents one of the most important characteristics of an image derived from a remotely sensed platform. Images can show either the reflected solar radiation in the visible and near-infrared parts of the electromagnetic spectrum or the energy emitted by the surface temperature of the Earth in the thermal infrared wavelength region (Aggarwal, 2004).

The energy that was measured in the microwave region was relative to the earth's surface since energy is emitted from the vehicle. This method is known as active remote sensing as it is the case whereby the remote sensing platform provides the energy source. On the other hand, the systems which depend on energy that is provided from an external source such as sunlight or light which is reflected by the object or surface under consideration, and which falls on an instrument that is separate from the object are referred to as passive remote sensing system.

Detection and discrimination of objects or surface features consist in detecting and recording of radiant energy reflected or emitted by objects or surface material. Different objects return different amount of energy in different bands of the electromagnetic spectrum. This depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy. (Aggarwal, 2004)

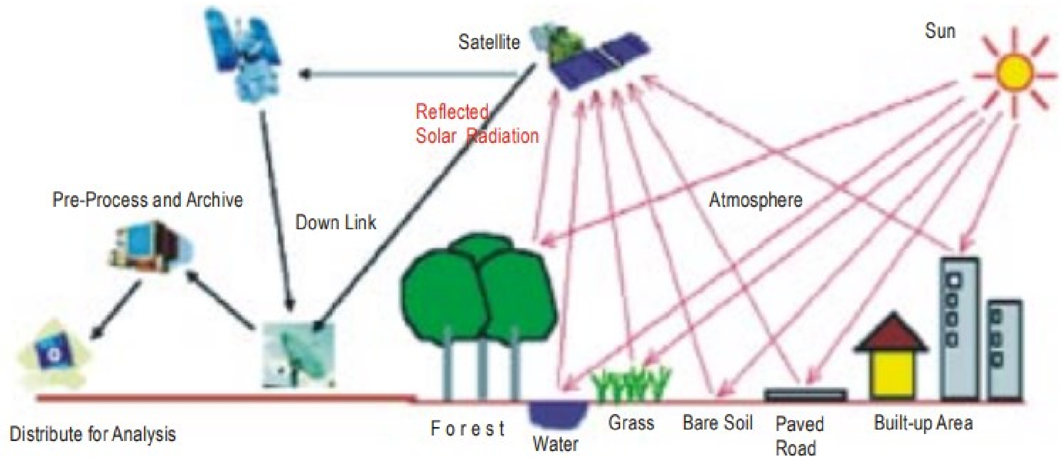


Figure 1: Remote sensing process (Source: Aggarwal, 2004)

Any object emits electromagnetic radiation since all materials and substances exist at temperatures higher than absolute zero degrees Kelvin manifested in atomic and molecular oscillations. The total emitted radiation increases proportionally to the object’s temperature and gets to its maximal value at the short-wave part of the spectrum.

Radiation is reflected, emitted, and absorbed in nature depending on the certain distribution of these values. These spectral characteristics, if applied wisely, can enable to differentiate between one item and another or to obtain data on the form, size, and other physical and chemical parameters of the subject.

Remote sensing systems can be classified into two categories: "passive" sensors and "active" sensors. Passive sensors detect either sunlight reflected from the earth's surface (visible and near-infrared light), or radiation emitted by the surface (thermal or microwave). Similarly to human vision, these sensors mostly work within the Optical range and produce such images which are easily interpretable. However, passive sensors are quite ineffective when cloud cover obstructs their view.

Active sensors operate independently of the sun's illumination because they have their own energy source, typically microwave, directed at the earth's surface. An example of this is Radio Detection and Ranging (RADAR), which emits microwave radiation at a specific polarization (horizontal or vertical). This radiation is backscattered from the earth's surface and recorded by the sensor. The energy received by the sensor depends on a range of factors, such as surface roughness and moisture content, and can be analysed accordingly. Although RADAR images are more challenging to interpret, the main advantage of active sensors is their ability to capture images at any time of day and in any weather conditions, including cloudy skies (IFAD, 2017).

When solar radiation reaches the Earth's surface, it can be reflected, transmitted, or absorbed and then released by the surface. During this interaction, the electromagnetic radiation (EMR) undergoes changes in magnitude, direction, wavelength, polarization, and phase. Remote sensing sensors placed on the device taking the picture detect these alterations, allowing their interpretation in order to extract valuable information about the object in the picture. For this reason, remotely sensed data are able to provide both spatial information (such as size, shape, and orientation) and spectral information (such as tone, colour, and spectral signature) (Aggarwal, 2004).

Remote sensing for agriculture

In agriculture, the key information pertains to the characteristics or traits of agricultural systems and how these traits change over space and time. According to Nock et al. (2016), functional traits can be defined as morphological, biochemical, physiological, structural, phenological, or behavioural attributes that impact an organism's performance or fitness.

These agronomic traits can be typological (e.g., crop type), physical (e.g., crop canopy temperature or soil moisture), chemical (e.g., leaf nitrogen content), biological (e.g., crop phenology), structural (e.g., leaf inclination), or geometrical (e.g., plant density). Some traits of interest, such as crop productivity, result from a series of interconnected biophysical processes occurring over a specific period (e.g., the crop growth cycle) (M. Weiss, 2020).

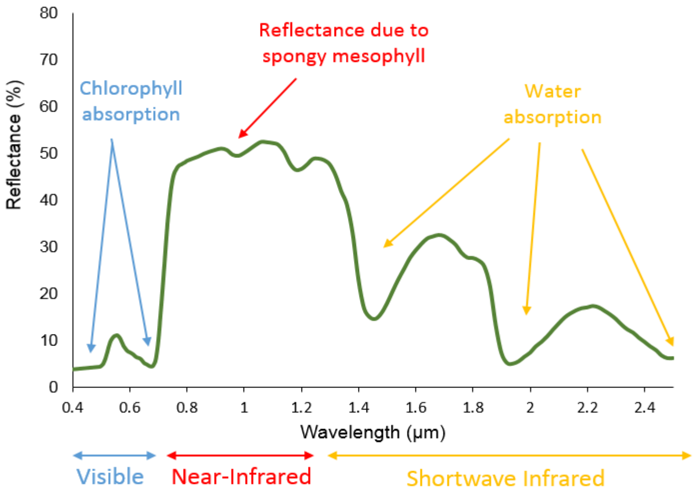


Figure 2: Leaf reflectance in different wavelengths (Source: Saturnalia)

It is important to observe that none of these traits are directly measured by remote sensing instruments. The relationship between what is measured and the traits themselves must be modelled to infer the latter from the former. The extent of the modelling required can vary depending on the specific trait analysed, with some traits requiring more significant modelling efforts than others (M. Weiss, 2020).

For example, defining a trait such as the height of the canopy of a plant does not require particular calculations and involves only geometric considerations, specifically the path of the photon beam reflected by the canopy. On the other hand, relating the area of green leaves in a canopy (known as the green area index or GAI) to measurements in the solar spectral domain involves not only geometric considerations but also other factors related to the canopy structure (such as leaf inclination, position, density, and shape) and the intrinsic radiative properties of the canopy elements (such as reflectance and transmittance influenced by the biochemical composition of the leaves and stems) (M. Weiss, 2020).

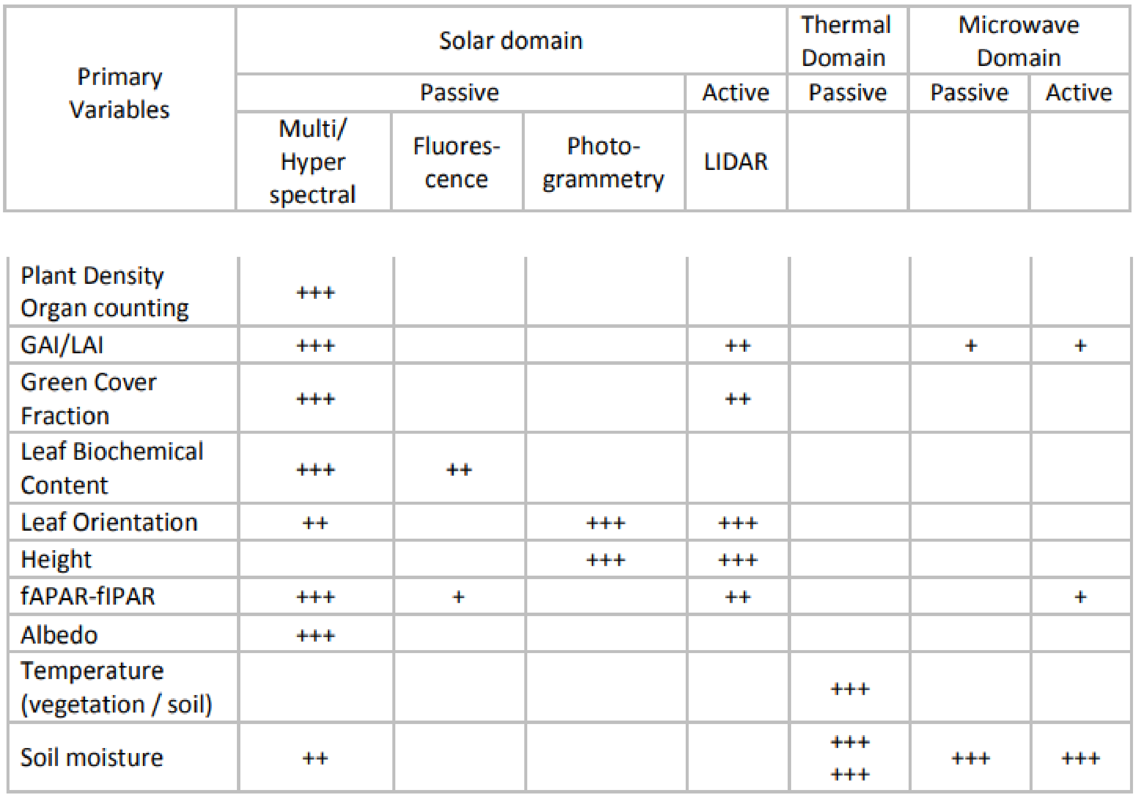
Also crop yield can also be estimated by remote sensing observations, but this requires characterizing additional driving factors related to atmospheric conditions (e.g., solar radiation, air temperature and humidity, precipitation), vegetation functioning (e.g., phenological stages and growth, transpiration and photosynthesis, redistribution of assimilates within plant organs), and crop management practices (e.g., nutrient and water supplies, pruning) (M. Weiss, 2020).

To bridge the gap between physical remote sensing measurements and agronomic traits three types of approaches exists: empirical, mechanistic or a combination of both. Empirical models rely on statistical methods to relate inputs to outputs, whereas mechanistic models emphasize the causality between inputs and outputs by describing the various mechanisms involved (Baker et al., 2018).

In practice, the main difference between the two approaches is that mechanistic approaches rely on assumptions and theoretical models, while empirical approaches depend on data acquisition (Baker et al., 2018). Depending on the objective of the research, one approach may be more appropriate than the other, both approaches can be used to study the same trait.

For instance, crop yield can be estimated with both methods. Empirically, with simple vegetation indices derived from satellite reflectance or mechanistically by combining remotely sensed data and crop growth modelling. The advantage of the empirical approach is its simplicity, while its limitation is that it requires the collection of ground data (e.g., yield and reflectance) and may lack the ability to extrapolate over various times and spaces. On the other hand, the mechanistic approach provides explanatory capability through deterministic modelling, but it requires assumptions that may not always reflect the reality accurately, potentially increasing uncertainty.

Two types of variables can be derived with remote sensing technologies: primary variables can be directly assessed from remote sensors as they are involved in the process of radiative transfer based on current scientific understanding (e.g., Green Area Index, surface temperature, soil moisture), and secondary variables (e.g., crop yield, evapotranspiration) depend on the combination of one or several underlying factors, some of which may not be derived from any remote sensing data (Weiss, 2020).



Primary Variables	Solar domain				Thermal Domain	Microwave Domain	
	Passive			Active	Passive	Passive	Active
	Multi/ Hyper spectral	Fluores-cence	Photo-grammetry	LIDAR			
Plant Density Organ counting	+++						
GAI/LAI	+++			++		+	+
Green Cover Fraction	+++			++			
Leaf Biochemical Content	+++	++					
Leaf Orientation	++		+++	+++			
Height			+++	+++			
fAPAR-fIPAR	+++	+		++			+
Albedo	+++						
Temperature (vegetation / soil)					+++		
Soil moisture	++				+++ +++	+++	+++

Figure 3: Main primary variables that can be retrieved from remote sensing data. (Source: M. Weiss, 2020)

In figure 3 are represented the main primary variables that can be retrieved from remote sensing data. The number of crosses in each square is proportional to the level of both maturity and accuracy found in the literature to retrieve the given variable an empty, cell indicates that the variable cannot be retrieved from the given spectral domain or that no relationship was yet investigated (Weiss, 2020). LAI stands for Leaf Area Index, i.e. half the total surface of leaves per unit ground horizontal area. fAPAR and fIPAR stand for the fraction of Absorbed or Intercepted Photosynthetically Active Radiation.

Generally, the most used remote sensing indicators for agricultural monitoring are rainfall estimates, soil moisture levels, evapotranspiration, and vegetation indices (IFAD,2017). Satellite-based estimates of rainfall and soil moisture can provide valuable information about the climatic conditions affecting crop growth. Vegetation indices are employed to assess the crop phenological stage at any time during the growing season and to distinguish between different types of land covers and, at times, between different crops. Finally, evapotranspiration measurements are used to compare a crop's water demand with the available soil moisture, capturing information on irrigation needs and water stress.

These indicators provide valuable insights into a crop health and productivity. They can identify crops that have been affected by weather-related damage, such as droughts or floods, as well as by pests or diseases. Also identifying land cover and specific crop types is crucial for creating masks[1] that serve as inputs for remote sensing interpretation (IFAD,2017).

Rainfall estimates

Weather stations are instrument that can provide stakeholders with highly accurate data on local weather, but they are often too scarce and unevenly distributed to achieve an accurate analysis of rainfall patterns in space and time.

Building a dense network of weather stations for monitoring is costly and requires continuous maintenance. However, satellite-based rainfall estimates (RFEs) present a potential solution to this challenge. Data on rainfall estimates are available daily and it is possible to retrieve time series data from over 30 years. On the downside, these data are not as accurate as weather stations, the spatial resolution of these products ranges from approximately 4 km to 25 km (IFAD,2017). It is important to note, however, that satellites do not directly measure precipitation and have certain limitations.

Thermal infrared sensors indirectly estimate rainfall by measuring the thickness of clouds or the temperature of cloud tops. Currently, most rainfall estimates (RFEs) utilize a combination of thermal infrared (TIR) sensors and passive microwave imagery, and they may also incorporate ground-based rainfall observations and modelled weather data. On the other hand, passive microwave sensors evaluate the atmospheric liquid water content and rainfall intensity, as microwaves can penetrate through clouds (Toté et al., 2015).

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[1] A crop mask is based on coarse resolution data and expresses a percentage of a crop represented in a pixel. It thus leads to better exploitation of mixed pixels in coarse resolution imagery, and it is increasingly used in regional and global crop monitoring systems. (IFAD, 2017)

What makes satellite-based rainfall estimates a good alternative to weather stations is their extensive spatial coverage, including remote areas, and their free availability. These rainfall estimates are useful for functions such as drought monitoring and early warning, flood modelling, wetland monitoring, and irrigation management (IFAD, 2017). Another advantage is that rainfall-based index insurance products are straightforward and easy to explain to smallholder farmers since they are directly related to measured rainfall. In addition, there are rainfall data time series available that extends for up to 35 years.

However, since rainfall estimates from satellites are derived from detecting and measuring clouds, are much less precise than weather station and they can lead to inaccuracies. Excessive cloud cover can complicate the satellite's ability to track specific weather systems. Moreover, in regions where rainfall is highly variable and individual events might only cover a few kilometres, this variability poses a significant challenge given the lower resolution of rainfall estimates. In fact, satellite rainfall estimates typically record fewer high rainfall events and more low rainfall events compared to weather stations data, often underestimating extreme rainfall events (IFAD, 2017).

Another weakness is the raw spatial resolution of the rainfall estimates products where a pixel can range from 5 km to 25 km and the fact that the performance of the different rainfall estimates products varies over space and time (IFAD, 2017).

Soil moisture estimates

The level of soil moisture is analysed to determine crop growth and land productivity. Observations from both active and passive microwave satellites can be used to map soil moisture in the upper soil layer (< 5cm) (Srivastava et al., 2016). The spatial resolution of the global products ranges from 1 km to 50 km.

Satellite soil moisture data are commonly used in water and irrigation management and, additionally, they can also be useful for monitoring droughts, floods, and wetlands, and they. The availability of long-term data series also makes them valuable for climate studies (IFAD, 2017).

Soil moisture data are not yet used in operational index insurance schemes, but they can potentially become useful in the future. Soil moisture-based index insurance products would be understandable and relatively easy to explain to smallholder farmers and there would be availability of long-term data series that are useful for developing insurance products. However, soil moisture products, like products based on rainfall estimates, are only suitable for insuring against drought-related crop damage, as lower soil moisture typically leads to reduced vegetation activity and lower crop yields (IFAD, 2017). Other drawbacks include the low spatial resolution and varying accuracy of global soil moisture products.

Evapotranspiration estimates

Evapotranspiration (ET) refers to the combined process of evaporation and plant transpiration from the earth's land and ocean surfaces into the atmosphere. Evaporation involves the movement of water from sources such as the soil, canopy interception, and water bodies into the air (IFAD, 2017).

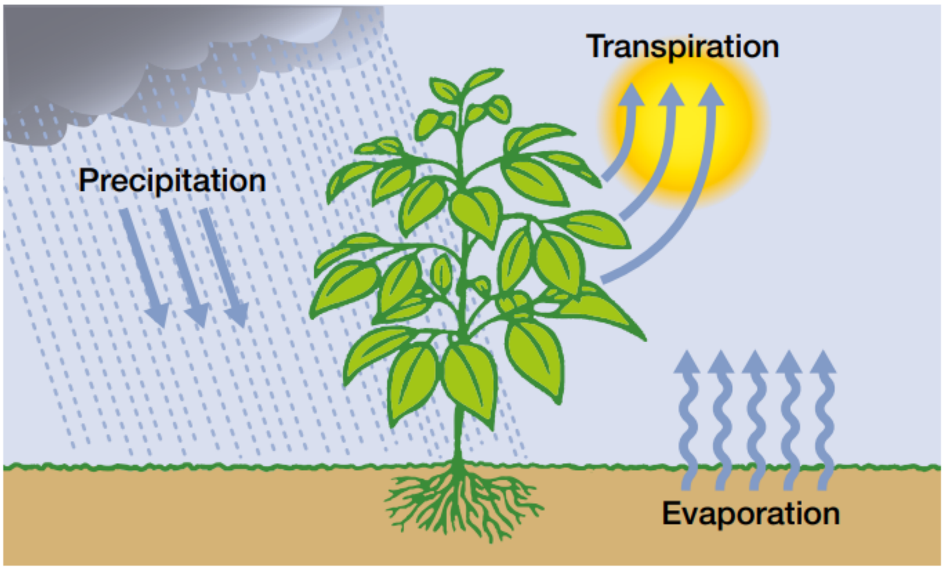


Figure 4: process of evapotranspiration (Source: IFAD, 2017)

In particular, actual evapotranspiration (ETa) is determined by the water requirements of the crop, also known as potential evapotranspiration (ET0), and the moisture content in the soil and it can be estimated by satellite sensors.

New evapotranspiration data are usually made available on an 8-day to 10-day basis and the spatial resolution varies from around 1 km to 3 km depending on the satellite observations used. Available time series can go back up to 35 years.

Evapotranspiration is a good indicator for agricultural drought. In the late 1970s, FAO addressed the relationship between crop yield and water use, proposing a simple equation where relative yield reduction is related to the corresponding relative reduction in evapotranspiration (Steduto et al., 2012).

In 2009, a micro-insurance project was launched by the EARS (Earth Environment Monitoring Agency from the Netherlands) with the objective of creating affordable micro-insurance solutions for Africa. The project adopted solutions based on evapotranspiration derived from Meteosat satellite data. Since 2011, similar crop-specific insurance products have been developed and offered for crops such as maize, wheat, rice, beans, and cotton in countries including Benin, Burkina Faso, Kenya, Mali, Rwanda, and Tanzania. These insurance products are based on evapotranspiration index insurance and have payouts that are triggered when the calculated evapotranspiration for one or more defined periods falls below a predetermined threshold.

Vegetation Indexes

Vegetation indexes offer insights into the vigour of the plant, providing a measure of its overall health, as well as specific issues such as water stress or chlorophyll levels (IFAD, 2017).

By utilizing satellite data and accurately interpreting it, the need for interventions in the field can be minimized, making crop scouting activities economically sustainable.

The most generally recognized vegetation index is the Normalized Difference Vegetation Index (NDVI). It is a straightforward metric derived from the comparison of reflectance measurements in the red and near-infrared wavelengths of the electromagnetic spectrum. NDVI serves as an effective indicator of vegetation quantity and health (IFAD, 2017).

The other main indexes used for agricultural monitoring are:

- SAVI (Soil-Adjusted Vegetation Index) allows for the evaluation of vegetation conditions during the emergence and initial stages of development by applying a correction to account for bare soil.
- LAI (Leaf Area Index) is a measure of the leaf area of a plant relative to the ground area it covers, expressed in square meters per square meter (m^2/m^2).
- TCARI/OSAVI (Transformed Chlorophyll Absorption Reflectance Index/Modified Soil Adjusted Vegetation Index): This specific index helps identify chlorotic areas within a field.
- WDRVI (Weighted Difference Vegetation Index): It analyses vegetation health, particularly useful when vegetation is well-developed and lush, as it reduces saturation effects seen in other vegetation indices.
- GNDVI (Green-NDVI): This index provides an indication of vegetation health and minimizes saturation effects, especially in highly developed vegetation.
- NDMI (Normalized Difference Moisture Index): This index evaluates vegetation water content and is suitable for use with developed vegetation.
- NMDI (Normalized Multi-band Drought Index): It assesses soil water content; high index values on bare soil indicate dry conditions, while high values in vegetated areas suggest the absence of water stress in plants.

As it is a good indicator of vegetation vigour (or health) and yield, NDVI is suitable for index-based insurance to provide cover against drought or other perils that are impacting crop yield. This includes pests or diseases that visibly impact plant health. However, the correlation between NDVI and crop yields can vary significantly depending on the crop and region. Additionally, using NDVI for insurance assumes the availability of sufficiently long and accurate yield data, preferably at a fine scale, for calibration. In practice, obtaining such data can be challenging, particularly in developing countries (IFAD, 2017).

Finally, another type of remote sensing technology is Synthetic Aperture Radar (SAR). These types of data are frequently used for crop mapping, but also for monitoring crop growth and development. SAR systems have the advantage of being able of penetrating clouds, making them particularly useful for monitoring crops in regions prone to frequent cloud cover. Unlike optical images, SAR images provide information about a crop's structure rather than its health. SAR's higher sensitivity to surface roughness and moisture content can give additional insights into soil preparation. For Example, a change in surface roughness can indicate soil tillage or the fact that a specific field activity is taking place. SAR data is commonly employed to monitor rice cultivation in countries such as Cambodia, India, Indonesia, the Philippines, Thailand, and Vietnam (IFAD, 2017).

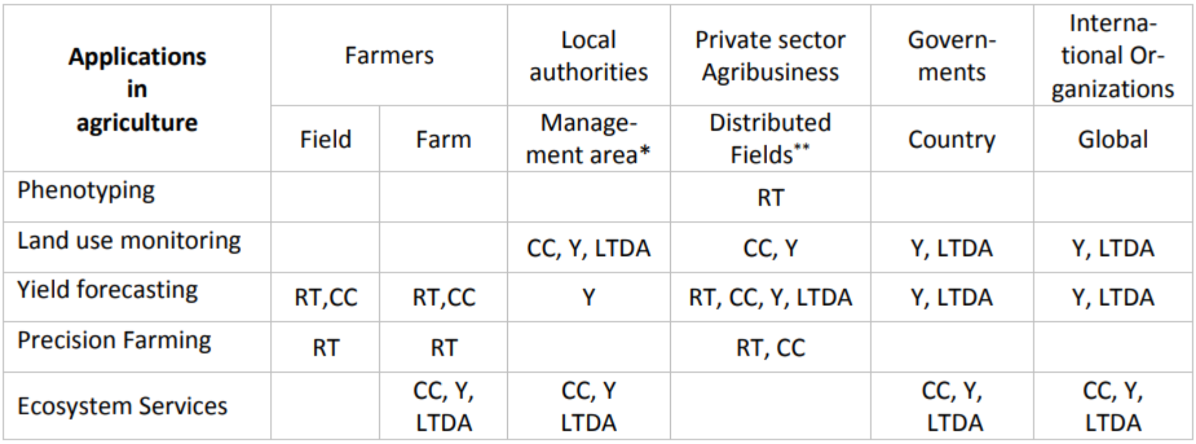
Main applications of remote sensing in agriculture

As we saw remote sensing can be used for different purposes in agriculture; it can aid in identifying new varieties that are better suited to challenging conditions (e.g., phenotyping), monitoring agricultural land use, forecasting crop production within a season, optimizing short-term production, and providing ecosystem services related to soil or water resources as well as plant and animal biodiversity (De Leeuw, 2014).

These different uses address different stakeholder needs at different levels (e.g., local, regional, or global) and temporal scales ranging from real-time to decades. Depending on the final objective they also require different levels of accuracy and prior knowledge about crop status.

Figure 4 shows the main application of remote sensing in agriculture up to now and the different uses at different scales, from the field perspective to a global perspective. RT stands for Real Time, CC is Crop Cycle, Y is year and LTDA corresponds to Long Term Data Archive.

It is possible to see how some applications are utilized both at the farmer level and at a governmental and international level but with different necessities. The same data that farmers use to optimize their production can be collected at a national or international level to have a general overview of the behaviour of national fields and can be used to influence national policies on agriculture (M. Weiss, 2020).



Applications in agriculture	Farmers		Local authorities	Private sector Agribusiness	Govern-ments	Interna-tional Or-ganizations
	Field	Farm	Manage-ment area*	Distributed Fields**	Country	Global
Phenotyping				RT		
Land use monitoring			CC, Y, LTDA	CC, Y	Y, LTDA	Y, LTDA
Yield forecasting	RT,CC	RT,CC	Y	RT, CC, Y, LTDA	Y, LTDA	Y, LTDA
Precision Farming	RT	RT		RT, CC		
Ecosystem Services		CC, Y, LTDA	CC, Y LTDA		CC, Y, LTDA	CC, Y, LTDA

Figure 5: Applications of remote sensing in agriculture for the different stakeholders and corresponding spatial and temporal scale requirements. Source: M. Weiss, 2020.

*Management Area: multi-actors within a regional area, with convergent or divergent interests

** Distributed Fields: in case of phenotyping activities, this concerns micro-plots planted with different genotypes and grown in different conditions (e.g. nitrogen, water), in case of faming cooperative or industry, the fields may be distributed over regions that may be located within a single or several countries.

The two application that are of our interest for this research and that can be used for crop insurance purposes are Agricultural land use monitoring and Yield forecasting.

Agricultural land use monitoring

One of the most straightforward uses of remote sensing for agricultural purposes is to map out agro-ecological region and monitor aspects relating to its utilization by farmers and crop management. The primary stakeholders interested in land use monitoring information are regional, national, and international entities (such as land planners and policy makers), more than individual farmers.

Crop yield forecasting.

Forecasting crop productivity before harvesting is directly relevant for different stakeholders. It would help individual farmers improve the quality and quantity of their production in their farming activities. Institutions of the international community and national governments use it to improve food security, especially among the developing countries. Moreover, also private companies, such as crop insurers and commodity traders, can benefit from these forecasts (Filippi et al., 2019).

The typical indicator of productivity in this context is crop yield, which is the ratio of the total mass of the harvested product (such as grain) to the area used for growing the crop. The spatial scale at which this information is relevant varies depending on the stakeholder.

Farmers focus on the field or farm scale, aiming to anticipate potential financial returns from their own fields. In contrast, governments, international organizations, and commodity traders are more interested in yield estimates aggregated at broader scales, such as individual administrative units or regional and national levels. This aggregated information helps policymakers make informed decisions on trade, market intervention, and humanitarian assistance. Finally crop insurers require both fine and large-scale data to assess potential crop yield losses of individual fields and to compare these to the regional context on a larger scale (De Leeuw, 2014).

Remote sensing for crop insurance

As we have seen in Chapter 1 there are two main categories of insurance, claim based insurance and index insurance; Based on the type of insurance remote sensing can be used for different purposes. Papers on the application of remote sensing in insurance predominantly focus on classical claim-based insurance in agriculture, as well as flood and fire risk management. Meanwhile, a smaller but rapidly growing number of papers discuss its potential in index insurance for agriculture.

Challenges faced by insurance companies.

Agriculture insurance companies encounter numerous issues throughout the insurance lifecycle. Here are some of the key challenges they face (De Leeuw, 2014):

- Difficulty in coordination and monitoring of field surveys: During unforeseen events, a large number of claims are raised by farmers, making it challenging to coordinate and monitor survey activities effectively.
- Inaccuracy in the extent and intensity of crop damage: Field executives often rely on visual interpretations to calculate crop loss, which can lead to inaccuracies in the assessment and consequently in the payouts to farmers.
- Inaccurate farmer plot location for damage assessment: There are difficulties in visualizing and understanding the precise size of farmer plots, hindering accurate calculation of losses.
- Lack of proper visualization for pre- and post-event crop comparison: There is a need for scientific information to be presented to the government for claim payouts, yet there is often insufficient visualization of each farmer's plot to compare crop conditions before and after events.

In this research we are going to review the current and potential contributions of remotely sensed information in supporting both conventional claim-based insurance and index insurance.

How Remote sensing can contribute to crop index insurance.

Earth Observation technology can assist agricultural insurers by providing a vast amount of historical and near-real-time data for several types of insurance products. The cost of this data has significantly decreased, and different resolutions are available to meet insurers' specific needs. The satellite industry can supply data for portfolio monitoring, underwriting, loss adjustment, and claims handling, enhancing the overall efficiency and accuracy of the insurance process.

Insurers require processed data to assist them in underwriting risk and adjusting for losses and to moderate the instances of moral hazard, adverse selection, and information asymmetry. From a more pragmatic point of view, insurance professionals need more information and better tools to successfully underwrite policies and perform loss adjustment tasks with speed and precision.

While satellite remote sensing and weather data are general information that can be used in underwriting and loss adjustment of agricultural insurance, they might not be easily integrated with the normal IT structure of an insurance company. Stand-alone platforms are suggested as a more cost-effective and practical solution to meet the needs of agricultural insurance providers. These platforms should include functionalities that enable agricultural underwriters and loss adjusters to download necessary documents and reports into the general IT systems. This involves analytical reports and specific information supporting underwriting decisions, which must be saved to individual underwriting files. The claims handling team needs to obtain and store available information such as yield estimations, crop damage maps, indexed imagery, index, and trigger calculation spreadsheets, and claim bordereaux. This ensures that detailed records are available for future reference in case insured farmers dispute the accuracy of loss assessments and claim calculations (De Leuw, 2014).

Technological advances in insurances present opportunities to make traditional, index, and hybrid insurances to provide automatic or on-demand queries for high resolution data which might be required for some fields or crop areas. New platforms specifically need this feature especially when applied on Area Yield Index and Hybrid Insurance Programs. It will greatly benefit traditional indemnity insurance by aiding loss adjusters in accurately estimating crop loss and yield across multiple fields.

These new platforms must be adaptable to accommodate a number of existing and new data types that may include optical and SAR imagery, historical and near real-time meteorological data as well as soil moisture data. Historical imagery and weather data can be utilized for setting and adjusting premium rates for individual farmers or fields, as well as for making underwriting decisions regarding the "insurability" of specific risks.

Several years ago, field location data that lies at the core of the premium rating process were hard to obtain and it has recently become a bearable problem. The new platforms must be capable of processing any field identification data, including GIS files or GPS coordinates, with the ability to automatically identify field boundaries.

It will be useful to include a portfolio mapping functionality in the new platforms because it allows the insurer to monitor his portfolio in real-time. The crop type identification feature may be more helpful for insurers in better understanding the total area under crops and comparing it to the area insured, which becomes helpful in managing market share and determining insurance penetration. Further, for insurers selling index insurance alongside other forms of agricultural insurance, the portfolio mapping feature provides valuable data for portfolio and product roles, reinsurance applications, risk accumulation, and business strategy.

Risk pricing web-based solutions for index insurance are already used by insurance companies and calculation agents. However, the structuring of index products (including trigger identification and payout schedule design) and pricing can often be very straightforward, especially when single datasets such as rainfall data or NDVI indices are used. This simplicity can result in significant basis risk for farmers, particularly if lower data resolution and large grid cells are utilized, which can impact the overall acceptance of index products and the level of trust from customers.

Future platforms have the potential to address this challenge by merging different datasets, including historical yield and weather data, as well as loss adjustment data available at the insurance company. Such additional data can be leveraged for testing index products, allowing insurers to identify any potential problems with product design or trigger response in specific regions. This approach can help enhance the robustness and reliability of index insurance products, thereby improving their effectiveness in managing agricultural risks (De Leeuw, 2014).

According to Geoville (2022) the most critical information required for index products include:

- High temporal/special uninterrupted data series
- Soil type mapping (for premium rate adjustment)
- Soil moisture monitoring (for embargoes, application deadline adjustments, actual soil moisture index products)
- Identification and verification of field location and boundaries (ensuring accuracy of insurance coverage)
- Crop type identification (for market share analysis, portfolio management, reinsurance submissions, and marketing campaign adjustment)

- Crop vegetation monitoring, including early vegetation stress identification (for portfolio management, policy cancellation, fraud and moral hazard management, and early warning for logistical arrangements and resource preparedness)
- Crop emergence and harvest dates forecasting
- Crop yield monitoring and estimation (for loss adjustment, claim calculation, fraud, and moral hazard management)
- Crop damage or loss identification based on vegetation index and weather data (for identifying risk events, assessing impact severity, identifying total loss cases, conducting more accurate loss adjustment in-field inspections, claim processing, fraud, and moral hazard management)
- Biomass monitoring (for pasture and forage crops insurance solutions, and production practice monitoring)

The desired functionality of innovative technology solutions for agricultural insurance may include automatic alerts regarding forecasted risk events, coupled with client communication products developed by insurance companies in the future. This can be accomplished by merging weather, Synthetic Aperture Radar (SAR), and optical data sets, with dashboards providing essential information to insured farmers. These alerts and communication tools would enable farmers to stay informed about potential risks and take proactive measures to mitigate losses, enhancing the effectiveness of agricultural insurance coverage (Geoville, 2022).

Remote sensing for claim-based insurance.

The literature provides numerous examples of how earth observation and GIS can assist the insurance industry in managing claim-based insurance operations.

Retrospective underwriting

Traditionally, insurers set premiums and assess risk based on past claims. This retrospective underwriting is effective for insurance products with a long history of claims and payments. However, this method is ineffective for new products targeting new populations, where historic records are lacking. In such cases, insurers rely on alternative information sources, such as in situ hazard measurements, rather than claims, to underwrite their risk (De Leeuw, 2014).

Accurate on-site monitoring of hazard-related variables is costly while remote sensing can offer a more cost-effective alternative for risk assessment. The idea is that satellite imagery can analyse the historical recurrence of hazards when records from other sources are insufficient. For instance, in areas lacking a historical record of drought recurrence, satellite-based rainfall estimates could potentially be used to construct a historic drought record (De Leeuw, 2014).

However, data mining of remotely sensed archives to retrospectively underwrite insurance risk is not a straightforward procedure. Data acquired through remote sensing is not yet completely reliable. Remote sensing rainfall records contain intrinsic errors (Tapiador et al., 2012), and these rainfall estimates need to be translated into agricultural and economic losses. For this reason, historical remote sensing data are used mostly for index insurance purposes.

Geographic stratification of risk exposure

Another use of remote sensing for claim-based insurance is the process of geographic stratification of risk exposure. In fact, the risk of exposure to hazards often varies geographically, and insurers vary insurance premiums accordingly.

Insurance companies differentiate their insurance rates geographically based on the spatial variations in exposure to certain risks. They may also rely on their historical records of claims and payments or use geo-spatial data related to the hazard to identify areas with increased risk, thereby justifying a higher premium (De Leeuw, 2014).

The geographical underwriting of risk has been extensively studied and experimented in flood risk insurance (Guzzetti et al., 2015). Several publications describe the potential and use of remote sensing for defining a spatial stratification of flood risk.

While detailed local hydrological models provide such information for smaller areas, it has been argued that insurers require models at regional and national scales more than sophisticated models for small areas. The main component that influences the most flood risk models is terrain elevation (Sanders et al., 2005)

Overall, flood risk can vary significantly over relatively short horizontal distances, and even a small vertical gradient of a few decimetres can differentiate between safe areas and those exposed to risk (De Leeuw, 2014). Not considering this fine-scale variability in underwriting can lead to underestimating or overestimating the risk, with significant consequences for both the insurer and the insured customer or asset. Therefore, insurance companies are challenged to enhance the vertical accuracy of their geo-spatial models.

In the UK, the utilization of airborne laser altimetry data as an input into flood risk modelling enabled the assessment of risk and calculation of insurance premiums at a much finer resolution, down to the postcode level (De Leeuw, 2014). This resolution was significantly higher compared to the spatial units typically used by the insurance industry, which often encompassed over two thousand households (Murtach et al., 1999).

Another example is the Flood Insurance Rate Maps (FIRMs) produced by the Federal Emergency Management Authority in the Southern USA. FIRMs exemplify the operational utilization of remote sensing in stratifying flood risk exposure. They rely on remotely sensed LiDAR (Light Detection and Ranging) data measuring terrain elevation with 15 cm vertical accuracy. Insurance companies base their underwriting on these maps, with higher premiums in more flood-prone areas. Actual premiums may be adjusted based on preventive actions and best management practices taken by communities to mitigate flood damage (Damron et al., 2000).

Damage assessment.

Another application of earth observation in claim-based insurance is related to the handling of claims.

In general, insurers aim to personally verify every claim and assess the damage independently. This would not always be possible, particularly in the case of low-value claims, when the expenses of an on-site damage assessment could become prohibitive.

Because of this, insurers might not need to investigate every claim in-depth; instead, they might try to find a compromise between managing costs, satisfying customers, and reducing insurance fraud losses.

For this reason, insurance companies often use automated statistical procedures to identify outliers from the normal pattern of claims, helping to flag suspicious cases that may necessitate further investigation (De Leeuw, 2014).

Earth observation imagery can be an alternative approach to verify whether a claimant has been affected by an insured risk and to investigate potentially suspicious claims. This capability arises from the well-established potential of remote sensing to detect damage on vegetation and crops caused by numerous factors such as drought, fire, frost, pests, hail, and diseases.

Contrasting conclusions have been reported regarding the feasibility of using remote sensing to support the insurance industry in assessing crop hail damage.

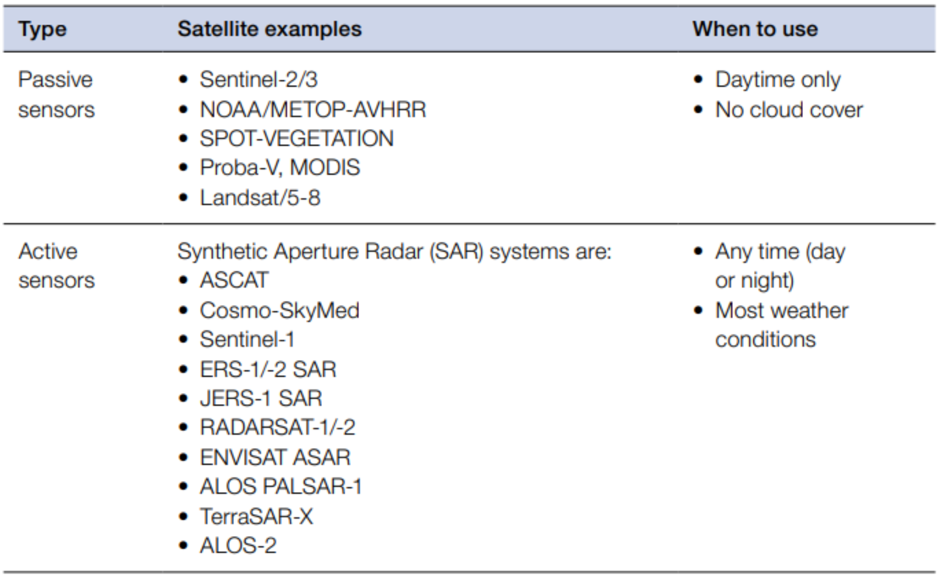
For example, Apan et al. (2005) in their research on the use of remote sensing to assess hail damage, argue that, although remote sensing can identify areas with lower biomass, it is still challenging to link such losses to hail damage because the lower biomass could have been caused by other sources.

However, it is plausible to assess that remote sensing can be used in a supportive and cost-saving role, targeting areas for further field verification. However, the ability to attribute remotely sensed evidence of crop damage specifically to hail could be enhanced by new developments in the technology used and combining optical remote sensing with polarimetric radar imagery to verify the occurrence of the hail event.

A clear example of how remote sensing can have a cost saving role comes from the United States Department of Agriculture (USDA) Risk Management Agency (RMA) that in 2007 subsidised the US crop insurance program, with insurance policies covering a liability of USD 55 billion in 2007 being sold by sixteen private insurance companies (De Leeuw, 2014).

The program initially included crop insurance covering risks from drought and hail, but it has expanded over the years to encompass a wide range of damages and various agricultural commodities. Like any insurance system, it is not free from fraud. Over a six-year period, employing data mining techniques on remote sensing information to detect anomalies and suspicious cases led to USD 450 million in cost savings. For example, to verify whether farmers had planted the crops for which they claimed losses. (Little et al., 2007).

There seems to great potential for further use of remote sensing in crop damage assessment, given the higher cost of field-based assessments. However, for assessments needed within a few days after a peril, satellites with long revisit times (>20 days) and optical sensors affected by clouds (e.g., Landsat) are not suitable. New satellite missions map the Earth at remarkably high spatial resolution (approximately one meter), while at the same time significantly reducing revisit times (De Leeuw, 2014).



Type	Satellite examples	When to use
Passive sensors	• Sentinel-2/3 • NOAA/METOP-AVHRR • SPOT-VEGETATION • Proba-V, MODIS • Landsat/5-8	• Daytime only • No cloud cover
Active sensors	Synthetic Aperture Radar (SAR) systems are: • ASCAT • Cosmo-SkyMed • Sentinel-1 • ERS-1/-2 SAR • JERS-1 SAR • RADARSAT-1/-2 • ENVISAT ASAR • ALOS PALSAR-1 • TerraSAR-X • ALOS-2	• Any time (day or night) • Most weather conditions

Figure 6: Passive and active remote sensing systems (Source: IFAD, 2017)

A common issue with these new satellite missions is that imagery is typically acquired through tasking rather than on a regular basis, unlike Landsat and other sensors with 10-to-30-meter resolution. As a result, suitable imagery describing the situation before a damage event may not be available. In this context, the increase of public-domain high-resolution optical and radar imagery with short revisit times, such as the European Sentinel-1 and -2 missions, is highly welcome. These missions will continuously monitor the Earth's surface.

The first Sentinel-1 satellite was launched in April 2014, since then several Sentinel missions have been launched in orbit, the last Sentinel-6 was launched in 2020 carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies (ESA, 2024).

Remote sensing has also been applied for forest fire damage assessment. Canaseva and Dagorne (1985) suggested that airborne colour infrared remote sensing imagery could be used to delineate forest areas affected by fire for insurance purposes. Since then, significant advancements have occurred in the remote sensing-based assessment of active fires, fire intensities, and burned areas, leading to the development of various operational products.

Remote sensing for index insurance

Satellites offer cost-effective, reliable, and unbiased information on a wide range of vegetation and hydrological parameters across different spatial resolutions. The main advantage of incorporating remote sensing data for index insurance is to have long-term datasets with consistent features over time and an ongoing information flow.

There are numerous initiatives taking place to produce reliable long-term records using a range of input sources derived from satellites, for example the European Space Agency's Climate Change Initiative and NASA's Land Long Term Data Record.

The continuously extending duration of the remotely sensed record will enhance its value as a historical record of the variation of natural processes, thus increasing its utility in index insurance.

Also index insurance based on remotely sensed rainfall indices from remote sensing has the potential to be used in addition to remotely sensed vegetation productivity indices (e.g., NDVI). Johnson (2013) notes that the automated weather stations, which form the backbone of the Kilimo Salama weather index insurance offered to over 150,000 farmers in Kenya and Uganda, are too expensive to maintain. This high maintenance cost has prompted research into the possibility of using satellite rainfall estimates instead.

An accurate spatial representation of the rain field requires a network of weather stations since rainfall is characterized by high spatial variability, particularly over short temporal scales. Satellite data can help bridge the gap in situations where these networks are unavailable or cannot consistently supply data.

These data consist of thermal infrared observations, mostly from geostationary satellites, and active and passive microwave observations from orbiting satellites. Many satellite rainfall data merge rainfall retrievals from various remote sensing sources. The reliability of the estimate may be enhanced by a local calibration using ground-based rainfall measurements, as the quality of these rainfall products may differ based on the climatic region (Dinku et al., 2012).

However, satellite rainfall estimates offer a suitable alternative to interpolated station data, and thanks to large international efforts, such as the Global Precipitation Measurement (GPM) mission, their accuracy will continuously increase.

Challenges for remote sensing in index insurance

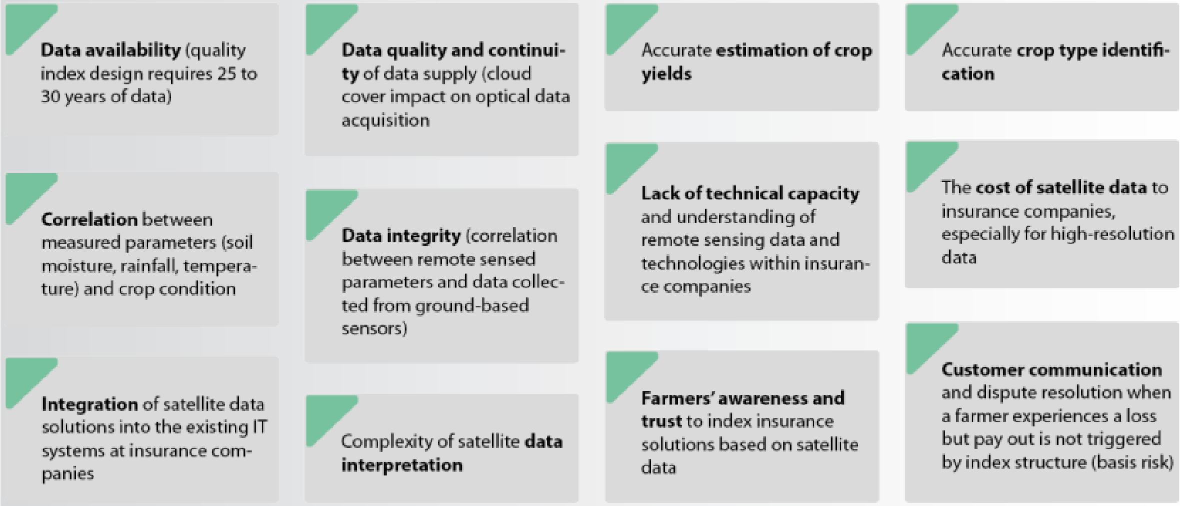
Agricultural insurance serves as an effective tool for managing risks, but its actual adoption is hindered by issues such as distribution models, availability of sufficient information about insurance options, the timeliness of loss payments, the complexity of the claims process, and the fairness of the payouts.

Farmers typically expect loss payments within 2-4 weeks following a loss event or within 30-45 days after harvest. In cases of total loss, payments can be processed quickly if the loss is clear. However, crop damage assessments may require more time to accurately determine the extent of the damage. While traditional indemnity insurance often meets these timelines, the process can sometimes be slow and involve significant administrative effort from the farmers. Additionally, farmers sometimes question the objectivity of loss assessments.

Index insurance products offer a viable alternative to traditional insurance because they enable insurers to make payments without conducting loss assessment inspections once the insured event occurs. With advancements in remote sensing technology, data providers can now supply the necessary information for claim processing rapidly, typically within 1 to 5 days. This quick turnaround is due to the reduced time needed for data acquisition, processing, reporting, and delivery to the insurer (Geoville, 2022).

Despite the advantages that remote sensing could bring to crop insurance there are some technical challenges that constraint the use of remote sensing in the insurance industry.

The main challenges for weather index, parametric, and satellite data index insurance products lie in the accuracy of the data and the correlation between payouts and the farmers' actual crop yield loss. Ensuring a strong correlation between loss compensation and actual loss is crucial for the success of any index insurance product. Farmers are willing to tolerate minor discrepancies in loss estimates, such as a 10% difference, but may raise objections if the estimates deviate significantly more than that.



Data availability (quality index design requires 25 to 30 years of data)

Correlation between measured parameters (soil moisture, rainfall, temperature) and crop condition

Integration of satellite data solutions into the existing IT systems at insurance companies

Data quality and continuity of data supply (cloud cover impact on optical data acquisition

Data integrity (correlation between remote sensed parameters and data collected from ground-based sensors)

Complexity of satellite **data interpretation**

Accurate **estimation of crop yields**

Lack of technical capacity and understanding of remote sensing data and technologies within insurance companies

Farmers' awareness and trust to index insurance solutions based on satellite data

Accurate **crop type identification**

The **cost of satellite data** to insurance companies, especially for high-resolution data

Customer communication and dispute resolution when a farmer experiences a loss but pay out is not triggered by index structure (basis risk)

Figure 7: The key challenges of index insurance from the satellite earth observation technologies perspective. (Source: Geoville, 2022)

The first challenge is data continuity. There need for a steady flow of data that can be relied upon by the insurance industry might limit the spread of remote sensing in index insurance. In the past it happened that satellites did not provide images for a certain period of time because of maintenance or other technical difficulties, but this type of problem has been overcome thanks to the substantial number of satellites that have been launched in the last years that currently assure data continuity (Geoville, 2022).

A second challenge of index insurance is related to the quality of data. Due to the high altitude and brief exposure time of earth observation sensors, the raw measurements obtained from satellite sensors are often noisy. In optical remote sensing systems, noise primarily results from undetected sub-pixel clouds and poor atmospheric conditions, such as haze (Geoville, 2022). Observation conditions vary significantly in space and time, leading to space-time dependent effects. As a result, satellite observations may lack statistical stability, making it challenging to convert data into usable probabilistic information.

A third issue relates to the spatial resolution of the images used. While it is evident that claim-based insurance benefits from higher spatial resolution to accurately assess damage, the significance of spatial resolution for index insurance is less apparent.

For instance, in the case of drought observation, the affected areas are often large, allowing strong impacts to be easily mapped from space even with low-resolution data. Indeed, many international organizations have successfully relied on this principle for years, for example for food security early warning systems. A finer spatial resolution may not necessarily provide additional information if the meteorological impact occurs at the meso-scale or larger. However, relying on lower resolution imagery may overlook spatial variations within a low-resolution pixel, which could be detected using finer spatial resolution imagery. For index insurance data quality and the quality of the data pre-processing, as well the available archive, seems of higher importance than the spatial detail (De Leeuw, 2014).

The final and perhaps the greatest challenge lies in effectively limiting basis risk within the insurance scheme. Insurance payouts that do not match the actual losses experienced by farmers, caused by perils that the policy is meant to cover, risk providing poor value to clients, leading to dissatisfaction, and damaging the reputation of the insurer and all stakeholders involved (IFAD, 2017).

A crucial requirement for achieving this is to have an index or a set of complementary indices that shows a high correlation with the losses experienced by farmers. This challenge comprises two main elements: index construction and calibration options.

Regarding index construction, De Leeuw (2014) shows that various data sources could be utilized, including satellite-derived vegetation indices (e.g., NDVI) and rainfall estimates. However, even after selecting an initial data source, there are numerous approaches available for its utilization.

Basis risk is directly related to the resolution of remote sensing, where index measurements can either be taken from single pixels or from groups of pixels that have been combined to make up the unit area of insurance (IFAD, 2017). Information related to yields in agricultural products is necessary for fine-tuning possible indices and choosing an adequate index to minimize the basis risk, as well as the integration option for the chosen index in space and time. The unavailability of standard crop data and sustainable agricultural yields data in several developing countries is, therefore, one of the main reasons for the limited use of remote sensing in crop insurance.

While it can generally be assumed in most of the cases that there is a logical correlation between the obtained agricultural yields and the decreasing levels of a vegetation index, the inefficiency of calibrating this index may result in the poor functioning of an insurance scheme. If this leads to no pay out to farmers during periods of high loss, it can greatly reduce on insurance premium for future seasons.

Financial Sustainability of Remote Sensing Applications in Insurance

In order to the determine the convenience of remote sensing for insurance products it would be necessary to investigate the effect of adopting this technology on the cost benefits of the insurance product. The costs to consider in such analysis include the cost of acquiring and processing imagery, as well as the cost of developing and calibrating indices that relate the remote sensing imagery to the insured agricultural loss. In cases where sophisticated models are required to establish links with underlying loss, the design of index-based insurance can be even more costly.

According to De Leeuw (2014) benefits from remote sensing information in insurance to consider in cost-benefit analysis include:

- Making insurance affordable for low-income households.
- Reducing fraud, moral hazard, and adverse selection.
- Eliminating the burden of costly on-the-ground verification of claims.
- Enabling faster and cheaper payouts to the insured.

Another advantage is that farmers in remote locations who are not eligible for traditional crop insurance can receive coverage through remotely sensed index insurance.

The promise of remote sensing in the insurance industry mostly depends on the financial sustainability of markets for various insurance products. De Leeuw (2014) found a strong dependence on financial support from government funding or donors for remote sensing applications in insurance.

The market's viability for these kinds of products is still unclear in developing nations, where several index insurance initiatives are taking off. A portion of this uncertainty comes from the heavy reliance on development donors, which may ultimately prove to be a temporary source of funding.

Key opportunities for insurers with remote sensing

Farmer enrolment, satellite resolution, and unit areas of insurance (UAI).

High-resolution pixel data can be very appealing to insurers, as it theoretically enables the payouts to be made based on the data of a particular local area such as a village. However, it is important to identify the right Unit area of insurance for the insurers. The size of the UAI should be large enough to allow for reasonable estimation of local losses but small enough to avoid problems with payout accuracy due to large numbers of farmers in each UAI or with index design due to the need for very fine calibration. Reducing the UAI to below a certain level could also lead to the problem of basis risk (IFAD, 2017).

Harnessing technology for distribution and sales

The advancement in geographical information system (GIS) technology to produce detailed maps helps insurers to identify the geographical location of the insured farmers, the locations, risks and usage of the land. It greatly enhances the distribution and underwriting of index insurance. For instance, ACRE (Agriculture and Climate Risk Enterprise) in Kenya sells insurance where farmers receive inputs, mobile phones, and are expected to report sowing and location (IFAD, 2017). The geographical distribution of insured farmers is significant for estimating the distribution of risk and potential financial results.

Portfolio Information, Mapping, and Geographical Information Systems

Remote sensing offers insurance companies a rich source of information in their sales areas through integration of client databases with GIS. Technology has become integrated in agricultural insurance in developed countries using tablets and other devices to capture the geographical location of the insured farmers and the mapping of information including land use, field boundaries, and the clients' insurance data such as premium, claims, and yield history. As index insurance relies less on the client data, it is still important for the insurers to know their clients, the places they are located, and the conditions influencing risks and land usage. Remote sensing is useful in developing complex GIS data systems that come with user interfaces that are ideal for insurers, and this presents good chances for increasing the precision and productivity of the insurers' work (IFAD, 2017).

Future developments of remote sensing for crop insurance

The Earth Observation (EO) industry is growing at a fast pace due to improvements in the algorithms for interpretation of EO data and the new opportunities that are coming up for use of index insurance. There is an anticipation of a steep rise in the flow of fresh data from new missions that have been launched and those planned by institutional satellite operators like the ESA and NASA. These missions are expected to offer insurers an opportunity to obtain significant volumes of quality data that can be used to improve the index insurance products and thus benefit insurers and farmers. Private satellite operators are also highly interested in improving the temporal and spatial resolution of new incoming data (Geoville, 2022).

Very high-resolution (VHR) optical datasets already exist and give insurers tools to meet agricultural underwriting and loss adjustment requirements. The available sub-meter resolution data can be used to address the issues related to index insurance as it is at present. Thus, when applying VHR optical data, it is possible to identify risk effects with a significantly higher level of detail.

The following are some of the ways through which VHR data can be used to control basis risk in index insurance. For example, if the trigger conditions were not met but an insured farmer has a loss, VHR imagery and weather data can be used to validate the loss. This helps the insurers to make better decisions that will help them to minimize fraud cases and make the index insurance products more trustworthy and reliable.

Remote sensing data operators will continue their research to improve the correlation of new data with crop loss and yield estimation, as well as enhance the identification of crop damage using VHR optical and Synthetic Aperture Radar (SAR) datasets (Geoville, 2022). While these technologies have advanced significantly in recent years, primarily using artificial intelligence, the lack of ground-based reference data to train and validate EO products remains one of the main bottlenecks in further operationalizing these services.

Thus, synergies between the Earth Observation sector and the agro-insurance sector (the latter has better data access in the field) are vital. This, in turn, can help them address the challenges associated with data validation that may affect the accuracy and reliability of the EO-based product that can be used in supporting agricultural insurance applications. Thus, the cooperation can contribute to the increase in the pace of innovation and the acquisition of new knowledge in the sphere of agricultural risk management.

The insurance industry will have to proceed with the integration of Remote sensing technologies into its business models as has been influenced by COVID-19 (Geoville, 2022). Over the course of the decade, insurers will request better clarity and coherence in the data interpretation to apply the Earth Observation technologies for insurance portfolio support and future product innovation. At present, insurers do not always have in-house professional remote-sensing personnel who can work with available data and generate the required reports on their own.

In return, the capacity gap within the Earth Observation industry will be expected to respond and meet the needs of insurers through the enhancement of data exchange and reporting. This enhancement is expected to enable more accurate underwriting decisions and the right timing to help process indemnity payments faster. The insurance and earth observation industries will have to work together closely in order to fully capitalise on the use of earth observation technologies in the insurance sector to enhance productivity and effectiveness, as well as promote the utilisation of more sophisticated risk management tools.

Another promising application of future EO technologies is the merging of traditional indemnity insurance products with innovative index solutions, driving the market towards technology-driven hybrid insurance covers in agriculture (Geoville, 2022). These innovative, data-driven approaches in agricultural insurance will assist in underwriting and claims processing by automating parts of existing business processes, enhancing claims settlement, and ensuring faster indemnity payouts to farmers.

Thus, solutions that can offer multiple data layering and issue the needed reports with more accurate estimations of crops yield or damage scope may be more attractive for agricultural insurers in the future. These capabilities would enhance the quality of risk estimations and losses, and in this way, insurance products would become more credible and desirable for insurers, and farmers. Through the incorporation of EO technologies into hybrid insurance frameworks within the insurance industry, the complexities several aspects of agricultural risk management can be well-handled.

Area-yield index insurance solutions will remain a work in progress in their attempt to find superior data sources to attain better measures of actual crop yields that will reduce the level of basis risk currently inherent in yield estimation processes. It could be assumed that the EO industry will create new index varieties more suitable for detecting the emergence patterns of specific crop types (Geoville, 2022). This is particularly the case in distinguishing between cereal crops which are look-alikes including wheat, rye, barley, and oats.

These advancements will improve the accuracy used in crop monitoring and yield assessment which will make insurance products more accurate. These solutions will also be enhancing the reliability and confidence of index insurance while simultaneously reducing the basis risk and improving the yield estimation hence helping both the insurers and farmers.

It is possible to foresee that in the next years new methods for calculation of crop yields will be found. The integration of a new artificial intelligence and machine learning algorithm, together with the big data processing algorithm in addition to the improved indices of the satellite data, may increase the precision of estimating crop yields.

The vegetation indices commonly employed for observing the conditions of crops are not strongly associated with crop yields in terms of insurance. To improve the accuracy of the crop yield estimates, one can fuse multiple sensors that include optical, radar, hyperspectral, and fluorescence data integrated with ground and climate data.

Presumably, this data should reflect yields at the farm level and should be obtained contemporaneously from sources other than the satellite data, for instance from yield monitor in the combine harvester or yield losses assessed by loss adjusters on the field. This approach enables the yield data that are often collected on the parcel with high level of accuracy to be fed into the operational satellite-based models that are in place improving their quality.

Currently, the Earth Observation industry offers effective applications for the assessment of soil moisture using passive microwaves operating within the topsoil layer, which ranges from 5 to 10 centimetres (Geoville, 2022). This technology is already applied for index insurance based on the soil moisture index which assists farmers to reduce the losses caused by severe drought.

While the water availability in the topsoil enables us to determine the moisture which is potentially available to the plant, this idea does not include the water stored in the deeper layers of the soil where agricultural crops can access because they possess deeper roots. Improving on remote sensing techniques will allow for a better estimation of water content in deeper soil layers of 1- 1. Five meter and thus design local index insurance products for managing drought (Geoville, 2022). The use of data on the content of top and deep layers of soil moisture, as well as other significant parameters, including evapotranspiration and the relative air humidity, can result in the creation of complex models. These models could, in future, provide a basis for the development of yet a new generation of agricultural insurance products.

It is expected that complex insurance solutions will become a more common phenomenon in the world insurance market, which implies the involvement of more insurance companies and EO data providers in the search for solutions and the needs of insured farmers (Geoville, 2022). Parametric index insurance products can be seen to have a great future in the insurance management and recovery phases following the disasters. In this regard, they are likely to improve on the above by extending them to cover more risks and crops as per the farmers' preference. Parametric catastrophe index insurance covers will further develop with the assistance and support of national governments and international development organizations. These insurance covers will be applied at meso- and macro-levels, potentially at a national scale, providing coverage for broader areas and populations.

Continued efforts to integrate different EO data layers will create increased prospects for agricultural insurance, crop monitoring, and yield estimation in the future. This comprehensive reporting will aid in efficient portfolio management, enhancing the development of improved insurance sales tactics and more effective client targeting strategies.

Crop insurance for economic development.

Developing countries have different problems related to the crop insurance market compared more developed ones. Losses in crop production due to natural disasters can severely deter rural development and make agriculture a precarious industry.

The financial burden of post-disaster reconstruction and recovery falls heavily on farmers, contradicting the UN Sustainable Development Goals of eradicating hunger and reducing poverty. Interventions in the land and agri-food sectors positively impact the UN Sustainable Development Goals, with agricultural insurance being one of the key instruments. Crop insurance is crucial for farmers to mitigate the risk of disasters and the excessive costs of recovery by sharing production loss risks with the insurance industry.

The primary obstacle for agricultural insurance in developing countries is establishing sustainable agricultural insurance markets. According to Wang (2023) overcoming this requires three key components:

- Creating high-quality, commercially viable products with minimal government assistance,
- Ensuring a substantial and enduring demand,
- Fostering a competitive supply primarily driven by the private sector.

As seen before, geospatial data can contribute to the first point improving the quality and efficiency of insurance products at a modest cost.

A high-quality agricultural insurance product compensates farmers only when they experience a crop or income loss, and the compensation amount directly corresponds to the extent of the loss. Traditional indemnity insurance products meet this high-quality standard, but due to information asymmetries and the high costs of monitoring and loss assessment, they are not commercially viable. On the other hand, index-based products incur low monitoring and loss assessment costs and largely eliminate information asymmetries. However, they introduce basis risk, which is the imperfect correlation between indemnity payments and the actual losses incurred by the insured.

Investing in agrometeorological research, geospatial data and crop-weather modelling is essential to identify weather indexes that minimize basis risk for the maximum number of households in a region, given the available weather data and improving the design of the insurance product.

The Weather Risk Management Facility (WEMF) identified key areas in which donors and governments could contribute to the development of the crop insurance sector and contribute to food security (IFAD,2011).

Build weather station infrastructure and data systems.

National weather services can have very restricted budgets, however, building their capacities can only be achieved by a systematic coverage of the area with weather stations located closer to insured parties. Furthermore, data needs to be collected, maintained, archived and made available promptly in relation to insured events. Closer collaboration with the national meteorological service might help meet these requirements. Therefore, it is necessary to carry out a comprehensive assessment of the national meteorological service's capacity and needs including mapping the existing weather recording infrastructure in order to support expansion (IFAD, 2011).

Apart from developing index insurance products, investment in weather infrastructure unlocks several other benefits. It also supports creating additional weather risk management tools for agriculture, food security, early warning systems and extension services.

Provide technical assistance, training and product development.

Product development and management can be significantly improved through government and donor support. A pilot product needs continuous review and improvement, as well as other products for different kinds of crops. For instance, policy support is required from governments and funders in product development particularly for new agro-meteorological research or risk profiling on the small holders to address the 'first mover' problem; this could lead to a large initial investment in research and development for new WII products that private companies may be reluctant to make alone because it lowers barriers to entry for competitors thus making it impossible to recover the initial expenses. This lack of inclination leads to market stagnation without external investments by governments and donors.

The government should concentrate its investments on the most expensive starting up stages, such as feasibility studies and technical assistance for testing new products with the participation of local private-sector partners (IFAD, 2011). But it would be reasonable to handle direct subsidies for premiums with care.

Besides supporting product development, it is necessary also to develop capacities and skills of local insurers and financial service providers (FSPs) so that they can effectively identify customer needs, predict demand, and offer risk management services. Other actors in the value chain like farmers' associations as well as input suppliers could benefit too from capacity building. International exchanges with other underwriters can enable new initiatives to learn from each other and avoid costly delays and mistakes.

Fund Innovation

Donors can also push the frontiers of index insurance by funding innovations that may open new directions for insurance products more affordable and efficient. As seen before, innovative approaches such as using new technologies or satellite-based indices can help lower the entry barriers for insurers and farmers alike (IFAD, 2011).

Facilitate development of an enabling legal and regulatory environment

Usually, it is not difficult to obtain regulators' backing for a test product; creating a conducive legal and regulatory environment for index insurance is however a challenge that cannot be compared. Index insurance requires enforceable contracts which are trusted by both sellers and buyers. Legislation must conform to international standards in order to facilitate access of insurers to the global risk transfer markets. In a number of countries, there are no appropriate laws and regulations governing weather insurance products. The development of the appropriate legal and regulatory framework for managing index-based insurance programs should also involve increasing human capacity and offering macro-level technical assistance services.

Educate farmers on the role of insurance.

While private insurers will invest in marketing their products, they are unlikely to invest in educating farmers and, in general, intermediaries on the appropriate role of insurance. Support from governments and donors can increase the probability that information is presented in a balanced way and that sufficient investments are made in a larger educational effort for untested insurance products.

Facilitate initial access to reinsurance.

Although they almost always work on an international basis, reinsurers primarily assist insurers with financial risk transfer, but they can also provide them with some technical support. In order to work with the government to create the required macro-level enabling environments, having the interest of a reinsurer is frequently essential. For their current business lines, established insurers already have relationships with reinsurance companies; however, IFAD could assist in luring an international reinsurer to collaborate on an all-inclusive index insurance program.

The recent growth of Index Insurance has motivated some major international reinsurers to commit resources to creating reinsurance for index insurance, even in developing nations. The potential for long-term business and relationship development, as well as the business development plan, must be understood by these reinsurers. However, the initial stages in establishing reinsurance can be a barrier if underwriting research or assistance needs to the insurer are high, but anticipated premium volumes are still relatively low.

Even with reinsurance in place, it may be necessary to develop catastrophe protection layers involving government and/or donor intervention, or through contingent loan arrangements (Mahul and Stutley 2010).

Support regular monitoring, evaluation and impact studies.

If the product is implemented on a long-term basis, the project team should carry out systematic monitoring and evaluation exercises in addition to the pilot phase's suggested monitoring and evaluation activities. These exercises are crucial for determining possible operational and technical problems, like delivery routes and pricing, and for evaluating how index insurance affects farmers' welfare and ability to make decisions. Impact studies are essential for gaining knowledge from program investments and proving that insurance can produce substantial long-term benefits. Positive results have the power to draw in and maintain governments' and donors' support for increased activity.

Impact analyses need to do more than just illustrate the desire for insurance adoption. The project team should assess whether insurance enhances household socio-economic development by expanding access to financial services like credit and savings in addition to risk transfer. Evaluations should also look at how having an index insurance policy has affected customary risk management practices, encouraged development through investments in better agricultural production inputs and technology, kept kids in school, or decreased migration from rural areas.

Chapter 3

Remote sensing as a support to crop insurance companies: Ticinum Aerospace case study.

Ticinum Aerospace

Ticinum Aerospace (TA) was founded in February 2014 as an academic spin-off from the University of Pavia to facilitate the commercialization of the significant research results that were obtained by the Remote Sensing Group at the University of Pavia, on the exploitation of Remote Sensing data in a risk assessment and management framework and to use this knowledge from the academic sphere to have a positive impact on our day to day life.

The mission of the company is to provide reliable, customer-oriented solutions taking advantage of machine learning techniques and heterogeneous remote sensing datasets, with the final aim of cutting the costs of uncertainties.

Ticinum Aerospace is specialized in the treatment of big data in the Remote Sensing world. Tons of data are collected from many different sources, each one featuring its specific and unique capabilities, making each of them well-suited for some specific applications. TA has the necessary expertise and is able to cleverly combine various datasets to find the most dependable solution for a given issue.

As a spin-off company of the University of Pavia, the company can rely on a strong backup from the underlying experience earned along almost two decades of scientific and technical activity of the Remote Sensing Group, within which the spin-off was founded.

TA offers two services, both approaches utilize satellite imagery to deliver value to the end customer, although in distinct contexts. The first service is named Deep Property, and it is focused on the analysis of urban constructions and buildings: it allows very fast, large-scale analysis of urban environment for many different application fields, such as risk management and real estate services.

The second service is named Saturnalia and applies satellite images to the field of agriculture. Saturnalia's vision is to better manage the climate changes that are affecting crops around the world. The goal is to make agricultural production more efficient and increase the resilience of crops to climate change, thereby helping to improve global food security.

As discussed in Chapter 2, Food and Earth-Observation Science have never been so close as in the last few years. The use of remotely sensed data from space, and in-situ environmental data are very powerful in agriculture. Saturnalia services are addressed to two types of customers, agricultural producers that can monitor their fields through satellites, allowing them to have daily updates of the health conditions of their fields with different vegetation indices and crop insurance companies that can have an extra help from space in loss assessments and claims management.

Introduction: Concept of the case study

Loss assessment has never been a precise science. Field assessors find it challenging to accurately measure the area and extent of damage over vast fields. Insurance companies generally provide crop damage estimates based on their personal experience and field samples which do not always accurately represent the investigated field's spatial variability (Gobbo et al., 2021).

It needs to be taken into consideration that in person field assessment procedures, may be influenced by post-event damage, weather, time, and human presence and other variables like crop condition caused by the supply of water and nutrients, insect or pest infestation, disease outbreaks and prevailing weather conditions (Rao, 1997).

Current field-based hail damage assessment practices are both time and labour intensive. A dependable, impartial, and less labour-intensive technique to calculate crop hail damages is what farmers and the insurance industry need. The integration of remote sensing and crop modelling provides a unique opportunity for the crop insurance market for a reliable, objective, and less labour-intensive method to estimate hail damage (Gobbo et al., 2021).

Integration with a Geographic Information System (GIS) database is crucial for interfacing with an interactive administrative system. Remote sensing and GIS provide a cost-efficient approach for documenting, correlating, analysing, and accurately evaluating hail damage, ensuring consistency and building a relational database. Value can be added by modelling historical claims data for risk analysis scenarios, offering planning and crop management insights to farmers. This information would also become useful for developers, land use planners, potential buyers, insurance brokers, and financial lending institutions. These features support the creation of a commercial Internet claims management platform (Young et al., 2004).

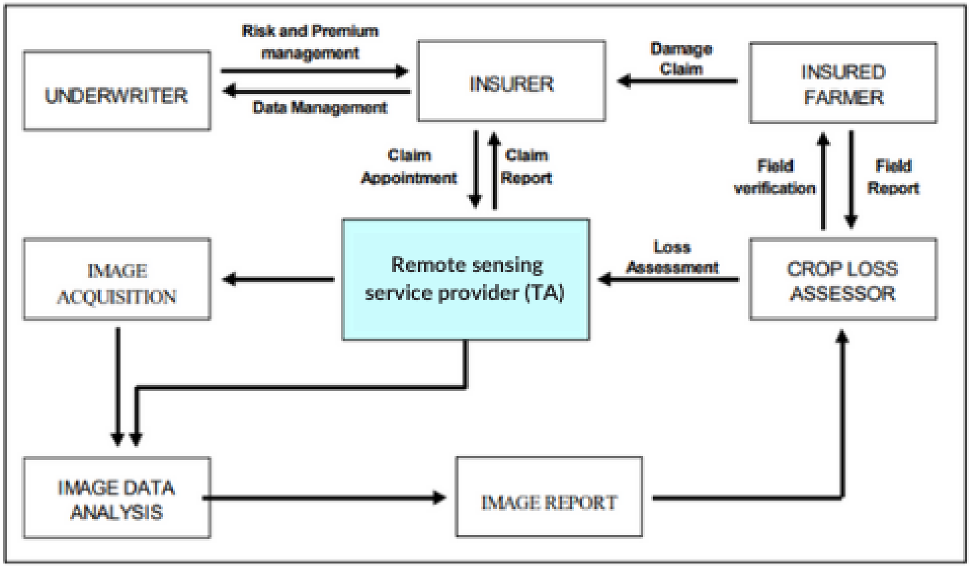


Figure 1: Remote sensing, GIS and insurance operational integration (Source: Based on Chandler 2001)

This case study focuses on maize and wheat crops. Remote sensing has been extensively utilized to assess maize damage caused by natural events (Erickson et al., 2004). Specifically, defoliation can be evaluated either by using satellite images (such as Landsat and Sentinel 2) taken immediately after the hail event or by comparing images captured before and after the incident. This method offers a cost-effective, time-efficient, and less labour-intensive alternative to traditional in situ measurements (Gobbo et al., 2021). For instance, Peters et al., (2000) employed remotely sensed data (including red, green, blue, and near-infrared bands) to estimate the extent and severity of hail damage on maize and soybean crops.

Moreover, Young et al., (2004) sustain that satellite sensing is highly effective for evaluating defoliation, even though the accuracy of this assessment is influenced by factors such as crop condition, vigour, and biomass. The findings revealed that remote sensing can analyse defoliation with an average accuracy ranging from 5% to 30% difference from field observations, depending on the technique and boundaries used. The NDVI method yielded the highest accuracy, with an average defoliation difference between 5.05% and 9.08%.

For maize, hail damage is evaluated by insurance company agents based on parameters such as reduction in plant density, the growth stage at the time of the event, the extent of defoliation, and direct damage to maize ears (Vorst et al., 1991). These parameters are manually assessed at specific sampling points identified within the affected area or field (Gobbo et al., 2021).

Manual surveys are labour-intensive, time-consuming, and subjective, often failing to represent the entire damaged area accurately. Consequently, as insurance companies encounter a growing number of claims, there is a demand for reliable techniques to estimate crop losses (Gobbo et al., 2021).

More information on the effects of pre-event and post-damage crop conditions, leaf shadow and aspect, stalk quantity, soil colour, and soil percentage are needed to better understand a crop’s reflectance values. The ideal solution would be evaluating these factors, along with assessments from agronomists and satellite imagery. Combining the agronomist's expertise with satellite imagery for multiple events seems to be a faster, more commercially viable method for developing an accurate and reliable application-oriented system (Young et al., 2004).

Italian current crop damage estimation methods

In Italian agricultural insurance, various methods exist to estimate the damage caused by hail (Capitanio and De Pin, 2018; Vroege and Finger, 2020). Insurance companies normally rely on visually inspecting the field, conducting surveys, and collecting leaf samples affected by damage. These samples are then compared against a scale that estimates potential yield losses. (Schillacci et al., 2022).

We are now going to see one of these methodologies, illustrated by Schillacci et al., (2022), that quantifies the damage from atmospheric adversities on maize by analysing the foliar inefficiency. Foliar inefficiency could be defined as the reduction in the functionality and ability of the plant to normally perform the functions of photosynthesis, respiration, and transpiration and does not correspond to the defoliation suffered by the plant (Schillacci et al., 2022).

During the evaluation phase for assessing defoliation damage, insurance company technicians document various parameters. These include identifying the plots, noting the vegetative condition of the affected crops, and detecting any diseases or non-compensable damages, among other factors. At this stage, technicians utilize various tables and graphs to correlate leaf loss (defoliation severity) at specific growth stages (defoliation timing) with resulting inefficiencies and reductions in grain or biomass production. These resources are employed within a methodology that also considers other factors contributing to the actual damage, such as direct damage to the tassel, direct or indirect damage to the ear, malformations, and more (Schillacci et al., 2022).

Figure 2 show one of these tables used by Italian insurance companies. In this assessment methodology, maize plants are categorized as non-damaged, moderately damaged, or severely damaged. The classification references the number of plants sampled and the percentage of damage assigned by the technician to each part of the plant sampled, including leaves, stalk, and kernels.

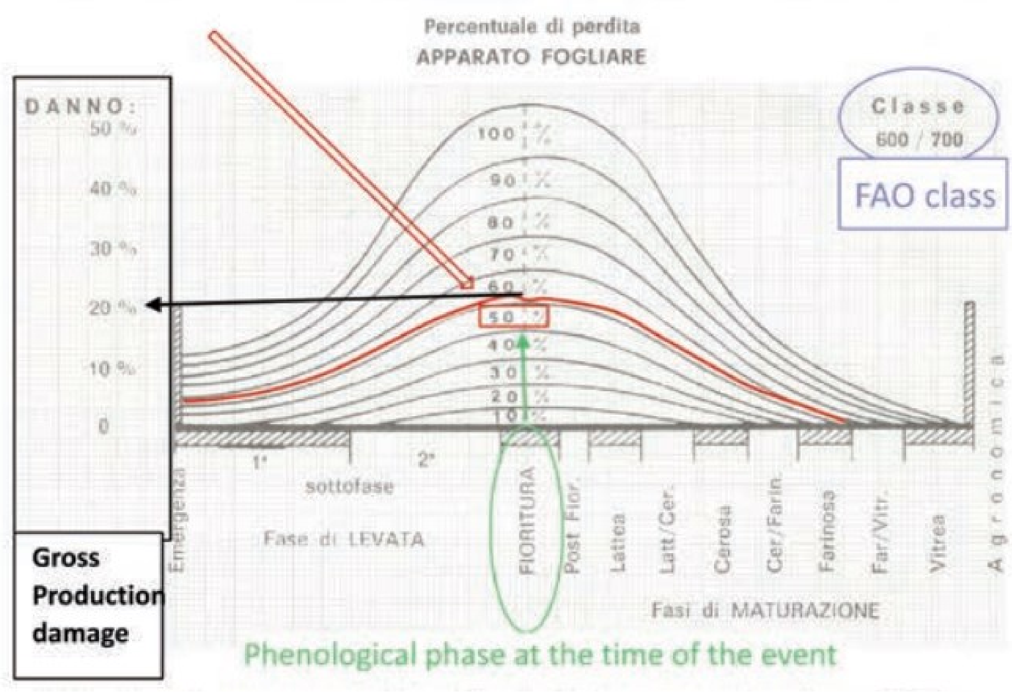
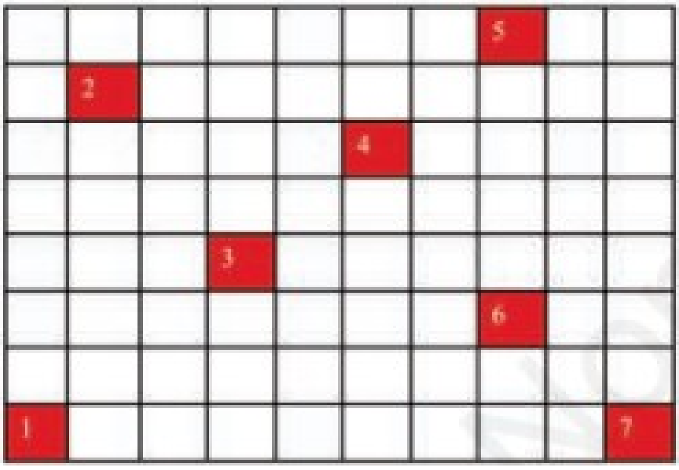


Figure 2: Computation of foliar inefficiency based on the chart (Source: Schillacci et al., 2022)

By calculating a simple weighted average from randomly sampled plants, which represent the non-damaged, moderately damaged, and severely damaged populations, the technician can obtain accurate estimates of the field damage percentage.

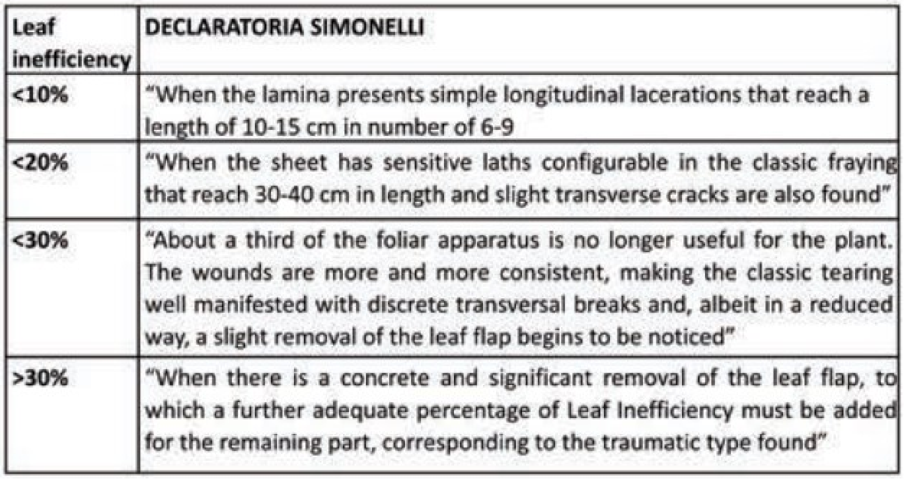


							5		
	2								
					4				
			3						
							6		
1									7

Figure 3: Random sampling table (Source: Schillacci et al., 2022)

The damage rate attributed to the 'leaves' component is determined by estimating the percentage of foliar loss, assessed by the technician. Using their expertise, or with the aid of additional equipment, the technician evaluates all the leaves on the maize plant and assigns an overall average percentage of damage to the plant's photosynthetic apparatus. This process is then repeated on several neighbouring plants chosen randomly. An estimated average percentage of damage is then calculated for the entire plot or field under analysis.

The calculated damage percentage is then correlated using empirical tables that link the inefficiency of the photosynthetic apparatus to the phenological stage of the crop at the time of the hailstorm or adverse event, as shown in Figure 4.



Leaf inefficiency	**DECLARATORIA SIMONELLI**
<10%	"When the lamina presents simple longitudinal lacerations that reach a length of 10-15 cm in number of 6-9
<20%	"When the sheet has sensitive laths configurable in the classic fraying that reach 30-40 cm in length and slight transverse cracks are also found"
<30%	"About a third of the foliar apparatus is no longer useful for the plant. The wounds are more and more consistent, making the classic tearing well manifested with discrete transversal breaks and, albeit in a reduced way, a slight removal of the leaf flap begins to be noticed"
>30%	"When there is a concrete and significant removal of the leaf flap, to which a further adequate percentage of Leaf Inefficiency must be added for the remaining part, corresponding to the traumatic type found"

Figure 4: assessment of the leaf inefficiency degree (Source: Schillacci et al., 2022)

Damage to the stem is closely associated with leaf damage, corresponding to a percentage of leaf damage. In contrast, kernel damage can be either direct (loss of kernels or parts of the ear due to the direct impact of hail) or indirect (such as an increase in the percentage of aborted or unfertilized kernels affected by hail).

In Figure 4, it is represented the specific leaves of the maize plant, for which a percentage of foliar inefficiency has been assigned according to the Declaratoria Simonelli, a document dating back to 1978.

Many Italian insurance companies, employ this methodology to assess production losses in grain maize. When evaluating silage maize, they also account for additional damage related to the loss of forage quality. This assessment involves using specific tables that correlate this increase in damage to a percentage based on the damage assessed for grain production.

In agricultural insurance, the predominant method for estimating damage, mostly used for hail damage, involves initially assessing the percentage of damage observed in randomly selected and representative plants within the field. This assessment is then correlated with the corresponding percentage of damage for a specific growth stage of maize, as depicted in the grain yield loss charts utilized by insurers (Lauer et al., 2004; Gobbo et al., 2021).

However, accurately determining field damage following a hail event using this method is challenging. Selecting representative plants that have been subjected to hail damage can be time-consuming and subjective (Battaglia et al., 2019). Typically, hail damage in a field exhibits an irregular pattern due to variations in topography, the direction of wind that dispersed the hail during the storm, and the random nature of how the crop was affected.

Additionally, parts of the plot that are affected by hail damage might be inaccessible, or the presence of tall and densely grown crops could obstruct thorough inspection of the canopy (Erickson et al., 2004). These operational challenges complicate the application of this methodology in practice.

An approach based on remote sensing would solve these problems making the process less labour intensive and time consuming. The benefits of this approach would significantly aid farmers in understanding how an atmospheric event may have impacted their farm. From an advisor's perspective, remote sensing support helps identify which parcels have been affected by recent weather events or allows for the evaluation of data from previous years. This information is crucial for optimizing management strategies during cultivation, enabling adjustments in fertilization and irrigation based on the extent of damage observed. Economically, adopting this technology can drive innovation within agricultural insurance companies and their providers by improving human resource organization and facilitating the development of sampling maps for detailed on-ground assessments. These advancements enhance the overall effectiveness and efficiency of agricultural risk management and insurance practices (Schillacci et al., 2022).

A more accurate assessment of damage would also be useful for defence consortia (e.g., Confagricoltura) to assess the damage at a district level and intervene alongside farmers.

Finally, local and national public entities can benefit from adopting the methodology as a forecasting and verification tool.

Case Study – Ticinum Aerospace and Italian crop insurance company

This case study reports the analysis of different fields, that an Italian insurance company indicated to Ticinum Aerospace in 2022, using remote sensing images. To showcase the utility and versatility of remote sensing in support to crop insurance we chose three different cases each one representing a natural event (hail, drought, high wind). The goal of TA for this research is not to substitute the on-field assessment by insurance experts, but to provide support to the experts allowing them to same time and increase the accuracy and efficiency of their on-field analysis.

Before analysing the fields team members from TA spent time with insurance agents and field inspectors in order to understand what their necessities are and how remote sensing images could have helped them.

The first challenge causing delays was field identification, a process that ideally should be immediate but often took hours to complete. Once the field is identified, the appraiser can proceed with the assessment following the method discussed earlier. However, this method involves approximations that can compromise the accuracy of the assessment.

Some appraisers have adopted an alternative approach using drones. While this method provides aerial views, it is economically costly (requiring payment for a drone pilot) and can also be time-consuming. Moreover, relying solely on visual analysis from drones may result in inaccuracies.

Recognizing these challenges, Ticinum Aerospace, in collaboration with an insurance agency, has developed a support platform for appraisers. This platform equips them with essential information on a tablet, including precise field location, aerial images, field anomalies, and historical damage records. This integration significantly reduces the time required for each assessment and allows for an increase in the number of assessments conducted per day.

The platform also facilitates real-time overview and automatic calculation of area correspondence with contractual agreements, enhancing the accuracy and efficiency of insurance processes. This digitalization initiative not only streamlines operations but also improves historical data management and ensures greater precision in insurance assessments.

Region of interest

This case study analyses different maize and wheat fields located in northern Italy, in particular in the regions of Lombardy and Emilia Romagna. The three natural events have been taken into consideration all took place in the summer of 2022, between June and July.

From the point of view of climatic conditions, summer of 2022 has been the second hottest summer ever registered in Italy, second only to summer of 2003. In general, the temperature anomaly for Northern Italy, compared to the 30-year average 1991-2022, is +2.32°C, while for Central and Southern Italy it is dampened, so to speak, to +2.15°C and +1.89°C, respectively. 2022 has been the least rainy year since 1961, marking -22% below the 1991-2020 climatological average, with precipitation below normal (-39%) from January to July. The anomalies were most pronounced in the North (-33%), followed by the Centre (-15%) and the South and Islands (-13%). Indeed, the year 2022 began with the return of the drought that had also characterized the first half of 2021, which then ended with the arrival of autumn rains (3B Meteo).

In regions where hailstorms are frequent, particularly in mid-latitudes, they can heavily impact crop growth. It is anticipated that climate change may amplify the frequency of these extreme weather events (Diffenbaugh et al., 2013), leading to heightened losses in agricultural production (Torriani et al., 2007).

Italy ranks among the top maize producers in Europe, with approximately 90% of its maize production concentrated in the Po Valley (Berti et al., 2019). Despite this, maize cultivation in Italy has decreased over the past 15 years, mainly attributed to the relatively low prices of maize grain and high production costs (USDA, 2017). Despite the recent decline, maize harvested for grain remains a significant pillar of Italian agriculture. In 2018, 2019, and 2020, its estimated economic value was 1074 million EUR, 1043 million EUR, and 1126 million EUR, respectively. This positions maize as the second most valuable crop in Italy, following wheat production (European Commission, 2021).

In Italy, hailstorms predominantly affect the northern regions, particularly the Po Valley and the Pre-Alps, specifically in Lombardy and Veneto (Baldi et al., 2014; Punge et al., 2014). Maize cultivation is prevalent in this area, accounting for 90% of Italian maize production (ISTAT, 2021). Typically, maize is sown in Italy from late March to mid-May, with peak growth occurring in June, July, and August, coinciding with the highest risk period for hailstorms in the country.

When hailstorms strike during the early growth stages of maize, plants are often broken at the soil surface level, resulting in reduced plant stands (Vorst, 1993; Nielsen, 2012).

Hail damage in maize plants can disrupt assimilate movement within the plant. Additionally, hail-induced damage can lead to pathogen attacks and loss of leaves, further diminishing the photosynthetically active area and consequently reducing grain yield and biomass accumulation (Furlanetto et al., 2021).

The timing of the hail event (i.e., the phenological stage of the maize plant when the damage occurs) and the severity of defoliation (percentage of leaf damage or removal) are crucial variables that determine the extent of damage in maize plants affected by hailstorms (Battaglia et al., 2018, 2019b).

The crop insurance industry employs the effects of different timings and severities of defoliation on final maize grain yield to estimate the extent of yield loss attributed to defoliation events (Österreichische Hagelversicherung, 2013). This approach aids in assessing and compensating farmers for crop damage caused by defoliation, such as from hailstorms or other factors affecting plant foliage (Schillacci et al., 2022).

Data used

The images utilized for these evaluations primarily include Sentinel-2, Landsat, and Planet Dove. Sentinel-2, part of the Global Monitoring for Environment and Security (GMES) program, features a multi-spectral imager (MSI) sensor capable of capturing 13 spectral bands reflected from the Earth's surface. These bands span from visible light to shortwave infrared (SWIR) with varying spatial resolutions of 10, 20, and 60 meters. Sentinel-2 offers an average temporal resolution of approximately five days, providing frequent updates for monitoring agricultural conditions and assessing damage from atmospheric events (Schillacci et al., 2022).

For a multi-temporal analysis, it is common to disregard some images due to the high cloud cover that limits vegetation’s detection, but for our purpose an automatic sorting based on the estimated percentage of cloud cover has not been applied to avoid problems such as the inexistence of a well-defined threshold (threshold) that would allow the images to be classified before their use and the elimination of useful images due to the position of the cloud cover concerning the position of the land analysed in the image: paradoxically, an image with high cloud cover may not affect the areas analysed or vice versa.

Case 1 – Hail

First case is a wheat field in Lombardy. The 4th of July 2022 a hail episode occurred on the field and damaged part of it. The strategy used to analyse the damage has been to identify a series of points within the field equidistant between them and analyse the NDVI corresponding to each point. In Figure 1 it is possible to see the field before the Hail event and the different points selected where their colour corresponds to the NDVI calculated (green represents a high level of vegetation meaning that the field is not damaged in that point while yellow/ red means there is a low level of vegetation meaning the field has been damaged by the natural event in that point).

Figure 1 (Source: Ticinum Aerospace)

Figure 2 represents the phenological phase of all the points identified in Figure 1 in one graph where it is possible to see the evolution in time of the NDVI level of every single point selected. The figure shows that there is clear change in path for some of the points selected, meaning a drastic change in the NDVI value of that point.

This change corresponds to the Hail event that, as we learn from this graph, affected only a part of the field, the part corresponding to the points that changed NDVI value. It has been identified that the percentage defoliation is more accurate when evaluated within 7-10 days after the hailstorm (Erickson et al., 2004 and Freemans 1999).

In addition, Figure 3 shows the field after the event, and it is clear which area of the field have been damaged.

Thanks to these images taken from satellites the insurance company can conclude that the hail event caused anomalies in the lower part of the crop. An abnormal behaviour can be seen in the lower and left (west) side of the field is evident.

These images are available to the insurance company right after the anomalies are detected but they still require to be compared with data collected from the field inspection.

Figure 4 and Figure 5 show the same field but with different types of images. Figure 4 is and RGB image, meaning that it is represented using three colour channels (red, green, and blue) where each pixel's colour is defined by a combination of intensities from these three primary colours, while Figure 5 calculated the NDVI for the whole area. In both pictures it is still possible to distinguish the area damaged by hail.

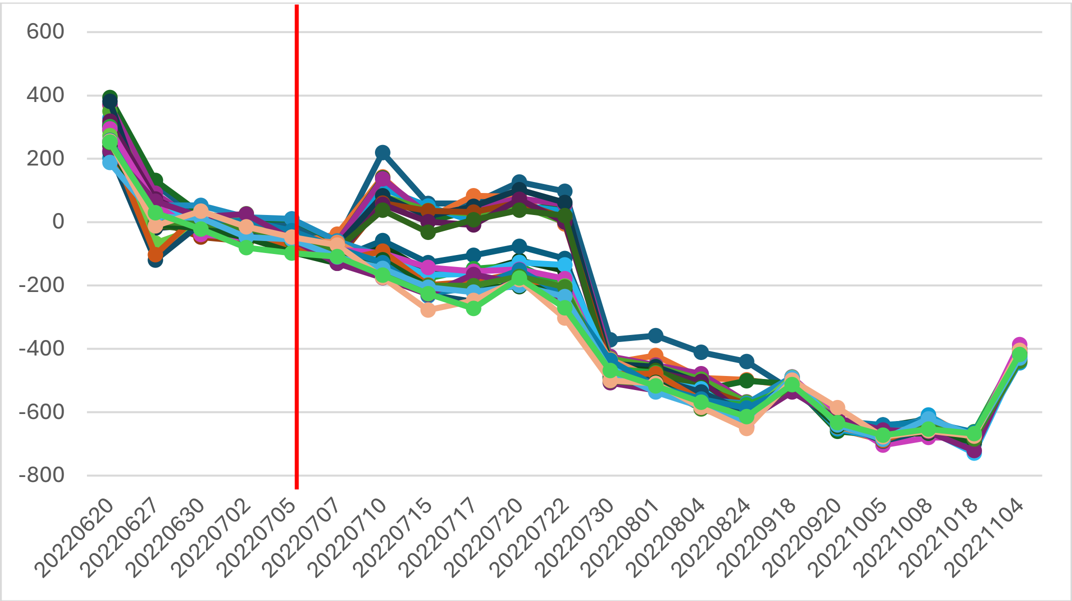


Figure 2 (Source: Ticinum Aerospace)

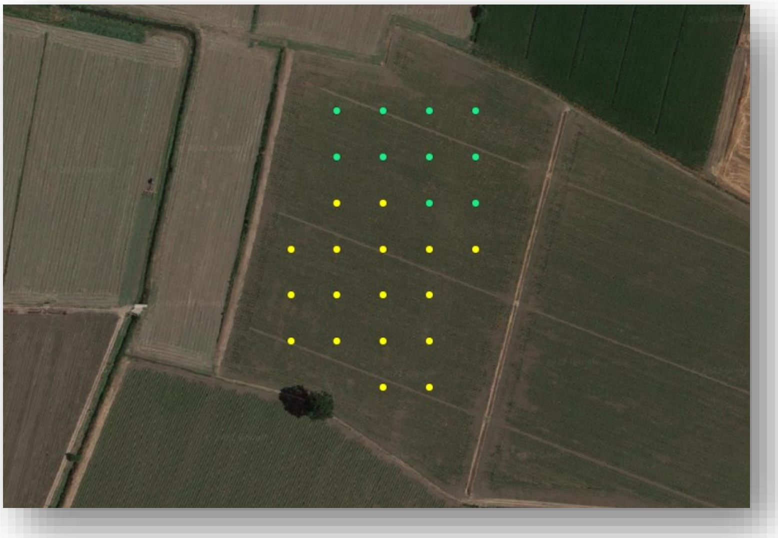
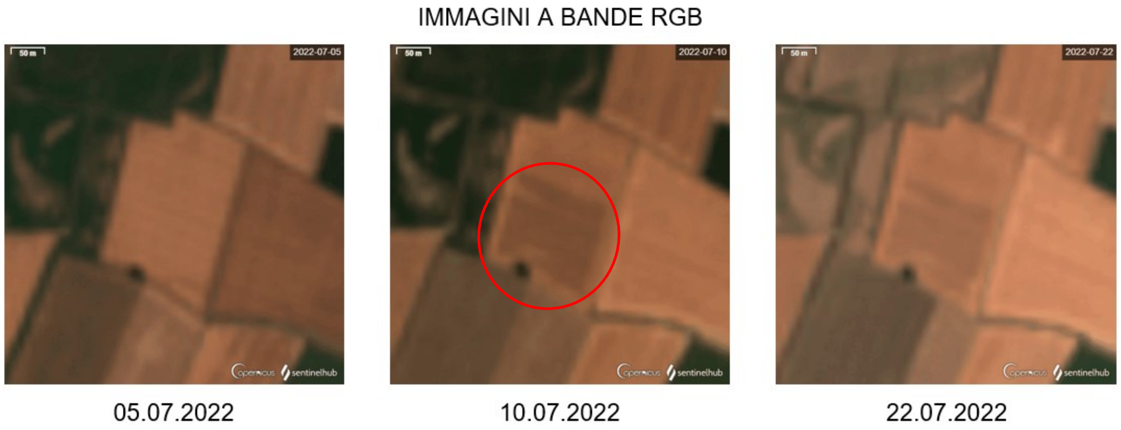
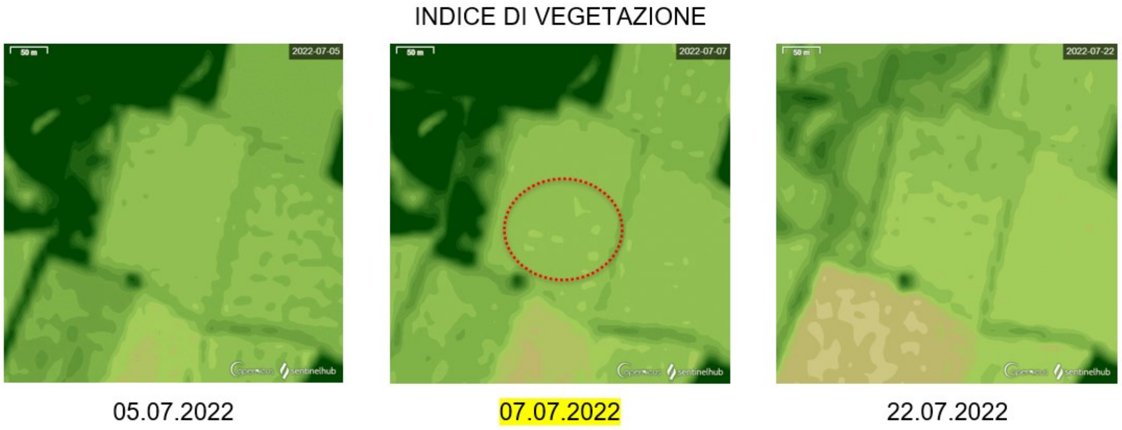


Figure 3 (Source: Ticinum Aerospace)



05.07.2022 10.07.2022 22.07.2022

Figure 4 (Source: Ticinum Aerospace)



05.07.2022 07.07.2022 22.07.2022

Figure 5 (Source: Ticinum Aerospace)

Case 2 – Drought

In this case we have a maize field in Emilia Romagna. We are going to see the effects drought had on maize that was officially indicated on the 13th of July 2022.

What we can see from satellite images is that drought affected the field, but the damage started to show before the date indicated by the insurance company. As discussed in the previous chapter one of the advantages of remote sensing is the possibility to retrieve images going back in time. This can be especially helpful to prevent fraud attempts by farmers.

Figure 6 shows clearly how the field in consideration was suffering from June of the same year and not from the 13th of July as it was declared. The graph shows that since June 2022 the field was not behaving homogenously. Some of the considered points were indicating a lower level of NDVI compared to other and we can see from Figure 7 how these points are located in the southwestern area of the field.

As further proof of this anomalous behaviour Figure 8 shows a comparison of how the same field behaved the previous year in the same period when it didn't suffer any damage compared to how it behaved in 2022, and it is clear the difference between the two periods.

This case shows one of the advantages of remote sensing applied to agriculture: the possibility to detect anomalies in the crop behaviour before they are visible to the human eye. Figure 9, using the NDVI index, shows that the damage was already showing in a small part of the field the 30th of June and with an appropriate on field intervention the farmer could have prevented the drought event and its consequent losses.

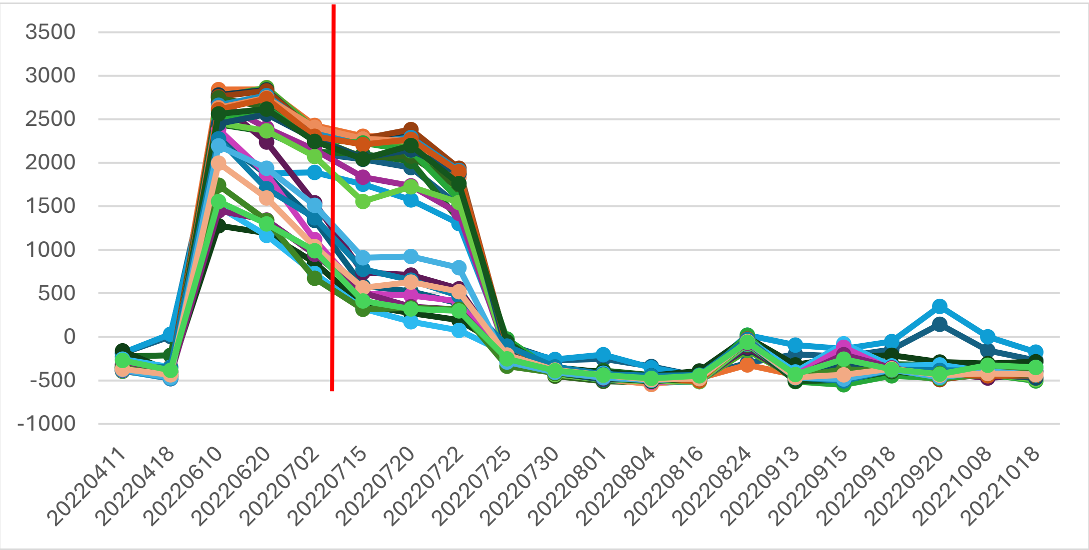


Figure 6 (Source: Ticinum Aerospace)

Figure 7 (Source: Ticinum Aerospace)

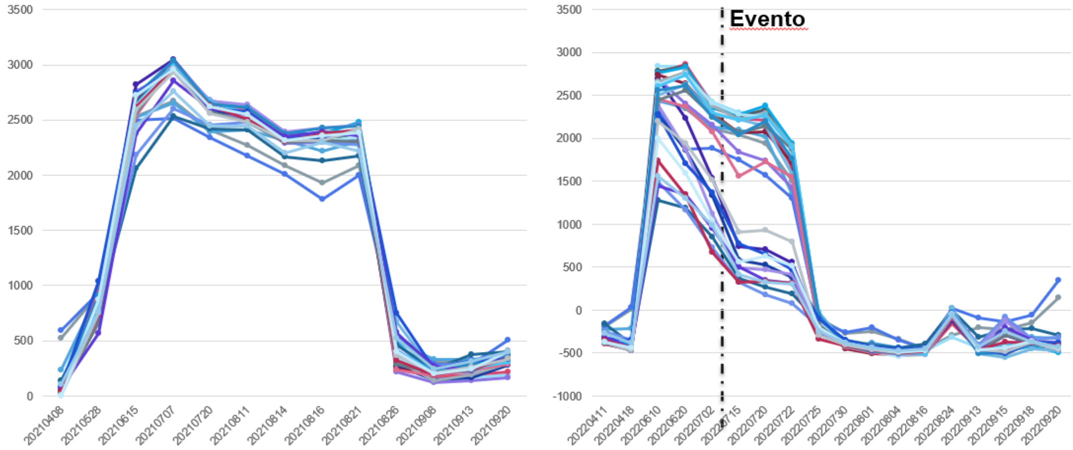
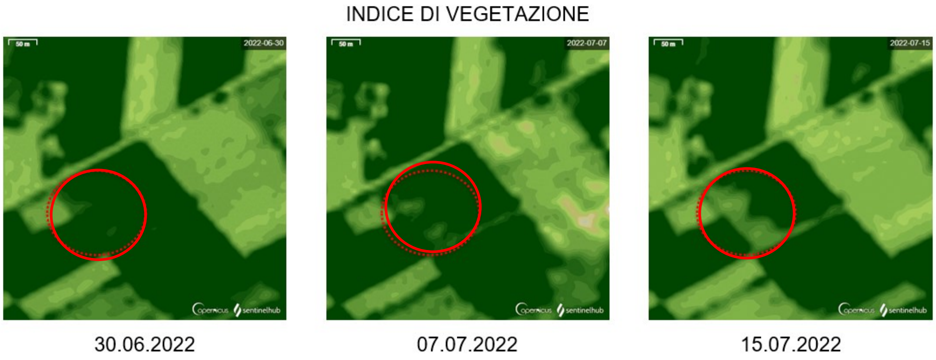


Figure 8 (Source: Ticinum Aerospace)



30.06.2022 07.07.2022 15.07.2022

Figure 9 (Source: Ticinum Aerospace)

Case 3 – High wind

The next case is based on a series of maize field reported to Ticinum Aerospace by the insurance company located in Lombardy. The event in consideration is high wind and it took place in May 2022.

The damages caused by high wind can be seen from space thanks to the fact that plants afflicted by high wind tend to lean on one side based on the wind direction and the plants inclined can be distinguished from space for their different shade of green. The methodology to calculate a field's damage cause by high wind is based on the different colours the field assume when plants are tilted by the wind.

Here are some examples of field affected by high wind:

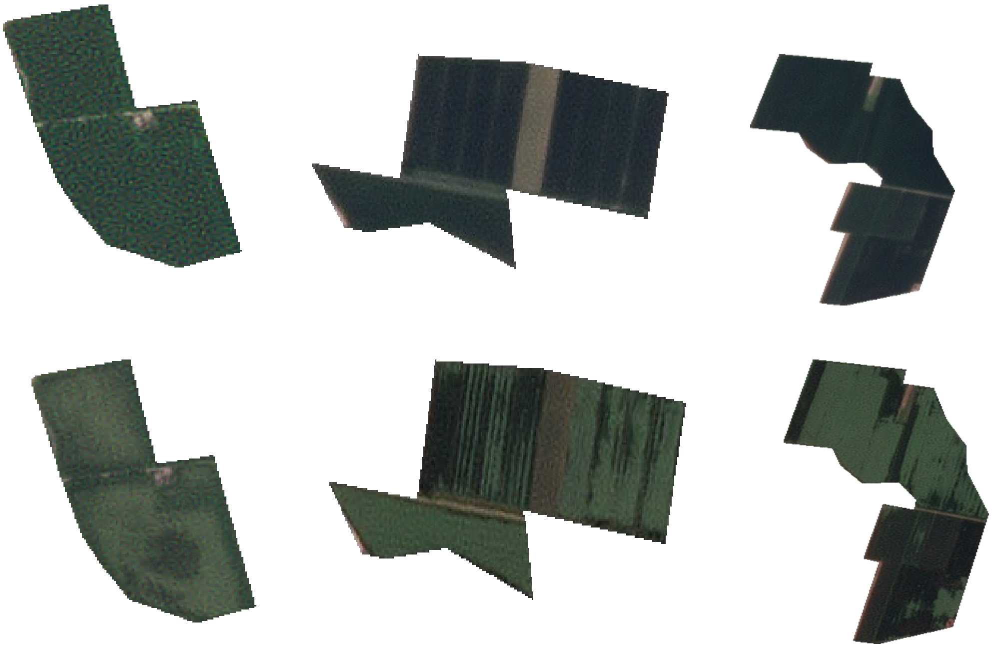


Figure 10 (Source: Ticinum Aerospace)

Starting from these images and comparing the field before and after the event is possible to better highlight the area damaged by wind.

The first step in this approach involves calculating the difference between the post-event and pre-event images. This highlights the changes in the field due to the wind damage. After calculating the difference, all values less than zero are set to zero. This step ensures that only increases in brightness, which may indicate damage, are considered. Finally, K-Means clustering with K=2 is applied to the resulting image. This algorithm separates the image into two clusters, representing damaged and undamaged areas. In this case the areas in black have been damaged by wind and those in white have not been damaged.

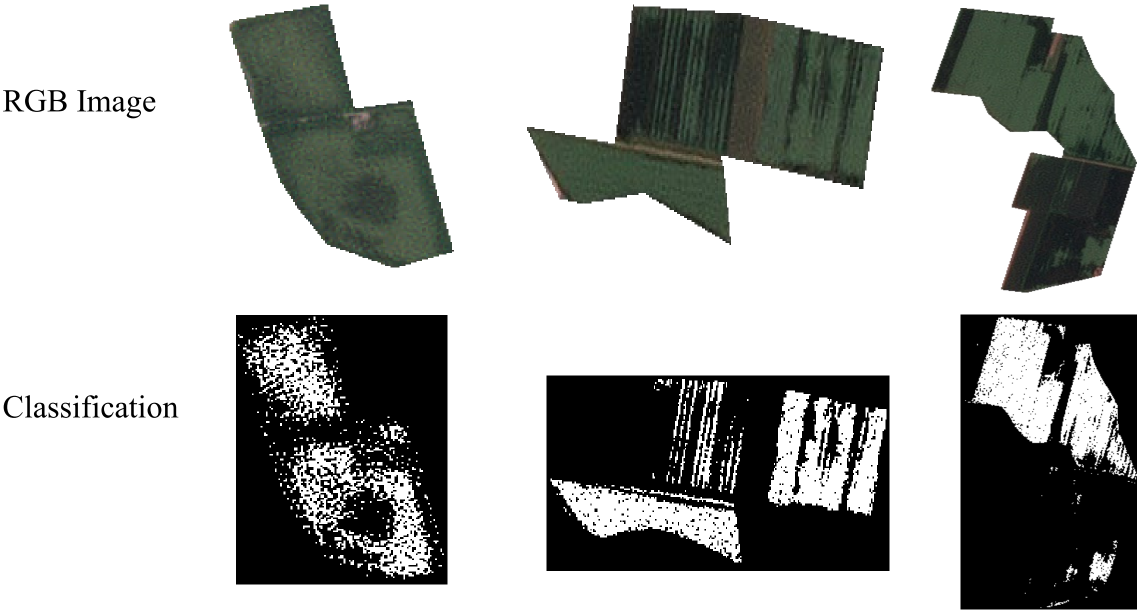


Figure 11 (Source: Ticinum Aerospace)

Conclusions

There is large space for improvement in the claim management and loss assessment process in crop insurance and this case study, backed up by many academic articles, wants to prove that remote sensing can have a role in this process. Using satellite imagery can lead to fewer and shorter field visits and increased accuracy in determining loss (Young et al., 2004).

The main cost or crop insurance companies when calculating the damage after a natural event is related to the field inspector. As seen before, remote sensing can make the inspector's work much more efficient allowing him to save time and therefore execute a higher number of inspections per day.

In addition to that remote sensing supported by a GIS system provide value to the insurance company collecting and storing data on every insured field allowing the company to have an overview of the field past events and decide if it's worth insuring a specific field and at what cost.

Continuously updated satellite data and traditional data sources can be leveraged for each new insurance claim to improve modelling and prediction of future hail damage intensity and location. This improvement in core business capabilities includes modelling damage paths and analysing past claims data for risk assessment scenarios.

Additionally, this information can provide valuable planning and crop management insights to farmers and decision support information to land developers, land use planners, prospective buyers, insurance brokers, economists, and financial lending agencies. It facilitates better risk management and decision-making across various sectors involved in agriculture and land management (Young et al., 2004).

It is also important to denote that the possibility to retrieve images from the past allows insurance companies also to reduce the risk of fraud by insured farmers, having the possibility to check if what the farmer claims that happened on a certain day actually happened; allowing the insurance company to save money.

The process of geo-referencing claims data and accurately documenting the extent of damage, combined with managing large volumes of paper-based records, requires substantial resources for detailed analysis. Integrating this data into a Geographic Information System (GIS) and continually updating it with new assessments and imagery can establish robust modelling and reassessment capabilities. To ensure accuracy, geo-referencing satellite data using GPS or Digital Cadastral DataBase (DCDB) information is essential. This approach allows for precise correlation with ground observations and calculations. Building an archive of spectral responses related to field variability will provide deeper insights into spectral data variations (Young et al., 2004).

Implementing remote sensing imagery for assessing hail damage and utilizing a Geographic Information System (GIS) for managing and analysing information can significantly enhance the commercial viability and competitive advantage of the loss adjusting business.

Considering Ticinum Aerospace's experience in the crop insurance industry, remote sensing offers clear advantages. However, the digitalization process is rarely straightforward. In the crop insurance industry, established large companies have operated under established dynamics for years, making them resistant to change.

While new technologies promise positive outcomes, their adoption requires significant initial investments, which can be challenging without strong incentives. Despite these obstacles, integrating technologies like remote sensing and Geographic Information Systems (GIS) holds immense potential. They can enhance accuracy in assessing hail damage, streamline operations, and improve overall efficiency.

Overcoming initial barriers may involve demonstrating the long-term benefits and competitive advantages of these technologies. As their value becomes increasingly apparent and industry standards evolve, embracing innovation could pave the way for transformative advancements in crop insurance practices.

Bibliography

AAAS, American Association for the Advancement of Science, what are geospatial technologies? https://www.aaas.org/programs/scientific-responsibility-human-rights-law/overview-geospatial-project#materials

Apan, A.; Chandler, O.; Young, F.; Maraseni, T. Opportunities and limitations of remote sensing for crop loss (hail damage) assessment in the insurance industry. In Proceedings of the Spatial Sciences Institute Biennial Conference: Spatial Intelligence, Innovation and Praxis (SSC2005), Melbourne, Australia, 14–16 September 2005.

Baldi, Marina, et al. "Hail occurrence in Italy: Towards a national database and climatology." *Atmospheric research* 138, 2014.

Baldwin, K. and F. Casalini, "Sviluppare la resilienza alla siccità del settore agricolo italiano", *OECD*, No. 158, OECD Publishing, Paris, 2021.

Battaglia, Peter W., et al. "Relational inductive biases, deep learning, and graph networks." (2018).

Bielza Diaz-Caneja M, Conte C, Dittmann C, Gallego Pinilla F, Stroblmair J. Agricultural Insurance Schemes. EUR 23392 EN. Luxembourg (Luxembourg): OPOCE; 2008.

Calogero Schillaci, Fabio Inverardi, Martin Leonardo Battaglia, Alessia Perego, Wade Thomason, Marco Acutis, Assessment of hail damages in maize using remote sensing and comparison with an insurance assessment: A case study in Lombardy, Italian Journal of Agronomy, 2022.

Canaseva, A.; Dagorne, A. Assessment of forest fire zones by airborne colour infrared remote sensing. Photo Interpret. 1985.

Claire Schaffnit-Chatterjee, Risk management in agriculture, Towards market solutions in the EU, Deutsche Bank Research, Sep 17, 2010, https://www.farm-d.org/app/uploads/2019/05/Deutsche-Bank-Research-Risk-Management-in-Agriculture-091710.pdf

Damron, J.J. Comparing Digital Flood Insurance Rate Maps (DFIRMS) to Interferometric Synthetic Aperture Radar (IFSAR) Products; U.S. Army Engineer Research and Development Center: Alexandria, VA, USA, 2000.

De Leeuw, J.; Vrieling, A.; Shee, A.; Atzberger, C.; Hadgu, K.M.; Biradar, C.M.; Keah, H.; Turvey, C. The Potential and Uptake of Remote Sensing in Insurance: A Review. Remote Sens. 2014.

Devot, A., Royer, L., Arvis B., Deryng, D., Caron Giauffret, E., Giraud, L., Ayral, V., and Rouillard, J. Research for AGRI Committee – The impact of extreme climate events on agriculture production in the EU, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels, 2023

Diffenbaugh, Noah S., Martin Scherer, and Robert J. Trapp. "Robust increases in severe thunderstorm environments in response to greenhouse forcing." *Proceedings of the National Academy of Sciences,* 2013.

Dinku, T.; Ceccato, P.; Connor, S.J. Challenges of satellite rainfall estimation over mountainous and arid parts of east Africa. Int. J. Remote Sens. 2011.

EO Factory, How Can Remote Sensing Play a Part in The Agriculture Insurance Claiming Process? 2021 https://eofactory.ai/blog/how-remote-sensing-can-help-agriculture-insurance-in-the-claiming-process/

Erickson, B.J.; Johannsen, C.J.; Vorst, J.J.; Biehl, L.L. Using remote sensing to assess stand loss and defoliation in maize. Photogramm. Eng. Remote Sens. 2004.

Fabian Capitanio and Antonio De Pin, Measures of Efficiency of Agricultural Insurance in Italy, Economic Evaluations, 2018.

FAO, ISPRA & ISTAT.. A disaggregation of indicator 6.4.2 “Level of water stress: freshwater withdrawal as a proportion of available freshwater resources” at river basin district level in Italy. SDG 6.4 Monitoring Sustainable Use of Water Resources Papers. Rome, FAO, 2023

Felix, M.O.K.P. Correlation of polarimetric radar hail signature with MODIS satellite ground truth data. Colorado state university’s chill radar REU program. In Proceedings of the 21st AMS Conference on Hydrology, San Antonio, TX, USA, 14–18 January 2007.

Funk, C.; Budde, M.E. Phenologically-Tuned MODIS NDVI-based production anomaly estimates for Zimbabwe. Remote Sens. Environ. 2009.

Furlanetto, Jacopo, et al. "LAI estimation through remotely sensed NDVI following hail defoliation in maize (Zea mays L.) using Sentinel-2 and UAV imagery." *Precision Agriculture* 24.4, 2023.

Geoville, The Challenges of Agricultural Index Insurance: Best Practices for the Earth Observation Sector, 2022.

Henrikson, Alan. (2013). The Map as an "Idea": The Role of Cartographic Imagery During the Second World War. The American Cartographer. 2. 19-53, 2013.

IFAD, Remote sensing for index insurance Findings and lessons learned for smallholder agriculture, 2018.

India Science, Technology and Innovation Portal, GEOSPATIAL SCIENCE & TECHNOLOGY. https://www.indiascienceandtechnology.gov.in/geospatial-technology

International Fund for Agricultural Development (IFAD), Weather Index-based Insurance in Agricultural Development a Technical Guide, 2011.

Janic Bucheli, Nina Conrad, Stefan Wimmer, Tobias Dalhaus, Robert Finger, Weather insurance in European crop and horticulture production, Climate Risk Management, Volume 41, 2023.

Johnson, L. Agricultural index insurance through remote sensing: Experiences from east Africa. Remote Sensing Beyond Images. 2013.

Little, B.; Schucking, M.; Gartrell, B.; Chen, B.; Olson, S.; Ross, K.; Jenkerson, C.; KcKellip, R. Remote sensing and US crop insurance program integrity: Data mining satellite and agricultural data. WIT Trans. Inf. Commun. Technol. 2007.

M. Weiss, F. Jacob, G. Duveiller, Remote sensing for agricultural applications: A meta-review, Remote Sensing of Environment, Volume 236, 2020.

M.V.K. Sivakumar P.S. Roy K. Harmsen S.K. Saha, Satellite Remote Sensing and GIS Applications in Agricultural Meteorology Proceedings of the Training Workshop 7-11 July, Dehra Dun, India, 2003.

Macauley, M. The value of information: Measuring the contribution of space-derived earth science data to resource management. Space Policy 2006.

Mahul and Stutley, Government Support to Agricultural Insurance, Challenges and Options for Developing Countries, 2010.

Murtach, J.; Cheesman, P. Laser altimetry and flood risk assessment: Practical application of laser altimeter data in the insurance industry. Geomat. Info Mag. 1999.

National Geographic, GIS (Geographic Information System), 2024. https://education.nationalgeographic.org/resource/geographic-information-system-gis/

OECD/FAO (2021), Building Agricultural Resilience to Natural Hazard-induced Disasters: Insights from Country Case Studies, OECD Publishing, Paris, https://doi.org/10.1787/49eefdd7-en.

Pappas, Is Climate Change Causing More Record-Breaking Hail?, Scientific American, SCIENTIFIC AMERICAN, a Division of Springer Nature America, Inc, Aug 11, 2023, https://www.scientificamerican.com/article/is-climate-change-causing-more-record-breaking-hail/

Peters, A.J.; Griffin, S.C.; Viña, A.; Ji, L. Use of remotely sensed data for assessing crop hail damage. PE&RS, Photogramm. Eng. Remote Sens. 2000.

Punge, H. J., et al. "A new physically based stochastic event catalog for hail in Europe." *Natural Hazards* 73, 2014.

Reusche, Gary & Watts, Myles & Yakubovych, Victoria & Zaripov, Andrey & Team, Project. Introduction to Agricultural Insurance and Risk Management, 2015.

Sanders, R.; Shaw, F.; MacKay, H.; Galy, H.; Foote, M. National flood modelling for insurance purposes: Using IFSAR for flood risk estimation in Europe. Hydrol. Earth Syst. Sci. **2005**.

Steduto, Pasquale & Hsiao, Theodore & Fereres, E. & Raes, Dirk. Crop yield response to water. Food Agric. Org. United Nations. 6-9, 2012.

Stefano Gobbo, Alessandro Ghiraldini, Andrea Dramis, Nicola Dal Ferro and Francesco Morari, Estimation of Hail Damage Using Crop Models and Remote Sensing, *Remote Sens*. 2021.

Tapiador, F. J., Turk, F. J., Petersen, W., Hou, A. Y., García-Ortega, E., Machado, L. A., ... & De Castro, M. (2012). Global precipitation measurement: Methods, datasets, and applications. Atmospheric Research, 104, 70-97.

Toté, C.; Patricio, D.; Boogaard, H.; Van der Wijngaart, R.; Tarnavsky, E.; Funk, C. Evaluation of Satellite Rainfall Estimates for Drought, and Flood Monitoring in Mozambique. Remote Sens. **2015.**

Vorst, J.J. Assessing Hail Damage to Corn; Iowa State University Extension: Ames, IA, USA, 1991.

Vroege, Willemijn and Robert Finger. “Insuring Weather Risks in European Agriculture.” EuroChoices, 2020.