How can data monitoring and crop modelling support agricultural risk management solutions in climate change scenarios?

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I. Background and Motivation

While agricultural activities are subject to a plethora of risks and the EU and Italian government financially support several different tools for risk transfer and sharing, the level of utilization of these tools is still limited and heavily concentrated on specific farm activities and areas of the country [1, 2].

Unlike some risks, specific to some areas and crops in the country (e.g. hail coverage on trees in northern Italy), which are subject to extensive insurance coverage, most of the national agricultural area is subject to catastrophic risks, such as freeze-frost, drought, and flood. These risks, in a climate change scenario, are subject to growing uncertainty, making them expensive to take on by the market and/or not convenient for farmers to adopt [3].

In this framework, new technologies provide the opportunity to have better measurements of the factors determining the risks, and crop models can improve the ability to predict the impact of adverse events on production [4]. Furthermore, new methods are now available to efficiently process these data. These elements offer the possibility to enlarge the set of risk management tools and to make the available tools more tailored to the needs of the sector and more accessible, also by reducing management costs.

From the crop model side, greenhouse gas emissions can have a direct impact on crop yield by influencing long-term averages of climate variables (e.g., mean temperature), climate variability and extreme weather events (e.g., extreme temperature, drought), and CO_2 concentration. Crop simulation models can be used to predict the complex interactions between climate scenarios and crops, and consequently potential crop yield. However, the modeling approach to climate impact assessment finds major limitations in the uncertainties generated by climate models and crop models. Apparently, crop models may introduce more variability than the former models because of a simplified approach in simulating the impact of major drivers on crop physiology.

The most investigated climatic driver is temperature, but other factors such as changes in precipitation, temperature-humidity feedbacks, and CO_2 concentration should be included. An important improvement in yield prediction is the use of multi-model ensembles according to standardized simulation protocols. The use of multi-model ensembles improves unit estimation by producing thematic uncertainty maps. Through uncertainty analysis, critical areas that need further investigation can be identified.

Currently, despite the potential availability of data, information on the sources of risk for agricultural systems is dispersed and inhomogeneous, owned by different subjects, both public and private, and observable on a different scale.

Scenarios and predictions require data-rich environments and adequate methods to spatialize information. Climate-related variables are notably affected by numerous factors that change in time and space. Scale is also an important aspect to consider, as spatial variability is a key factor; e.g., hailstorms can be of extreme magnitude in very limited areas. These data must be collected, harmonized, and normalized in order to be fed to models.

This calls for a strong collaboration from researchers from different field of science: agro-meteorology, remote and on-site

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data, soil quality, plant phenology, crop models, risk analysis, and farmers behavior.

It seems advisable that future research should focus on the needs of the final users (farmers) and should capitalize on what is currently available in terms of risk management tools.

This paper provides a presentation on the current knowledge about data availability relevant for risk assessment in agriculture, crop modelling, and available tools used in the agricultural sector to transfer and share risks related to crop production, and finally to promote further development of risk management in Italy. This analysis highlights the main needs for the development of an information chain to improve risk management tools and policies based on the observation of risk factors, the application of crop models and the design of tools and policies. The product of this process puts farms in the position to improve their resilience against catastrophic production risks and climate change.

II. Agricultural insurance

According to ISMEA [5], the Italian market is characterized by a limited adoption of insurance contracts. Subsidized insurance market involved in 2020 only 10.3% of utilized agricultural area (UAA) in Italy. Among both different areas and species, northern regions show higher level of uptake, with at least 35% of UAA insured in Veneto, Lombardia and Friuli Venezia Giulia, Emilia Romana, and Piemonte. These regions amount to 20.5% of the Italian UAA and represent the 81.7% of insured UAA in Italy. The relevance of northern regions is mainly linked to higher per hectare value of crops compared to central and southern Italy, with some locale exceptions.

Mainly subsidized insurances in Italy are traditional indemnity insurances, which request physical assessment for indemnification. Disadvantages of these insurances have been discussed intensively [6]. First, asymmetric information about the riskiness and cultivation measures cause both adverse selection and moral hazard [7]. Subsidies on insurance costs may reduce adverse selection by enlarging the market while reducing ex-post disaster assistance [8]. Furthermore, the need for physical damage assessments (e.g., field inspections) are costly [9]. For these reasons, classical indemnity based agricultural insurances are usually designed for high value crops and/or large farms, able to reduce the incidence of transaction costs [6].

Despite policy support, due to unfavorable climate conditions in recent years, registered total payout rose constantly. This lowered the economic sustainability of the system, and increased the insurance price, exacerbating adverse selection: with rising contract price, farmers exposed to lower risk of production exit the market, contributing to the increase of the total amount paid by insurers for compensation [1]. These dynamics reduced recently the willingness of insurance companies to cover risk as they expect indemnification with a higher probability to occur with climate changes.

To partially overcome these drawbacks, index insurances can be considered as an alternative to traditional indemnity insurances. Payouts are based on the value of a related observable index such as regional average yield, rainfall, or temperature measured at a weather station. In order to success, the underlying index should have a high explanatory power for the on-farm yield. Moreover, this index should be independent, transparent and comprehensive to farmers [10].

The probability of an index to not be able to precisely fit the yield losses of a farmer is referred to as basis risk [11]. It follows that there is always the chance that an individual farmer who experiences a loss will not receive an insurance payout (negative basis risk). There is also always the chance that a farmer who had a year without any losses will receive a payout (positive basis risk).

Basis risk is further differentiated in [12]:

- Spatial basis risk, when index is not measured at the same location as the insured crop is situated;
- Temporal basis risk, due to a biased temporal aggregation of observations (e.g., observations are aggregated into months while the vulnerability of plants is rather related to plant phenological phases) [12, 13];
- Design basis risk occurs when the chosen underlying index is not a good approximation of the underlying sources of yield or revenue variability [6].

Basis risk reduces the efficiency of index insurances by compromising transparency. Accurate indexes are complex and may reduce the comprehensiveness to farmers Together with the fairness of the contract this may reduce market uptake by farmers. The combination of remote sensing and satellite technology seems to be able to overcome the design basis risk, while improving data storage and accessibility. Spatial agricultural analysis and monitoring of plant growth may aid to reduce spatial and temporal basis risks.

III. Index insurance scenario

Index insurances are divided into three categories: area-yield insurances, weather index insurances and satellite insurances [6].

Area-yield insurances cover yield losses based on statistical information on yield losses at area level. They provide reliable and better data because yield data of large areas is characterized by lower error compared to one individual farm. Furthermore, available data of large areas bear the advantage of reducing moral hazard and transaction costs. However, spatial basis risk may rise as payouts are triggered whenever the average yield in one year in a certain area falls below a certain pre-set critical threshold (strike level). Hence, the payout is independent from individual losses and covers yield losses independently of its source [14]. This insurance scheme is especially useful in areas facing mainly systematic risks [15]. An example can be retrieved in the Area Risk Protection Insurance (ARPI) applied in the US: the insurance plan provides coverage based on the experience of an entire area, usually a county. Even though farmers could choose to protect individual higher yields (up to 150% of the county average) [16], the application of this index insurance and the uptake by farmers decreased [17]: they seemed to prefer individual assessments over comparison with group performance [6].

Weather index insurances can be effectively used to reduce the impact of harmful weather on farms whose economic margins widely depend on climate [9].

Some weather index insurances targeting drought in developed countries, also called weather derivates, are available in Austria, Canada, Germany, Switzerland, and the US. In these designs, a payout occurs whenever the index estimating dry conditions undercuts a certain strike level [6]. Only one example can be retrieved for Italy applying an experimental index insurance for grassland. Yield losses are covered based on precipitation and temperature [18]. The main advantage of this tool is that it is easily understood and accepted by farmers [9, 19] revealing good market performance. It has been observed that exchange and integration of knowledge could substantially reduce basis risk and increase farmers' willingness to participate and pay for such insurances [20, 21]. Furthermore, high spatial resolution decreases temporal basis risk as it makes the design of more precise index time frames possible. The diffusion in the European Union is mainly constrained by legal settings requiring to proof that the insurance indemnifies each farmer for her/his exact losses. This is due to (negative and positive) basis risk that may incentivize farmers to gamble, as payout is not directly linked to losses [6].

Satellite insurance assesses the impact of adverse events by measuring variation on vegetation's images or activity. Like for weather index insurance, the effectiveness of such tools depends on the ability of satellite observation to forecast the level of yield or quality damage due to a specific or general adverse event. An insurance successfully incorporating satellite imagery reduces costs and basis risk without increasing asymmetric information [22] and may have a great potential for insuring agricultural production [23]. Applications in Spain realize a payout to farmers whenever a homogenous pasture zone (aggregation of 355 pixels of 250x250 m^2) exhibits a fall, below a defined strike level of the reference Normalized Difference Vegetation Index (NDVI) (adjusted every five years) [24]. In France, a forage production index insurance measures the fraction of ground covered by grass (fCover) daily at a resolution of 300x300m^2, aggregated to municipality level, supplemented with farm individual elevation level and soil type [25]. Such tools, thanks to growing data availability, can improve the performance of all type of insurances, combining traditional ones with index-based solutions. A broad diffusion of these innovations is however inhibited by the ability of farmers to understand such tools, becoming an opportunity only for more innovative individuals. Therefore, the trade-off between the minimization of basis risk and the level of transparency and understanding of the index for farmers need to be considered.

The performance of an index insurance depends on certain requirements: indexes must be independent, transparent and comprehensive [10], and based on sufficiently long historical time series. Furthermore, the index data has to be attainable, and it should be ensured, that the data on which the index is based stays available in the future [26]. Basis risk should be minimized as high basis risk reduces the uptake by farmers [20, 27]. Data must be unbiased, sufficient, and credible and the selected index should be tightly linked to the event being insured and not prone to manipulation by either the insured party or the insurer [25]. Due to new data availability and climate trends, including climate change, indexes and associated triggers should be recalculated frequently to enhance good performance of insurance contracts.

IV. RESEARCH NEEDS

This paper aims at fostering the collaboration among researchers from different fields of science notably agronomists, engineers, geomatics, data analysists and economists, among others.

The paper would highlight the area of connection among data scientists, agricultural modelers and agricultural economists aimed to propose innovative solutions for risk observation, data platform, crop modelling, risk management tools, and policies to favor the Italian agriculture.

Within this perspective, the current use of available tools by farmers and third parties, the risk they face (i.e., insurance) and share among other partiers (such as in the case of mutual funds), even supported by the Italian application of current and future Common Agricultural Policy, need to be further innovated.

In this framework, new opportunities are arising from the application of the upcoming Common Agricultural Policy starting from 1st January 2023. Beside the opportunity to improve current insurance tools, enlarging the application of index insurance beyond experimental solution, the introduction of a National Mutual Fund called Agri-cat, will allow to enlarge the management of so-called catastrophic risks: frost, drought, and flood [18]. The Italian National Strategic Plan for the new CAP, starting from 2023, will allow a National Mutual Fund managed by Agri-cat srl will manage a budget of around 360 million euro per year build from the 3% of national farmers' direct payments and co-financed up to 70% by second pillar measure in risk management [28, 29].

The agricultural sector will have the opportunity to benefit from the investments in the Spoke 4 of the Agritech National Research Center, funded by the European Union Next-GenerationEU and managed by the University of Padova (Italy). The third WP of the Spoke 4 project, titled "Integrated climate change risk modelling and management", aims at supporting, among other activities, the development of a supply chain of information on risks in agriculture, crop modelling, and risk management tools.

The first step aims at the "Creation of a knowledge-base hub in a relational environment for risk-related information" through the development of an integrated digital information system for collecting and linking data related to the hazards and vulnerabilities in the realm of agriculture.

Data sources will be integrated from public and private information sources. A confederated approach will be used to link existing data by developing communication protocols for each node andclustering such sources in a single search engine. This activity will interact with other activities that require data sources, with the objective of collecting, in a single hub, the availability of such information.

A second activity aims to organize an "Ensemble of tailored models for predicting crop productivity and land vulnerability under different climate scenarios." The activity will deal with the assessment of advanced algorithms and models to predict the productive response of agricultural systems to climatic adversities. Proximal sensing and remote observations will also be assimilated into multi-model ensembles for improving future yield predictions. The climate change scenarios simulated by the multi-model ensembles will allow identifying the best strategies and crop patterns to reduce the climate vulnerability of agricultural systems.

The third activity will be focused on the implementation and adoption of innovative tools for the risk management of farms crop production and income. The development of these innovative tools will start from the identified and observed risks, developed in the first described activity. The process of risk assessment will be linked to the crop growth model assessed by the second activity as described above. The probability of adverse events, their intensity, distribution of losses, and the assessment of the value at risk, in current and future climate scenarios, will be assessed for the most relevant annual and permanent crops in Italy and applied to develop innovative (e.g., index-based insurances, mutual funds, water management policies) risk managements tools.

Conclusion

The research is expected to stimulate the discussion among different scientists belonging to different applied sciences, fostering the mutual understanding of the system that should be developed in order to make the best use of new technologies and tools. By linking knowledge bases, the best of different worlds will be combinedto create a common network. This seems key to provide new or better tools to manage risk and to ensure that this will benefit a larger share of farm population than today. There is also the need to include new risk and damage assessment within the risk management tools supported by the agricultural policy to encourage the spread of these innovative tools also in sectors and territories where there is still a marginal use of risk management solutions.

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