Satellite support to insure farmers against extreme droughts

Agricultural insurance is a valuable strategy to cope with extreme weather risks. Improved satellite observation capabilities can be particularly helpful with droughts, but will not translate into better insurance unless key challenges are overcome.

Willemijn Vroege, Anton Vrieling and Robert Finger

Extreme weather events are a major risk to agricultural production. Droughts, for example, can ruin a whole year's production despite major investments made by farmers to mitigate their effects. Climate change is expected to increase the frequency and magnitude of extreme weather events, resulting also in increased agricultural drought risks. Coping with droughts is thus paramount for agricultural production and farmers' income stability.

Agricultural insurance can play an important role in increasing farmers' risk-coping ability around the globe, especially in combination with other risk-management strategies — such as the selection of drought-tolerant crops or crop varieties, irrigation, income diversification and savings — which are often costly and may be insufficient during extreme droughts. Indeed, the global agricultural insurance market is already large and growing[1]. Yet, as major droughts often occur at large spatial scales, and thus simultaneously affect many farmers within a region or country, it is difficult and expensive for local insurance companies to raise the financial and human resources that are needed to adjust these losses[2].

The increasing number and quality of datasets derived from Earth-observing satellites can play a crucial role in improving agricultural drought insurance solutions[3]. Yet, the large variety of satellite-derived data sources and processing options also raises questions on how to use these data effectively in an insurance context, in a way that provides value to farmers.

Global availability of satellite data facilitates risk-pooling across larger areas and more farms and thus enables the establishment of insurance schemes that go beyond individual countries. With historical records of satellite-retrieved data becoming longer, and spatial and temporal resolutions becoming higher, satellites' ability to monitor changes in agricultural productivity is increasing. This results in a continuous stream of high-resolution openly accessible data that can be transformed into relevant and validated information for drought monitoring[4]. Many satellite data products are free and immediately available at global level, so insurers can rely on these data at low costs. Therefore, satellites may play a vital role in realizing more efficient, large-scale loss adjustment in a quicker and cheaper way. They may also allow for immediate loss estimates within the cropping season, ensuring timely payouts to farmers. However, several obstacles need to be overcome to unlock this potential.

Satellites support different types of insurance

Three insurance types are dominantly used for agricultural production risks: indemnity insurance schemes (most widely used; they base payouts on incurred losses directly, usually after individual loss claims); area-yield insurance (underwrite farmers' risks depending on regional yield statistics or targeted crop-cut exercises, but not on their individual-farm yield experience[5]); and index insurance (which adjust farmers' losses based on a biophysical index). The latter could, for example, trigger payouts when the rainfall observed in a specific period is exceptionally low[6].

Drought risks are rarely insured through indemnity insurance because in situ loss assessments are expensive and challenging, especially in case of systemic events that hit entire regions or countries. Information asymmetry between the insured and the insurer may lead farmers to increase their risk exposure or even cease other loss-avoidance strategies and solely rely on insurance payouts (moral hazard). In addition, farmers with higher risk exposure have more incentives to buy insurance, while it is difficult and/or costly for the insurer to distinguish different levels of individual risk exposure (adverse selection). To avoid abusive claims, most indemnity insurance schemes come with a deductible, implying that insured farmers are not fully covered for their losses.

High-resolution satellite imagery can be used for direct loss adjustment processes so that farmers receive payouts based on observed damages quantified with satellite imagery (indemnity insurance). However, to accurately estimate yield losses at the level of individual fields, long (for example, greater than 10 years) records of timely vegetation observations (for example, through spectral reflectance) are needed at spatial resolutions smaller than the field size. Incontestable proof of losses may even require spatial resolution of less than 1 m, which implies high data costs given that such resolutions are only obtainable from commercial satellites that, in addition, lack sufficiently dense long-term data records. The frequency of cloud-free field-level observations throughout the crop season remains a challenge for consistent comparison of vegetation status between seasons, particularly for longer time periods.

Due to the limitations and costs of indemnity insurance, area-yield insurance and index insurance have emerged as alternatives. Area-yield and index insurance both avoid individual-farm in situ damage assessments for triggering payments. These types of insurance can therefore overcome problems of adverse selection given that historical regional yields or related biophysical indices are the basis for payouts and premiums — and this information is equally available to all parties. Moreover, moral hazard is overcome as individual insured farmers cannot influence the payout, either because their farm management does not affect this measure (for example, rainfall), or because the measure (as for area-yield insurance) comprises a larger geographic area.

Satellite data can have a pivotal role in area-yield and index insurance. Satellite imagery allows to derive timely information on different biophysical parameters that

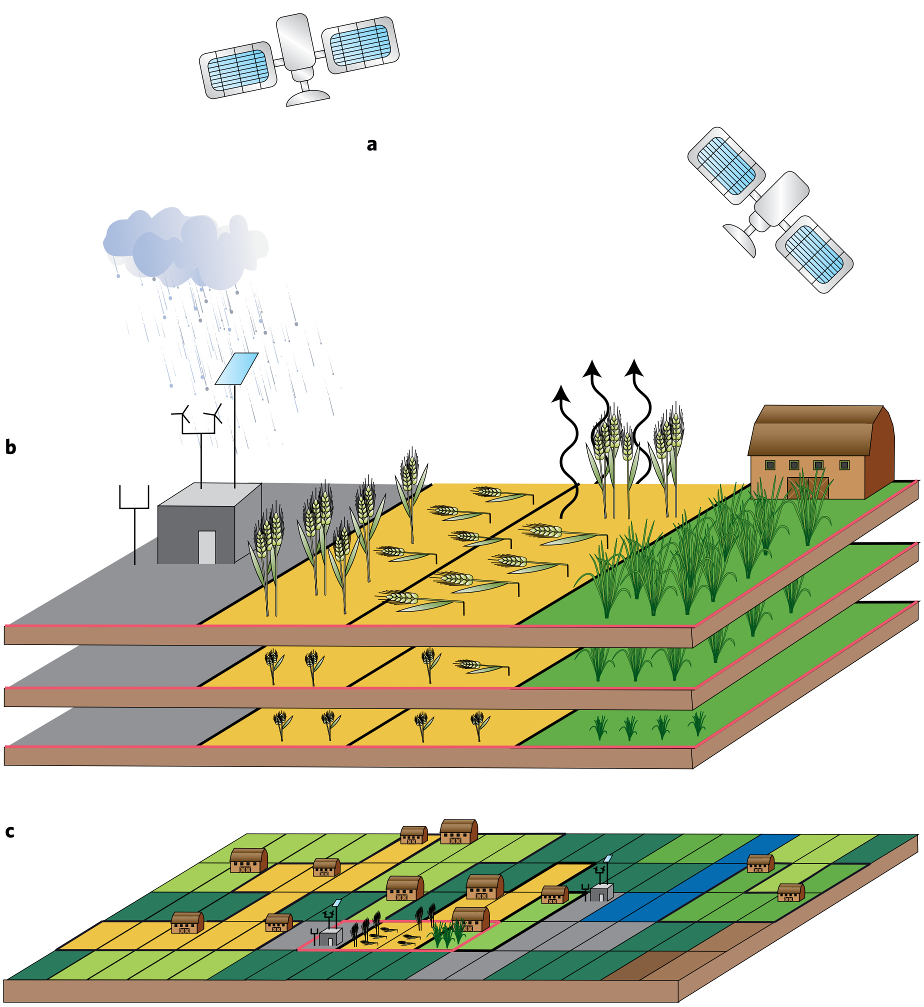

Fig. 1 | Key requirements for the design of index insurance from satellite-retrieved imagery. a, Context-dependent selection of parameters and data products. **b**, Transparency on modelling steps and uncertainties. **c**, Spatial aggregation to meaningful insurance units.

can be used as area-yield estimates or index variables, such as vegetation conditions, precipitation, evapotranspiration and soil moisture[4]. Satellite imagery can make these insurance schemes more effective and more efficient, and thus can be a game-changer in the agricultural insurance sector. However, area-yield and index insurance both suffer from basis risk — the potential deviation between a farmer's yield loss and the payouts from the insurance. For example, regional yield levels might not reflect a single farmer's yield losses well. Moreover, for index insurance, basis risk can also emerge due to an imperfect relationship between the index and yield losses, or because the index data was not (or not exclusively) collected for the location of the insured field. Finally, the timeframe of assessing the index can have poor correspondence with the actual moment when yield damage occurred or became visible[7]. Basis risk makes these insurance types unattractive, especially for risk-averse farmers[8].

Challenges and opportunities

Satellites offer ample opportunities for novel insurance schemes that help farmers cope with drought risks, but challenges for effective use of satellite data to inform insurance design and reduce basis risk remain.

The first challenge concerns the selection of drought-related parameters to serve as a basis for insurance payouts (Fig. 1a). Satellites allow for retrieving information on different components of the water cycle, including precipitation as well as soil moisture and evapotranspiration, which are key factors for agricultural drought[9]. Yet, such products are not available at field level for long timescales. Synthetic aperture radar data provide information on crop structural changes. Although consistent acquisition schemes — such as by Sentinel-1 satellites — allow to effectively monitor crop development under any weather conditions[10], their signal may be hard to interpret for many crops. Much more commonly used in insurance schemes are spectral vegetation indices, such as the normalized difference vegetation index (NDVI), which summarize spectral information into a measure of the crop's photosynthetic activity. Yet, these are sensitive to atmospheric conditions like haze and clouds, and soil background[11]. For insurance purposes, this means that droughts may not be the sole factor leading to reduced vegetation index values[12]. Likewise, insurance based on vegetation indices covers additional production risks, since other yield-reducing factors, such as damage by hail, wind, pests or weeds, may also affect vegetation reflection. Region- and farm-specific circumstances must therefore be carefully considered in insurance design, as they may influence which parameter has the strongest correlation with (drought-related) yield losses[13].

The second challenge is that satellite products come with uncertainty. While spectral vegetation indices, such as the NDVI, are unitless indicators that are derived from pixel-level reflectance measurements, complex radiative transfer models and/or empirical calibration to ground observations may allow to derive more meaningful biophysical vegetation parameters (Fig. 1b). An example is the 'leaf area index', from spectral reflectance data. Such retrieved vegetation parameters may conceptually relate better to yield losses. However, it remains an empirical question whether this is actually the case, given that modelling comes with errors and that biophysical parameters are generally strongly related to spectral indices. Similarly, gridded products that describe precipitation, evapotranspiration and soil moisture rely to a greater extent on modelling and data integration, which potentially adds to the products' uncertainty. This further increases the basis risk of insurance. Transparency by satellite product providers about related uncertainties, as well as a good understanding of potential errors of these products within the geographical region under consideration, remains critical for informing effective insurance design.

Finally, spatial integration of satellite-derived data must be done carefully. Moral hazard is a major issue if parcel- or farm-specific remotely sensed parameters are the basis of payout decisions. For example, field-level vegetation indices directly relate to individual farmers' management practices. Therefore, farmers could decide to avoid irrigation in order to receive insurance payouts. Even if satellite data allow estimating index parameters at field-level, this will not necessarily translate into better insurance solutions. Yet, high-resolution observations can still be used to obtain more accurate spatially detailed loss estimates, which can subsequently be aggregated for larger spatial units (Fig. 1c). Reflectance in low-resolution multi-spectral imagery partially results from the agricultural field of interest, but also from other land cover surrounding the field. In contrast, high-resolution imagery can be aggregated to the level of a region, while focusing the signal to specific fields and/or crops using crop maps. Such crop maps may either result from existing farmer reporting mechanisms, or alternatively be derived from remote sensing. This can be observed from existing studies[14], commercial efforts (for example, OneSoil), and funded projects (for example, the WorldCereal project) that try to bring field-based crop mapping to scale. Field-scale drought indices can then be aggregated either at the level of administrative units or insurance units based on environmental similarity observed with remote sensing[15].

A way forward

To improve agricultural insurance, satellite datasets should be smartly chosen and/or combined, with the aim to design tailor-made insurance with low transaction costs, a low basis risk, and free of moral hazard. At the same time, data uncertainty should be minimal and the indices based on them should be well-validated and carefully aggregated.

Each insurance design should consider the complete range of available remotely sensed and ancillary datasets. An increasing number of remotely sensed data are freely accessible and may help offer farmers better protection opportunities against extreme weather. For practitioners, it is important to collect and integrate products in a small number of platforms (for example, the Copernicus Global Land Service), and provide easily understandable information on key aspects such as data validity, consistency and continuation, as well as product version updates, likelihood of product failure, and performance under extreme (dry) conditions. In this framework, the World Bank's Next Generation Drought Index Project is also developing integrative tools for low-income countries, exploiting multiple Earth observation datasets for addressing trade-offs in index design[16]. By providing key information to farmers and other stakeholders, such platforms and tools can incorporate more than only remotely sensed data and serve applications other than agricultural insurance with the aim to contribute to drought risk management at large[17]. Integrated platforms will also facilitate solving the case-specific empirical question of which index design is optimally suited for the considered application. More intensive exchange and collaboration between the Earth observation community, insurance practitioners, and agricultural economists is necessary to efficiently evaluate available databases and data quality aspects. Projects such as the ESA Earth Observation Best Practice for Agro-insurance project, where the Earth observation sector and agricultural insurance companies exchange knowledge and discuss targets, are an important starting point.

Another point to consider is that agricultural insurance premiums tend to be massively subsidized, which often leads to inefficiency[18]. New Earth observation and smart farming applications[19] can aid the development of better agricultural insurance and increased insurance coverage even without direct premium subsidization. For example, governmental support that facilitates the collection of and access to relevant data sources, such as yield data, will enable new forms of insurance solutions to develop.

Irrespective of the remote sensing techniques used, local yield data is key for the calibration of yield-related insurance products. Potentially, however, the advent of new technologies such as precision farming and related data collection (for example, via crop yield monitors) will provide new opportunities for acquiring such data[20]. Governmental support to increase the public availability of field- and farm-level crop yield data should induce innovations that broaden farmers' risk management toolbox.

Using satellite-retrieved data in insurance schemes can support farmers to cope with increased exposure to droughts. Building such tools effectively requires insurers, agronomists, economists and the Earth observation community to work together. ❐

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