Agricultural Systems 168 (2019) 101–111

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Index insurances for grasslands – A review for Europe and North-America

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ARTICLE INFO

Keywords:
Risk management
Index insurance
Grasslands
Satellite imagery
Weather insurance

ABSTRACT

Grassland based farming systems are exposed to extreme weather events causing volatile farm incomes. Grazing and lacking yield measurements make it largely impossible to insure grassland production with traditional insurance products. In contrast, index insurance products have the potential to insure grasslands, as their payoff relies on an endogenous index that is highly correlated to, but independent of, the actual grass yield. To support future development of these products, we provide the first systematic overview of 12 index insurances put into practise for grasslands in Europe and North America. Additionally, based on this overview, we present prevailing findings that are important for further research and insurance practitioners. We find that a large diversity of index insurance types is applied in practise, including insurance solutions based on regional yield levels, weather variables or satellite imagery. We reveal separated insurance markets (i.e. country-specific products), which prevent knowledge spillovers and lead to largely isolated product developments. Thus, grassland insurance schemes can be improved by knowledge exchange and combining methods that are applied elsewhere. More specifically, insurances tailored to single farm's risk exposure, the combination of satellite with other geodata (e.g. land use information) or adapting legal specifications that disadvantage some types of insurances can improve an insurance's risk reducing capacity and make grassland based farming systems more resilient to weather extremes. This paper provides an entry point for such process, ensuring the development of efficient measures for farmers to cope with climatic risks.

1. Introduction

Grasslands cover the majority of the world's agricultural area, are the backbone of animal based food security and provide a wide array of ecosystem services globally (e.g. O'Mara, 2012; Soussana and Lüscher, 2007). Farmers face a high uncertainty regarding the productivity of grasslands, e.g. due to the variability of weather conditions (Kreyling et al., 2008; Smit et al., 2008). Forage yields and/or qualities below farmers' expectations result in economic losses and can have significant implications for livestock production that may result in economic losses (Finger et al., 2012; Soussana and Lüscher, 2007). To cope with weather risks, farmers in grassland based production systems (i.e. dairy or meat production based on pasture, hay and silage as feedstock) use various on-farm risk management strategies. For example extensification of grassland production, increase of hay or silage storage and reduced stocking densities have been reported in the literature as viable strategies (e.g. Bielza Diaz-Caneja et al., 2008; Briner et al., 2015; Gao et al., 2014; Mosnier et al., 2009). These strategies have however drawbacks. First, they are expensive in terms of forgone profit and/or the building up of capacities (Hardaker et al., 2015). Second, the losses caused by extreme weather events such as droughts cannot be easily borne if solely these strategies are applied (Fig. 1).

In contrast, market-based risk management instruments such as insurance solutions can reduce risk cheaper and more extensively, i.e. also covering extreme events. Thus, these could complement other risk management instruments. A diversity of insurance approaches is used in practice, ranging from indemnity based insurances to index insurances where payoffs are based on e.g. weather realizations or satellite imagery. Index insurances are well developed and important risk management tools for grassland-based farming systems in several developed countries, for example in the USA (Risk Management Agency, 2015) and Spain (Agroseguro, 2016).[1] Additionally, due to the increasing amount of high quality freely available databases, we observe a rapid expansion of index insurance possibilities. The increase of data

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[1] Several index insurances for grassland based systems exist also in developing countries, for example in Kenya, Ethiopia, Mongolia, Mexico, Uruguay and Argentina (e.g. Jensen et al., 2015; Bacchini et al., 2015). We exclude these from our analysis because of the differences in legal background, the financial infrastructure and the agricultural systems and resulting the future challenges between North America and Europe on the one side and the developing countries on the other.

https://doi.org/10.1016/j.agsy.2018.10.009
Received 6 July 2018; Received in revised form 25 October 2018; Accepted 31 October 2018
Available online 13 November 2018

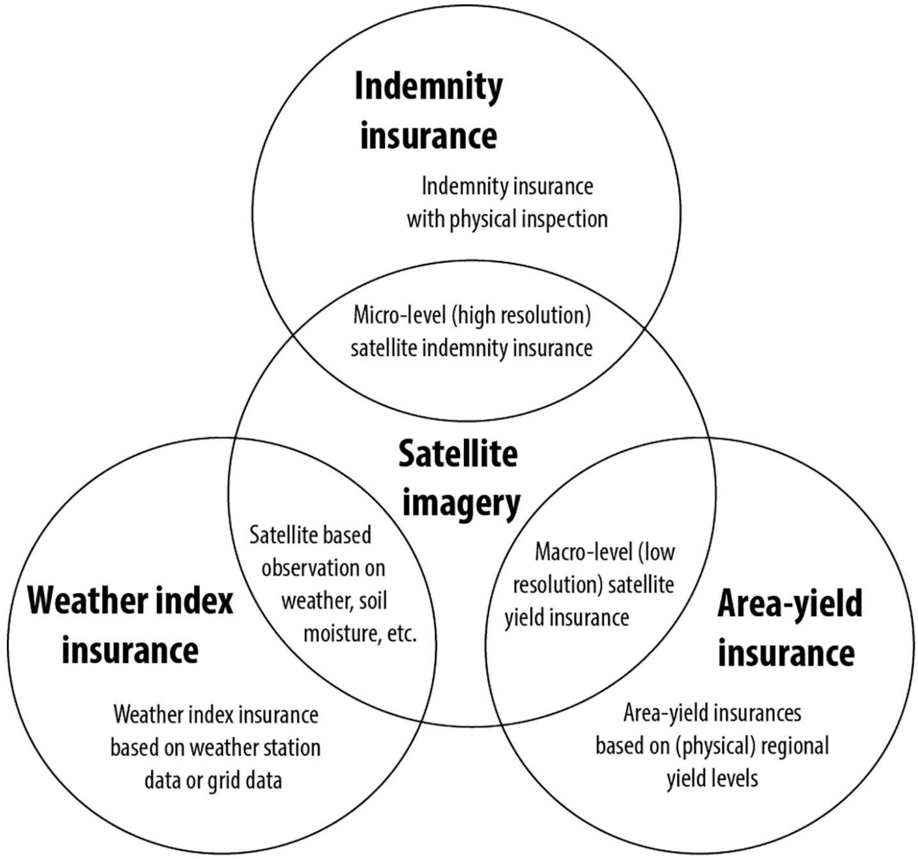

Fig. 1. A classification of grassland production insurance.

availability has a large potential for developing new ways of insuring grasslands in the future (de Leeuw et al., 2014). For instance, the launch of the first Sentinel-2 satellite in early 2015 has made the direct monitoring of grassland vegetation with open source data possible (Roumiguié et al., 2017).[2] In Europe and North America, recent examples of newly developed index insurances include the 'Assurance des Prairies' in France (Roumiguié et al., 2015b) and the 'Gras-Pauschal-versicherung KLIMA' in Switzerland (Schweizer Hagel, 2018a). To improve risk management possibilities for farmers, a need for exchange about these diverse innovations emerges (e.g. Gobin, 2018; Iglesias et al., 2016; Kellner and Musshoff, 2011). Despite the fact that several novel insurance solutions for grasslands have been developed and implemented, there is no review and critical assessment of the existing schemes. We aim to fill this gap by describing different types of insurance solutions with respect to the underlying mechanisms and by summarizing and discussing current applications as well as future possibilities for grassland production insurances. Therefore, we identify all grassland insurances in Europe and North America using literature review and expert interviews. We extract information for the central characteristics of each insurance. Based on this background, we discuss the advantages and disadvantages of the different types of insurances used. Eventually, we compile the critical points identified and present a research agenda in the field of risk management instruments to cope with extreme weather risks in grassland-based farming systems.

2. Agricultural insurance

Agricultural insurances have a long and rich history (see Smith and Glauber, 2012). In traditional indemnity insurances, a physical assessment is needed to trigger indemnification (Musshoff et al., 2011). Disadvantages of these insurances have been discussed intensively. First, asymmetric information about the riskiness and cultivation measures cause both adverse selection and moral hazard (Chambers, 1989). Adverse selection indicates that farmers with a higher risk exposure (which is unknown to the insurer) have a higher incentive to insure than farmers with a lower risk exposure. Moral hazard implies that insured farmers shift to riskier agricultural practices than uninsured farmers. Both phenomena lead to market failure without further control instruments (e.g. screening, deductibles), which imply higher costs and/or lower risk coverage. Second, physical damage assessments (e.g. inspections in the field) are costly (Leblois and Quirion, 2013). As a result of this, specific disadvantages occur when insuring grasslands with traditional indemnity insurance schemes. Due to mowing and grazing, it is particularly difficult to place indemnity insurances on pastures or grazing land (e.g. de Leeuw et al., 2014). Moreover, low prospects of standard insurances in grasslands are due to the relative low value per area unit. For these reasons, classical indemnity based agricultural insurances are usually designed for cash crops and not for grassland based farming systems in general and grassland yields in particular (see Wu, 1999 for an example from the US).

To overcome these drawbacks, index insurances have been suggested as an alternative to traditional indemnity insurances (e.g. Barnett et al., 2008; Cole et al., 2013; Turvey, 2001). In contrast to indemnity insurances, payoffs are not based on the result of a physical loss assessment on the farm, but on the value of an index that is related to grassland production, such as regional average yields or rainfall at a weather station. The payoff then occurs when the predetermined strike level of the underlying index is undercut or exceeded. Three advantages of index insurances are especially important for the insurance of grasslands: i) symmetrical information about the insured index for both parties, i.e. insurer and insured, ii) continuous remote assessments to

[2] This has also led to a project call of the European Space Agency (ESA) for best practices of using this information in agricultural insurances.

solve the problem of yield measurement in the presence of grazing and mowing and iii) reduced transaction costs.

In order to design a successful production index insurance, 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 (Cole et al., 2013). Additionally, a sufficiently long historical time series of 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 (Vrieling et al., 2014). The potential mismatch between the index value and its associated payoffs with the actual performance indicator of interest (here yield) is referred to as basis risk (e.g. Jensen et al., 2018; Woodard and Garcia, 2008). Basis risk should be minimized as it reduces the uptake of index insurances by farmers (Clarke, 2016; Conradt et al., 2015a) and is problematic in a legal context. Basis risks can be divided into three major components, i.e. spatial, temporal and design basis risk (Dalhaus and Finger, 2016). Spatial basis risk occurs when the index is not measured at the same location as the insured crop is situated. This for example occurs when indices are based on measurements from remote weather station(s). Temporal basis risk emerges due to a biased temporal aggregation of observations, mainly because observations are aggregated into months, while the vulnerability of plants is rather related to plant phenological phases (Conradt et al., 2015b; Dalhaus et al., 2018). Design basis risk is present when the chosen underlying index is not a good approximation of the underlying sources of yield or revenue variability.

Insurance solutions and specific index designs are diverse and manifold and as a result, there are multiple ways to categorize index insurances. Usually, index insurances are positioned in contrast to indemnity insurances. Index insurances have been divided into three types: area-yield insurances, weather index insurances and satellite insurances.

2.1. Area-yield insurance

In *area-yield insurance* schemes, payoffs are triggered whenever the average yield in one year in a certain area falls below a certain pre-set critical threshold (strike level) (e.g. Breustedt et al., 2008; Miranda, 1991; Skees et al., 1997). Similar to indemnity insurances, area-yield insurances cover yield losses independent of their source. These insurance schemes are especially useful in areas where risks are mainly systemic (Skees et al., 1997). Area-yield insurances have several advantages over indemnity insurances (Miranda, 1991). First, usually there are longer records of high quality yield information than at the level of individual farms, implying a better risk assessment and facilitated payoff system. Second, the risk of moral hazard is reduced, because the influence of the behaviour of a single producer on the total yield in an area is less than on her/his individual yield. Third, administration costs are lower as payoffs are made collectively and not individually for each farm. The disadvantage of area-yield insurances is that they are affected by spatial basis risk. That is because payoffs are only triggered by an average loss from which individual losses can differ. Due to aggregation biases the regional average yields may exclude important farm-level information such as elevation (Fig. 2, Marra and Schurle, 1994), so that a single farm's risk exposure might be underestimated.

2.2. Weather index insurance

Weather index insurances aim to 'reduce the impact of harmful weather on farms whose [economic] margins widely depend on climate' (Leblois and Quirion, 2013). All sorts of weather phenomena can be used in the underlying index. Precipitation, temperature, wind, solar radiation or combinations thereof, and also water capacity-based indices (e.g. soil moisture indices) have been considered (see Leblois and Quirion, 2013 for an overview). For grasslands, especially extreme droughts during the growing season cause stressful conditions (Kreyling et al., 2008). Therefore, weather index insurances for grasslands are usually designed to insure against lacking precipitation. In these designs, a payoff occurs whenever the index estimating dry conditions undercuts a certain strike level. The trigger of weather index insurances is thus fully independent of the farmer's decisions. This has multiple advantages. The weather index, if measured by an independent organization, cannot be influenced, erasing issues of moral hazard. Another advantage is that weather index insurances can also insure for reduced quality of the grassland (Finger et al., 2014; Grant et al., 2014; Walter et al., 2012) and for increased input costs in response to weather shocks. For instance, irrigation might be used to compensate the lack of precipitation. In contrast to area-yield and indemnity insurances, these additional costs are at least partly covered in weather insurance schemes. However, weather indices suffer of basis risk, which is considered as one of the most important adoption hurdles (see also Clarke, 2016; Dalhaus and Finger, 2016). Spatial basis risk occurs if the measured weather (e.g. at a remote weather station) differs from actual weather at the production site (Fig. 2). Temporal basis risk occurs if the yield determining weather is measured at an incorrect point in time, i.e. ignoring vulnerable phases of plant growth (Conradt et al., 2015b). Design basis risk includes all remaining discrepancies between modelled production and realized production. Only insuring a single weather peril for instance ignores the influence of other drivers of yield variability such as other weather events to be considered, resource availability and pests (Leblois and Quirion, 2013).

2.3. Satellite imagery in agricultural insurance

In recent years, as (open-source) satellite data quantity and quality are constantly improving, satellite imagery has been found to have a large potential for insuring agricultural production (de Leeuw et al., 2014),. An insurance successfully incorporating satellite imagery reduces costs and basis risk without increasing asymmetric information. As shown in Fig. 1, satellite imagery can be used as a data source to design and/or support both index insurances and indemnity insurances. Spatial, temporal and spectral resolutions of collected imagery are numerous. Moreover, imagery from passive (measuring the reflection of sunlight) and active scanners (measuring self-emitted radiation) are operative. Fig. 2 illustrates that satellite imagery is collected at different spatial scales. For example, satellite imagery can be used to support indemnity insurances by improving micro-level damage assessments. This can be achieved by using medium-resolution imagery (50–500 m) supplemented with farm-level data or by using high-resolution imagery (< 50 m). The resolution required to conduct micro-level damage assessments also relates to the usual farm and field size in the region. In recent years, the accessibility of high-resolution satellite imagery has improved, especially since the launch of the Sentinel satellites, it has become available to a large group of users (Roumiguié et al., 2017). But even when using micro-level satellite information in indemnity insurances, insurances based on satellite imagery come with basis risk. Design basis risk of satellite insurances arises because the measured quantity and quality may not perfectly correlate with actual losses in vegetation growth and health on the field. A large body of remote sensing literature discusses possibilities to monitor and estimate grassland yields (e.g. Barrachina et al., 2015; Barrett et al., 2014; Li et al., 2016; Porter et al., 2014). Multiple grassland index insurances use the Normalized Difference Vegetation Index (NDVI) measuring the relationship between the canopies' reflectance in the red and infrared region as the underlying index of the insurance. The NDVI is found to be powerful for the detection of droughts in grasslands (Porter et al., 2014; Yengoh et al., 2015). While the accuracy of the predictions are generally quite good, they do not come without errors. The relation between NDVI and grass yield for example is affected by leaf coverage, atmospheric scattering and soil background. All these factors can cause

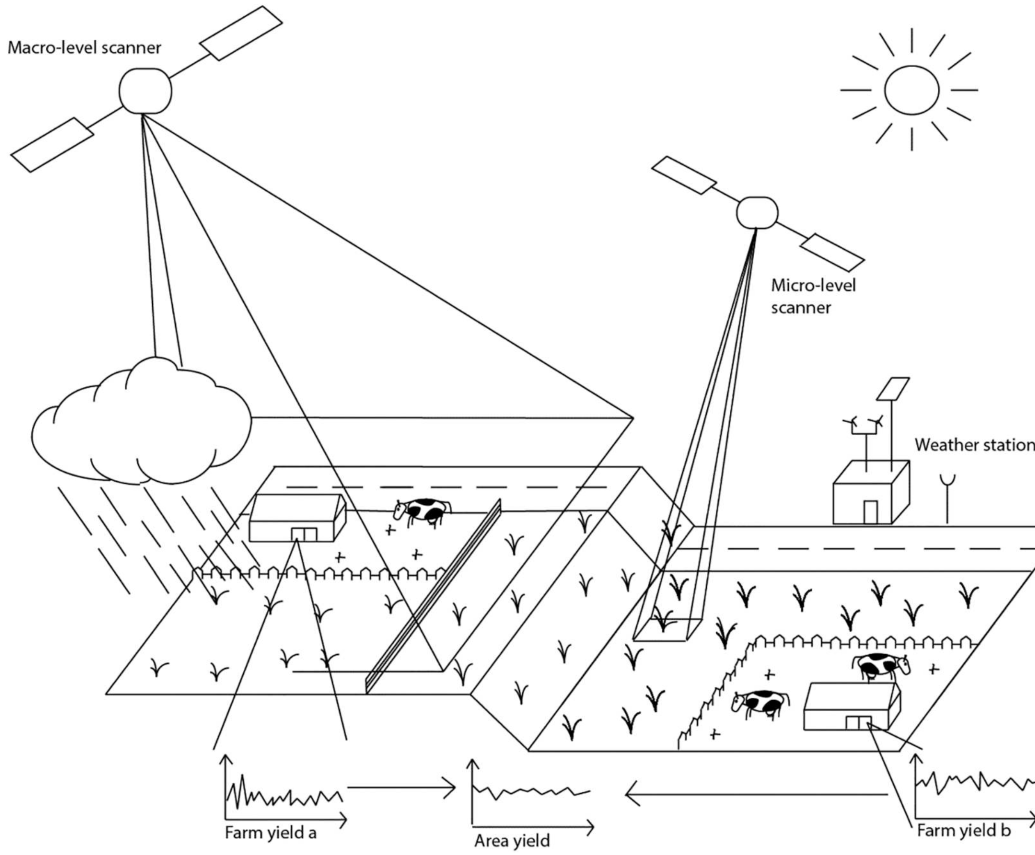

Fig. 2. An overview of data collection for agricultural insurances.

considerable deviations between field measurement and satellite measurement (Carlson and Ripley, 1997; Gao, 1996; Huete et al., 1997). Additionally, we find that spatial basis risk in satellite insurances occurs especially when the physical circumstances within the defined area or pixel are heterogeneous, causing high heterogeneity of grassland yields within such area. This problem generally decreases with higher resolutions (e.g. Roumiguié et al., 2017). However, with increasing spatial resolutions, problems of indemnity insurances occur (Mosnier, 2015). For example, insurances based on micro-level satellite imagery can effectively reduce the problem of adverse selection but moral hazard must be considered and controlled for when assessing the damage. The presence of temporal basis risk of satellite-based index insurances depends on the relation between the orbit type[3] (and the payoff design of the insurance.

Satellite information can also be useful to improve area-yield insurances. For example, estimations of the vegetation's condition at a macro-level can be used to support and/or design area-yield insurances, with the advantage that yield estimations can be made on a regular basis. Another application of satellite imagery are satellite-based weather estimates (Black et al., 2016; de Leeuw et al., 2014; Dinku et al., 2009). In Zambia, for example, a rainfall index insurance for cotton based on satellite data is operational (Black et al., 2016). Satellite weather estimates are, in contrast to weather station rainfall measurements, by default regularly gridded and do therefore not depend on the distribution of ground-based measuring stations. Yet, ground-based weather stations are important for the validation of satellite weather estimates and the use of satellite weather estimates is still 'an exploratory field in index-based insurance' (Roumiguié et al., 2017). This specifically holds for developed countries, where weather station coverage is dense and where, if a dense network is available, precipitation radars might deliver more accurate weather predictions than satellites.

3. Grassland index insurances in Europe and North-America

3.1. Overview of grassland index insurances

We compile an overview all grassland insurance schemes in Europe and North America. Income or revenue insurances are excluded from this overview, since they do not focus on insuring grasslands specifically. We focus on North America (Canada and US) and Europe[4] for the following reasons. First, we intend to address market-based products offered by private insurance companies. Thereby, we focus on countries in which insurance systems are traditionally well developed. In many developing countries, insurances are in general relatively new and the insurance market has been developed by government-led projects instead.[5] Second, we aim to compare index insurances in countries where high-quality yield and weather data is available for private insurance companies. Information on the existing insurances was gathered from scientific literature and from online documents of insurance companies.

[3] Geostationary satellites remain at the same position above the equator and provide information on the same location frequently (minute scale) while polar-orbiting satellites pass around the poles and provide more detailed, yet less frequent imagery (daily-weekly scale).

[4] Australia and New Zealand were also considered, we did not encounter any index insurances for grasslands in these countries.

[5] The IBLI in Kenya is led by the International Livestock Research Institute (ILRI) and works together with private insurance companies.

Table 1
Overview of operational index insurances for grasslands.[a]

Country	Type of insurance	Insurance name	Index variable(s)	Insurer	Measurement temporal resolution	Index temporal resolution	Measurement spatial resolution	Index spatial resolution	Strike level (deviation from long-time average)	Offered since
Austria	Weather index	Dürreindex Grünland	Rainfall	The Austrian Hail Insurance (Die Österreichische Hagelversicherung)	Daily	5 months or 42 days	Depending on municipality size (one central point in each municipaltiy)	Municipality	≤36% (5 months) or ≤ 70% (42 days)	2015
Canada, Alberta	Weather index	Moisture Deficiency Insurance	Rainfall	Agriculture Financial Services Corporation (AFSC)	Daily	Monthly	Depends on weather station density	Clients choose up to three weather stations	< 70 or 80%	2002
Canada, Alberta	Area-yield (satellite)	Satellite Yield Insurance	PVI	Agriculture Financial Services Corporation	Daily, aggregated to weeks	Annual	1kmx1km	Township	< 85% (split season) or 90% (full season)	2001
Canada, Ontario	Weather index	Forage Rainfall Plan	Rainfall	Agricorp	Daily	Monthly, bi-montly or three-month	Depends on weather station density	Clients choose up to three weather stations	< 85% (month) > 5 or 7 mm (10 days)	2000
Canada, Saskatchewan	Weather index	Forage Rainfall Insurance Programm (FRIP)	Rainfall	Saskatchewan Crop Insurance Corporation	Daily	4 months	Depends on weather station density	Clients choose up to three weather stations	< 80%	2001
France	Indemnity-based with index (satellite)	Assurance des Prairies	FPI	Airbus Defence and Space with private insurers	Daily	10 days	300mx300m	Municipality	Only absolute deductible	2015
Germany	Weather index	Wetterversicherung	Weather variables correlating with yield individuelly defined	gvf Versicherungsmakler AG	Daily	Individually defined	Depends on weather station density	One weather station	75, 80, 85 or 90% (individual differences possible)	2014
Spain	Area-yield (satellite)	Seguro de Compensación por Pérdida de Pastos	NDVI	Agroseguro	Daily	10 days	250mx250m	Homogeneous pasture zone (355 across Spain)	0.5, 0.7, 1.2 or 1.5 times deducting the SD	2001
Switzerland	Weather index	Gras-Pauschalversicherung KLIMA	Rainfall and country-specific evaporation coefficient	Schweizer Hagel	Daily	6 months	1kmx1km	1kmx1km	< 75%	2016
USA	Area-yield	Area Risk Protection Insurance (former Group Risk Plan)	County-yield	United States Department of Agriculture, Risk Management Agency (USDA-RMA) and Federal Crop Insurance Corperation (FCIC) with private insurers	Yearly	Yearly	County	County	70, 75, 80, 85 or 90%	1994
USA	Weather index	Rainfall Index Pasture, Rangeland, Forage (RI-PRF)	Rainfall	USDA-RMA and FCIC with private insurers	Daily	Bimonthly	Depends on weather station density	0.25°x0.25°	70, 75, 80, 85 or 90%	2007
USA	Weather index	Rainfall Index Annual Forage Program (RIAFP)	Rainfall	USDA-RMA and FCIC with private insurers	Daily	7 months (2 different)	Depends on weather station density	0.25°x0.25°	70, 75, 80, 85 or 90%	2014

On 8.10.2018. the total premium sum for 2018 of grassland index insurances in the USA added up to 558 million US Dollar (ARPI: $ million, RI_PRF: $552 million., RIAPF: $0.8 million) (https://www3.rma.usda.gov/apps/sob/current_week/crop2018.pdf, accessed 08.10.2018).

To verify and complete this information, systematizing expert interviews were conducted (Bogner et al., 2009). For this, the interviewees were shown a working version of Table 1 on the overview of operational insurances. For each country listed, we interviewed a representative either from an insurance provider or an insurance policy maker (such as the United States Department of Agriculture (USDA)). Information on the interviewees, the interview questions as well as product links are summarized in Tables A1, A2 and A3 of the appendix.[6] In total, seven interviews were conducted. Table 1 shows the overview of operational index insurances. We found that twelve index insurances for grasslands are operational in Europe and North America.

3.2. Area-yield insurance

In the US, an area-yield insurance has been provided since 1993 under the name 'Group Risk Plan', initially exclusively for soybean producers (Skees et al., 1997). In 2007, the insurance was extended to other crops as well as to forage. With that, the number of contracts increased significantly (Glauber, 2013). Recently, the Group Risk Plan has been replaced by an insurance called Area Risk Protection Insurance (ARPI), but this is still the original insurance (Schnitkey, 2014). The difference with its predecessor is that all group products including income products are now captured under the same name. The payoff occurs whenever the total yield of a county, estimated by the National Agricultural Statistical Service (NASS), is below a threshold of the NASS yield forecast for that respective county (Skees et al., 1997). This forecast is published around six months before the harvesting date (Skees et al., 1997). The NASS forecasts area-yield for a growing season based on central tendencies in historical data of the same area. The spatial resolution of the insurance is set to the county level. This is because in the US, counties are the smallest spatial unit with historical area yield data available (Skees et al., 1997). Because farms average yields might be higher than the average county yield, a protection of up to 150% can be bought (Miranda, 1991).

3.3. Weather index insurances

Weather index insurances protecting farmers against droughts are available in Austria, Canada, Germany, Switzerland and the US.

The Austrian Hail Insurance chooses a central measurement point in the municipality where a rainfall gauge is then placed. In this scheme, a payoff is triggered when the full season rainfall (spanning over 5 months) is < 70% of normal, or when the rainfall during a 42-day period is < 64% of normal (Die Österreichische Hagelversicherung, 2017). In addition to rainfall measurements, the Austrian insurance accounts for heat stress, focusing on days with temperatures above 30 °C (Die Österreichische Hagelversicherung, 2017).

In Alberta, Canada, the 'Moisture Deficiency Insurance' of the Canadian Agriculture Financial Services Corporation insures against rainfall deficits in any month. Additionally, clients have the option to insure themselves for spring soil moisture deficits (Agriculture Financial Services Corporation, 2017). Producers in Ontario, Canada, can insure their forage against droughts (< 85% of normal rainfall) during any month and additionally against heavy rainfall (> 5 or 7 mm) during ten days of the harvesting period (Agricorp, 2015). In Saskatchewan, Canada, a full season option is offered to grassland producers (Saskatchewan Crop Insurance Corporation, 2018). In all Canadian weather insurance schemes, the producer can choose up to three weather stations at which rainfall will be measured on a daily basis.

In Germany, the insurance company provides individual weather damage assessments for each client. Based on these assessments, tailor-made index insurances are offered (S. Mahler, personal communication, February 27, 2018).

The Swiss insurance scheme uses an index based on rainfall measurements of five ground-based radar weather stations and integrates a country-specific value on the evaporation of Swiss meadows in the index calculation (H. Lusti, personal communication, December 7, 2017). The 1×1 km^2 gridded radar data is validated with rainfall measurements at 260 weather stations. The daily measurements are aggregated into a six months' timeframe and the development of drought during the year is made available publicly.[7] The strike level, i.e. the level that triggers insurance payoff, is 75% of normal rainfall (Schweizer Hagel, 2018b).

Since 2007, the 'Rainfall Index Pasture, Rangeland, Forage' (RI-PRF) is available for producers in the east of the US. Daily measurements at rainfall stations are made available in a grid of 0.25×0.25 degrees[8] by the National Oceanic and Atmospheric Administration (NOAA) and are publicly available.[9] Whenever the rainfall in the pixel in a two months' timeframe (chosen by the producer) is < 70–90% of a long-year trend (level can be chosen by farmers) a payoff is made (United States Department of Agriculture, 2017). The RI-PRF is designed by the US Risk Management Agency (RMA) but sold by private insurers. In 2014, the rainfall index for grasslands was extended with a version for annual forage called 'Rainfall Index Annual Forage Program' (RIAPF). The RIAPF and the RI-PRF are similar products, the only differences can be found in the validation of the product insured and in the timeframe coverage. While in the RI-PRF insurance, farmers can choose bimonthly coverage frames, farmers buying a RIAPF insurance are insured for a seven months' period (Maples et al., 2016). In 2015, the original PRF-RI product was extended to the west of the US (Risk Management Agency, 2015).

3.4. Index insurances with satellite imagery as data source

Satellite imagery is used in insurance designs in Canada (Alberta), France and Spain. In Canada and Spain, satellite imagery is used to assess macro-level droughts. For this, the vegetation's photosynthetic activity is measured. More specifically, the NDVI is used as the underlying index of the insurance (Agriculture Financial Services Corporation, 2017; Agroseguro, 2016). In Canada, measurements with a resolution of 1x1km^2 are averaged to weekly values and a payoff is made when the yearly average of a weekly value at a certain pixel is below the strike level. In Spain, pixels of 250x250m^2 are aggregated to 355 homogenous pasture zones, and a payoff is made whenever the ten days' composite within this zone falls below the strike level of the reference NDVI (adjusted every five years). In France, the Forage Production Index (FPI) insurance developed by Airbus Defence and Space measures the fraction of ground covered by grass (fCover) at a resolution of 300x300m^2 measured at a daily basis (Roumiguié et al., 2015a). The pixel values are aggregated to the municipality level and supplemented with farm individual elevation level and soil type (B. Lepoivre, personal communication, December 20, 2017). The daily measurements are aggregated to ten days composites.

4. Discussion

4.1. Area-yield insurance

The American ARPI was the only identified area-yield index insurance for grasslands. Despite a history of more than twenty years, this scheme has not been copied elsewhere. On the contrary, the participation rate of American farmers buying the area-yield insurance has

[6] Transcripts of the interviews are not made available as some of the interviews contain sensitive information.

[7] http://swissagroindex.hagel.ch/grasland-web/, last accessed 04.10.2018.

[8] At the geographic centre of the US this refers to an area of $\pm$ 27 $\times$ 21 km^2.

[9] https://prodwebnlb.rma.usda.gov/apps/prf, last accessed 04.10.2018.

decreased since the introduction of weather and satellite insurances (Glauber, 2013). It is assumed that farmers prefer individual assessments over a comparison with the performance of their neighbours (T. Worth, personal communication, December 12, 2017). Moreover, as measuring grassland yields is difficult due to mowing and grazing, payoffs of the ARPI are made based on estimated grassland yields resulting in additional design basis risk of the product. Based on this and based on the developments made in the alternative insurance options, we do not see a large potential for area-yield insurances based on regional yield level data in the future.

4.2. Weather index insurance

Most operating grassland insurances are found to be weather index products. Rainfall products are the most comprehensible for farmers, which is important for the market performance (Leblois et al., 2013; Patt et al., 2009). Moreover, these products come with comparably low transaction costs, as high-quality weather measurements are mostly free available. We find that differences between the products show that the exchange of knowledge between the insurance markets is restricted. Exchanging and integrating knowledge could substantially reduce basis risk. This would increase farmers' willingness to participate and pay for such insurances (Clarke, 2016; Elabed and Carter, 2015). Currently, insurance schemes differ with respect to the spatial and temporal aggregation level of yield measurement data used to design insurance products. This might result in different levels of basis risk. For example, we find large differences in the spatial resolution. Higher spatial resolutions are expected to decrease spatial basis risk, as the discrepancy between measurement station and production site is reduced. Moreover, higher temporal resolutions are expected to reduce temporal basis risk, as it makes the design of more detailed index time windows possible. Index insurances with time windows that consider the phenological phases of plants are better able to insure losses, especially in phases when plants are particularly vulnerable to changes in the environmental conditions (Dalhaus and Finger, 2016; Dalhaus et al., 2018). We find that only the German insurance scheme tailors the weather index-based insurance to a single farm's risk exposure. This, however, also increases transaction costs. In contrast, e.g. programs in the US that are designed based on county level information, provide low risk reduction (Maples et al., 2016) or can be even risk increasing (Westerhold et al., 2018). Moreover, the inclusion of other than rainfall related weather variables, as applied in Austria and Germany, might further reduce basis risk for products that so far only include a single weather peril. Moreover, weather grid data, that is used in the US, Canada and Switzerland, seems to be a promising alternative for German and Austrian products as the possibility of technical failure of weather stations and transaction costs of identifying a weather station relevant for a specific farm can be reduced (Dalhaus and Finger, 2016). Additionally, when asked about their view on the future development on their index insurances products (question 7 of the interview, see Table A2 for a complete overview of the interview questions), the French, Swiss and German interviewees replied that the main restriction to further development is the legal setting. This is particularly because (negative and positive) basis risk is problematic from a legal perspective. As payoffs not necessarily will coincide with damages at the farm-level, such insurance product could be linked to gambling. For example, the provider of the Swiss weather index insurance, Swiss Hail, is obliged by Swiss law to conduct a physical field assessment. This should ensure that a payoff was triggered correctly and is not in conflict with the Swiss gambling law (H. Lusti, personal communication, December 7, 2017). Similarly, for subsidization within the Common Agricultural Policy of the European Union, it is necessary to prove that the insurance indemnifies a farmer for her/his exact losses (B. Lepoivre, personal communication, 20 December 2017). This is especially of importance for France, where subsidies of insurance premiums are particularly important (Bardají et al., 2016). Additionally, as index insurance are so far not considered as '*insurances*' in the European systems, they are disadvantaged with respect to taxation. For example, in Germany the index insurance premium is subject to a value added tax (19%[10]), while indemnity insurance are taxed based on a share of the insured value using a rate of 0.03%. In Switzerland, index insurance underlie a stamp duty (5%[11]), while indemnity based products are exempted. In the United States, index insurance programs have the same rights as indemnity based products, which are excluded from any taxation scheme. Here, steps should be made by policy makers to reduce the disadvantages of index based over traditional agricultural insurance products. This would allow the development of a broader portfolio of insurance solutions, which will contribute to more efficient risk management possibilities for a wider range of farmers.

4.3. Satellite imagery

By providing information with high spatial and temporal resolution, most insurance companies state that they are interested in satellite technology. Interviews revealed that the use of micro-level observations is the key future development path. In contrast, innovations in other countries such as tailor-made solutions, the inclusion of other geodata as for example pasture zones remained unmentioned. Indeed, satellite imagery can improve all types of grassland insurances as there are several options to make use of the data. Yet, as for other index products, the problem of basis risk remains. More specifically, irrespective of the limitations of the NDVI, it is used in two out of three current grassland insurances using satellite information. In France and Spain developments are ongoing to introduce more detailed geodata (B. Lepoivre, personal communication, 20 December 2017; J. C. Cuevas, personal communication, 21 December 2018) and in Canada the use of scanners with higher resolutions is considered (M. Roznik, personal communication, 23 March 2018). In contrast, the USDA RMA dropped an insurance based on satellite imagery similar to the Canadian insurance in 2015. More specifically, the insurance (Vegetation Index-Pasture Rangeland Forage) is no longer (since 2016) available as it was found that the NDVI was not comprehensible enough for farmers. Specifically, farmers did not understand well enough when a reduced NDVI correlates with reduced yields (T. Worth, personal communication, December 12, 2017). This is especially important for farmers in the US, as they choose the time-frame covered themselves. This advocates that insurance companies determine meaningful time frames when offering complex insurance schemes. This also highlights a trade-off between minimizing basis risk and the transparency of the index for farmers as well as transaction costs for satellite insurances. This trade-off has also been described for weather index insurances (Cole et al., 2013). This shows that the performance of alternatives depend on local circumstances, but also that there is a large potential to redesign grassland insurances based on new technological possibilities. Policies supporting the development of better risk management instruments should be forward-oriented and include these possibilities.

4.4. New opportunities

The increasing amount of freely available databases and the various insurance types indicate a large potential for insuring grasslands in the future (e.g. de Leeuw et al., 2014; Wolfert et al., 2017). Especially satellite imagery might have potential to support several innovative applications. Firstly, satellite measurements relating to yield other than the NDVI (e.g. canopy temperature and height measurements) remain

[10] §6 Versicherungssteuergesetz, Germany, https://www.gesetze-im-internet.de/versstg/_6.html, accessed: 16.10.2018.

[11] Bundesgesetz über die Stempelabgaben (StG), Switzerland, https://www.admin.ch/opc/de/classified-compilation/19730173/201601010000/641.10.pdf, accessed: 16.10.2018.

barely explored in insurance design. A first example of a broader use of satellite products is the recently developed FPI used by the Assurance des Prairies (France). The prospects which this innovation offer should be a motivation for policy makers to expand investments in this area. Secondly, high-resolution satellite imagery may be used to improve area-yield insurances, as the area-yield estimation can made more precisely, while keeping the risk of moral hazard low. In a current application in South East Asia (ASEAN Sustainable Agrifood Systems, 2015), imagery from the Sentinel-1 satellites is used to monitor the height of rice plants and to create rice area map. This data is used in a combination with ground-based weather, soil and farm management data used in a crop growth model in an area-yield insurance scheme (Setiyono et al., 2018). Additionally, as for the Sentinel satellites, only a short historical time series is available, the historical time series is based on MODIS imagery (Setiyono et al., 2018). Thirdly, satellite weather estimates have the advantage that not the vegetation itself, but its environment is measured. As the environment, in particular rainfall, is less or not susceptible to the behaviour of the producer, this reduces the problem of asymmetric information. Additionally, remotely-sensed weather estimates can be designed with limited calibration datasets (Greatrex et al., 2014). Such a solution would reduce the dependence on weather station data and would avoid the problems of moral hazard emerging in other satellite applications. For example, a study showing a possible weather insurance using satellite rainfall measurements has been conducted in Zambia (Black et al., 2016). Fourth, double trigger approaches might be used to overcome limitations of index insurances. The payoff schedule is then determined by two triggers instead of a single one. For example, such double trigger indices could be based on a combination of satellite and weather data.

More general, future insurance solutions for grassland based production systems could also respect other components relevant for these farms. In particular, grassland index insurances can compensate for other risk management practices such as increased herd sizes and hay stockings. Livestock production systems not only face climate risk via fodder production but also due to effects of climate on meat and milk production (see e.g. Finger et al., 2018; Key and Sneeringer, 2014 for examples in Europe and North America). Intensively studied livestock index insurance products that aim to insure livestock via grassland monitoring include the Index-Based Livestock Insurance (IBLI) in Kenya (Chantarat et al., 2013; Jensen et al., 2018; Mude et al., 2009; Vrieling et al., 2014), Ethiopia (Jensen et al., 2015) and Mongolia (Bertram-Huemmer and Kraehnert, 2018; Rao et al., 2015), but also for instance in Mexico (The World Bank, 2013a), Uruguay (The World Bank, 2013b) and Argentina (Bacchini et al., 2015), grassland index insurance products are (being) developed.

5. Conclusion

We investigated twelve operational grassland insurance schemes in North America and Europe. We find the used approaches to be diverse and insurance possibilities to be rapidly expanding, due to the increasingly free availability of (satellite) data. For grasslands, three advantages of index insurances prevail: i) it enhances symmetrical information about the insured index for both parties, i.e. insurer and insured, ii) remote sensing allows to assess yield over the entire growing season and thus can deliver yield information even under grazing or mowing, and iii) it offers insurance at reduced transaction costs.

We provide an overview of all marketed index insurance schemes for grasslands in Europe and North America. Our work contributes three predominant findings that are important for future research and insurance practitioners. Firstly, we find that three different insurance types exist including indices that are based on area yields, weather variables or satellite imagery. Secondly, for grasslands, weather index insurance solutions are currently found to dominate over satellite-based insurance solutions while area-yield insurances play only a minor role. Thirdly, our review reveals isolated insurance markets that prevent knowledge spillovers. Lessons that were learned in other countries, seem to remain unconsidered in the design of new and the improvement of existing schemes, i.e. insurances tailored to single farm's risk exposure, the combination of satellite with other geodata (e.g. land use information) and the adaptation of legal specifications. However, knowledge spillovers between the different products and insurance systems can decrease basis risk and increase climatic risk management opportunities for farmers.

For the future we expect especially satellite-based insurances to become increasingly important as data quality increases while costs remain low. However, important conflicts need to be considered. Satellite imagery provides a possibility to directly measure a single farm's yield. Thus, with decreasing basis risk, the possibility of moral hazard, i.e. insured farmers shift to more risky production practices, increases as well. Hence, measures to prevent market failure, e.g. deductibles, need to be introduced leaving parts of the risk uninsured. Summarizing, there is a trade-off between the reduction of basis risk and the reoccurrence of risks of asymmetric information. Because basis risk is often reduced using more complex indices, this also would go along with reduced transparency of the underlying to farmers. Several solutions potentially handle these trade-offs: i) satellite measurements estimating yield with other indices than the NDVI might reduce basis risk, and might be more understandable for farmers ii) high-resolution satellite imagery can be used in area-yield index designs to reduce basis risk, while keeping the risk of moral hazard low iii) like weather index insurances, satellite weather estimates have the advantage to measure the vegetation's environment, and are independent of the distribution of weather stations iv) double-trigger approaches might overcome limitations of index insurances.

Acknowledgements

This research was undertaken within the SURE-Farm (Towards SUstainable and REsilient EU FARMing systems) project, funded by the European Union (EU)'s Horizon 2020 research and innovation programme under Grant Agreement No 727520 (http://surefarmproject.eu). The content of this article does not reflect the official opinion of the European Union. Responsibility for the information and views expressed therein lies entirely with the authors.

We thank the experts who participated in our interviews for their collaboration and Julia Heinrichs (University of Bonn) for support. Furthermore, we thank two anonymous reviewers and the editor for constructive feedback on a previous version of the paper.

Appendix

Table A1
Interviewees.

Country	Company/Institution	Interviewee	Date
Austria	The Austrian Hail insurance (Die Österreichische Hagelversicherung)	J. Fank	December 14, 2017
Canada	AgriRisk Initiatives	M. Roznik	March 23, 2018
France	Crédit Agricole	B. Lepoivre	December 20, 2017

(continued on next page)

Table A1 (*continued*)

Country	Company/Institution	Interviewee	Date
Germany	gvf	S. Mahler	February 24, 2018
Spain	Agroseguro	J. C. Cuevas	December 21, 2017
Switzerland	Swiss Hail (Schweizer Hagel)	H. Lusti	December 7, 2017
US	Risk Management Agency	T. Worth	December 12, 2017

Table A2
Questions expert interview.

Part 1
Is the product still on the market? If not, why not?
Is the information we gathered about your insurance still correct? If not, can you correct?
If any, can you add missing information on your product?
When was the first grassland index insurance sold?
What adjustments have been made since then? Why have these adjustments been made?
Are there any adjustments planned for next season?
How do you think the insurance will develop in the long-term future?
Part 2
Does your company offer other grassland insurances?
Does your company offer other index insurances?
Do you know about grassland index insurances that are missing in our table (also outside your country)?

Table A3
Links to product webpages.

Insurance name	Insurer	Link	Accessed
Dürreindex Grünland	The Austrian Hail Insurance (Die Österreichische Hagelversicherung)	https://www.hagel.at/wp-content/uploads/2018/04/oehv_Acker_Folder_2018_18x27_1.1.pdf	20.09.2018
Moisture Deficiency Insurance	Agriculture Financial Services Corporation (AFSC)	https://www.afsc.ca/doc.aspx?id=8032	20.09.2018
Satellite Yield Insurance	Agriculture Financial Services Corporation	https://www.afsc.ca/doc.aspx?id=3360	20.09.2018
Forage Rainfall Plan	Agricorp	http://www.agricorp.com/en-ca/Programs/ProductionInsurance/ForageRainfall/Pages/HowItWorks.aspx	20.09.2018
Forage Rainfall Insurance Programm (FRIP)	Saskatchewan Crop Insurance Corporation	http://www.saskcropinsurance.com/ci/weather-based/forage-rainfall-insurance-program/	20.09.2018
Assurance des Prairies	Airbus Defence and Space with private insurers	https://www.credit-agricole.fr/agriculteur/assurances/activite-agricole/assurance-des-prairies.html	20.09.2018
Wetterversicherung	gvf Versicherungsmakler AG	http://www.gvf.de/die-wetterversicherung/	20.09.2018
Seguro de Compensación por Pérdida de Pastos	Agroseguro	http://pecuario.agroseguro.es/fileadmin/propietario/410/2017/CES-410-17-1.0.pdf	20.09.2018
Gras-Pauschalversicherung KLIMA	Schweizer Hagel	http://www.hagel.ch/de/versicherungen/grasland/	20.09.2018
Area Risk Protection Insurance (former Group Risk Plan)	United States Department of Agriculture, Risk Management Agency (USDA-RMA) and Federal Crop Insurance Corperation (FCIC) with private insurers	https://www.rma.usda.gov/policies/2017/17-arpiforage.pdf	20.09.2018
Rainfall Index Pasture, Rangeland, Forage (RI-PRF)	USDA-RMA and FCIC with private insurers	https://www.rma.usda.gov/Fact-Sheets/National-Fact-Sheets/Pasture-Rangeland-Forage-Pilot-Insurance-Program	16.10.2018
Rainfall Index Annual Forage Program (RIAFP)	USDA-RMA and FCIC with private insurers	https://www.rma.usda.gov/policies/ri-vi/annualforage.html	20.09.2018

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