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Global disparities in agricultural climate index-based insurance research

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A B S T R A C T

Agricultural climate index-based-insurance (IBI) compensates farmers for losses from adverse climatic conditions. Using a systemic review, we show that research related to agricultural climate index-based-insurance efficacy and application is lacking in many climate and food security vulnerable countries. We concluded that there are countries with high climate and food insecurity risk based on several climate and food security indicators that lack agricultural climate index-based-insurance research that could help farmers in these countries. Research to date has also largely focused on cereal crops and drought, which only represent a fraction of the crops and climate risks that agricultural climate index-based-insurance could be beneficial in managing. Our paper provides evidence-based recommendations for countries that should be focused on to redress the current disparities in agricultural climate index-based-insurance research.

1. Introduction

Climate strongly influences crop yields (Ray et al. 2015, Lesk et al. 2016). As such, the intensification of climate and the damage caused by extreme events will be particularly pertinent for developing countries heavily reliant on agriculture to supply food, employment and economic growth and often no financial safety nets to manage their risks. Many countries while heavily dependent on agriculture are at the same time devoid of effective financial safety nets, or insurance schemes that help farmers and agricultural communities cope with losses resulting from extreme climate events (Chantarat et al. 2013). Insurance is now an important and emerging tool in managing climate related agricultural risk especially for low frequency and high impact risk events (Mushtaq et al. 2020).

Heltberg et al. (2009) recognised climate risk insurance as a major tool in coping with, and adapting to, the financial impacts of climate change. The importance of insurance as a climate adaptation tool was also highlighted by the United Nations Convention on

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Climate Change in 1997 by the Kyoto Protocol. The protocol argues for a need to facilitate capacity building to assist developing and least developed countries adapt to a changing climate (Barnett and Dessai 2002). The capacity includes identification and facilitation of adaptation options (like agricultural climate index-based-insurance) which would require technological capabilities for monitoring and assessment of climate risks.

In developing and least developed countries uninsured risks are seen as a handbrake on investment and productivity growth and thus a major inhibitor of poverty reduction (Carter et al. 2017). For example, financial protection options, such as insurance could allow farmers to better manage risks, protect assets and undertake activities that are more productive (Tirivayi et al. 2016; Croppenstedt et al. 2018). In the context of global change, developing risk transfer strategies that will help countries cope with likely increases in the range and magnitude of uncovered climate risks should be seen as an important area of research.

Agricultural climate index-based-insurance is one form of index-based insurance that is an important tool in helping manage the currently wide range of uncovered climate-related risks, particularly in developing countries (Collier et al. 2009; Chantarat et al., 2013). Relative to other forms of insurance (e.g. Multi-peril crop insurance), agricultural climate index-based-insurance products are a potentially more cost-effective means of insuring farmers against climate risk (Barnett and Mahul, 2007). Agricultural climate index-based insurance (IBI) pays the holder of the insurance contract when a certain value on an index (e.g. a threshold amount of rainfall) is realized (Barnett and Mahul, 2007). Agricultural climate index-based-insurance typically has cheaper premiums than yield-based insurance or revenue-based insurance, as it does not require expensive on-ground assessments and limits moral hazard resulting from information asymmetries or the false reporting of losses. One important benefit of index-based-insurance is its ability to deliver fast pay-outs (<72 h compared to weeks, or even months, for traditional insurance) and it comes with low transaction costs and no cost for risk assessment. Agricultural climate index-based insurance has been applied in many countries. For example, among others, agricultural climate index-based insurance has been deployed in Kenya (Chantarat et al. 2013), Mongolia, Mexico and Ethiopia (Collier et al. 2009), Canada, India and Malawi (Shi and Jiang, 2016) and India and Bangladesh. This list is not exhaustive, and there is potential for it to be applied in far many more countries (Hellmuth et al. 2009).

Despite its potential benefits the successful application of agricultural IBI requires extensive research to ensure that its options are targeted, affordable and sustainable (Vedenov and Barnett 2004, Skees 2011, Binswanger-Mkhize 2012). Monitoring and evaluation to establish if a scheme works will also be crucial in establishing drivers of successful programs in order to inform future implementations and effective distribution of the products. Agricultural IBI requires researchers to both design a suitable index and also to assess its benefit(s), drawbacks and/or the potential of maladaptive outcomes (Müller et al. 2017). Insurance products, like agricultural climate index-based-insurance, therefore, serve as means towards cushioning risks in order to avoid risk avoidance. Nevertheless, the insurance products need to be properly designed to avoid maladaptive outcomes (Muller et al 2017). In particular, research is needed to ensure basis risk (i.e. payouts not occurring when losses do, or vice versa) is minimised and that farmers are purchasing a product that efficiently supplements their income when they need it (i.e. during extreme climatic conditions) (Kath et al. 2018). Similarly, research is of paramount importance in order to effectively distribute agricultural climate IBI products. However, as crops show highly variable sensitivity to climate in order for the IBI products to be an effective means of compensating farmers against the losses caused by particular climate events tailored crop and location-based research is needed - there is no one-size-fits-all insurance solution (Hudson et al. 2020). Agricultural climate IBI research requires detailed datasets on yield, climate and researchers with skills to analyse this data to determine if a proposed index is indeed likely to be economically beneficial for farmers at a given location (Kath et al. 2019). The research-intensive nature of agricultural climate IBI development means countries lacking the data (e.g. historical yield records or weather records to test whether the index is fit for purpose) and technical capacity may be less likely to develop suitable agricultural climate IBI products to help farmers cope with the impacts of extreme climate events.

In the face of intensifying extreme climate events under climate change a lack of agricultural climate index-based-insurance research, and by extension insurance choices, leaves many farmers exposed to the economic impacts of drought, floods, cyclones and alike (Pielke Jr et al., 2003). When extreme weather events do hit many countries lack the requisite emergency response capabilities and the financial services infrastructures (i.e. Disaster Risk Finance) needed for swift and effective compensation (Croppenstedt et al., 2018; Hazell and Varangis, 2019; Demirgüç-Kunt et al., 2020). Countries lacking Disaster Risk Finance could therefore use agricultural climate IBI as a means to swiftly respond to disaster risk. Most developing countries do not have the resources for immediate response and they often depend on foreign aids before responding to urgent needs resulting from the events. Flowing on from the immediate financial consequences of agricultural losses caused by climate disasters there are also implications for food security, social well-being, economic growth and employment.

Climate impact on agricultural yields has led to a link between climate risk and food insecurity (Lesk et al. 2016). For example, climate variability may increase agricultural production risk avoidance, as owners of production capital shift them towards other uses. While, this avoidance may be more prominent among affluent farmers, if unchecked the shift in production capital may lead to food shortages and other supply-side challenges (Bandara and Cai 2014, Garnett 2014). Insurance products, like agricultural climate IBI, therefore, serve as means towards cushioning risks in order to sustain the future of agricultural enterprise. Nevertheless, the insurance products need to be properly designed to avoid maladaptive outcomes (Muller et al 2017).

Alongside food insecurity there are economic risks. Sixty percent of the world's population depends on agriculture for employment across the world (Zavatta 2014). In developing countries, such as Burundi and Chad, agricultural dependence is even higher, with>80% of the labour force dependent on agriculture (Roser 2013). Uninsured climate impacts on agriculture thus expose countries to substantial food production and negative economic (e.g. spikes in unemployment) impacts, many of which remain uninsured risks in developing countries. Agricultural insurance penetration is high amongst high-income countries (86%), and almost non-existent (0.03%) in lower income developing countries (Hazell and Varangis, 2019). While agricultural climate IBI by itself cannot fully address the numerous economic consequences caused by adverse climatic conditions on agriculture it is one important option among a suite of tools (like multiple peril crop insurance (MPCI), government aids, revenue insurance, etc.) that can help agricultural communities cope with the impacts of extreme climatic events on agricultural production. For example, improved climate forecasts and trigger points to adjust livestock numbers are valuable tools to help prepare for drought, while IBI can compensate for financial losses, which cannot be managed through adaptation options and may facilitate swift restocking, enabling producers to resume production.

Given the important implications that insurance, or its lack of, has for managing the financial consequences of climate impacts on agriculture we carried out a quantitative systematic literature review on research that has been carried out on agricultural climate IBI. We assessed how agricultural climate IBI research (253 journal articles were surveyed from 1988 to 2019) corresponded with the potential need and benefit of insurance in terms of indices of climate risk, food insecurity, contribution of agriculture to GDP and employment in agriculture. Our aim was twofold. First, to systematically assess what climate risks, crops and data sources have been investigated, and or overlooked, in agricultural climate IBI research to date. Second, to map out whether or not agricultural climate IBI research has been undertaken in countries where it has the potential to have the greatest benefit (i.e. mostly developing countries subject to high climate risk, food insecurity and with high economic dependence on agriculture especially the developing countries). Our objective here is to identify whether there is a systemic bias in where agricultural climate IBI research has been undertaken and if so to suggest countries that should be the target of future research in order to redress this.

There have been numerous reviews on agricultural climate index-based-insurance and agriculture (Binswanger-Mkhize 2012;

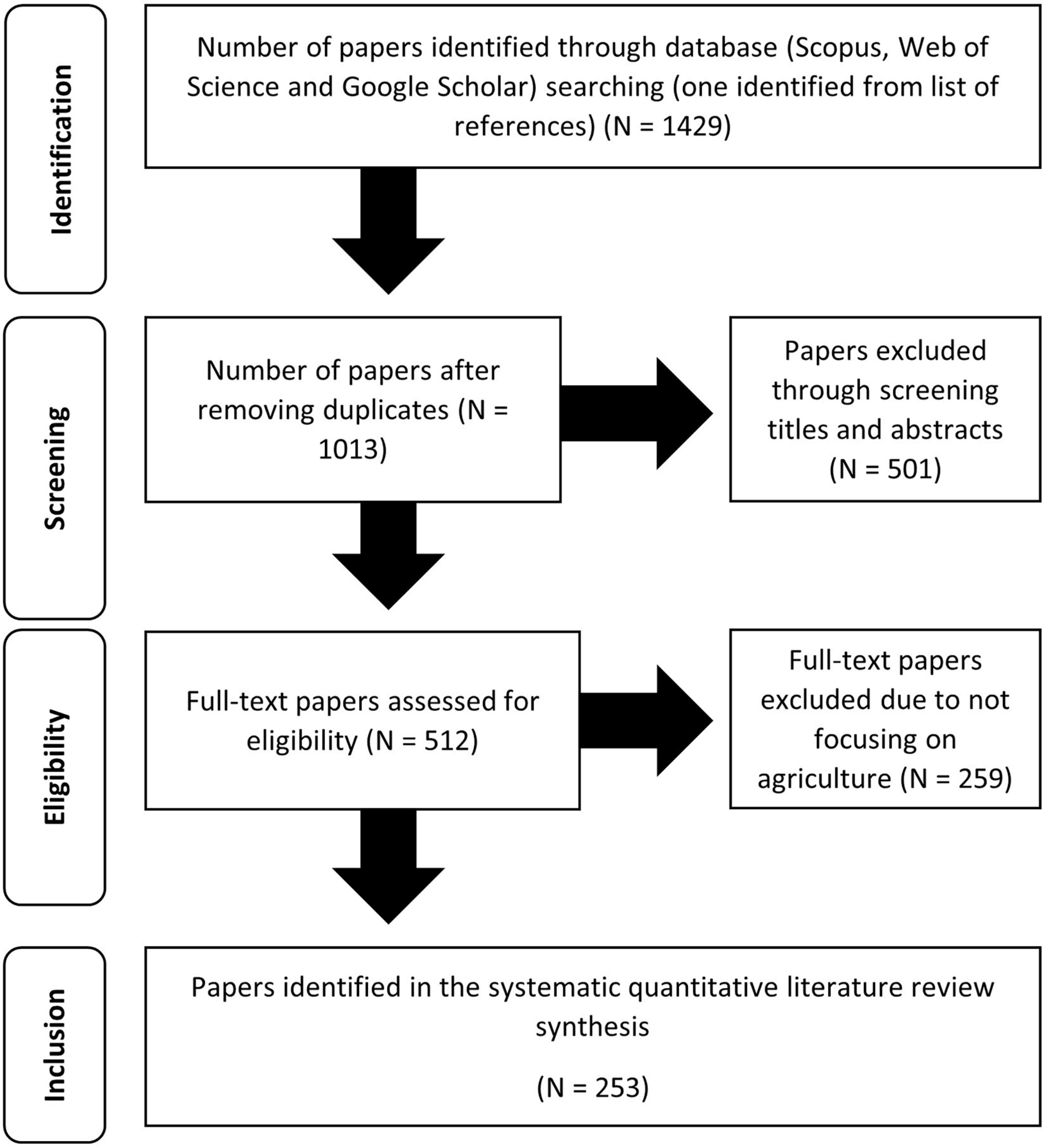

Fig. 1. Steps taken for the systematic quantitative literature review (adapted from Moher et al. 2009). N refers to the number of research papers.

Ntukamazina et al., 2017; Clement et al., 2018) but none have investigated if agricultural climate IBI research is being carried out in the countries that may need it the most. More generally, reviews on financial protection (of which insurance is one component) have consistently identified disparities between countries, highlighting a lack of data and assistance in those countries that have the highest need (Croppenstedt et al. 2018; Hazell and Varangis, 2019). Our review is global in scale and so we believe will be useful for researchers, policymakers and international organizations and development agencies working on agricultural climate IBI and help inform priorities about where insurance research and consequent insurance options may offer the greatest benefit.

2. Methods

2.1. Using a systematic quantitative literature review (SQRL) to assess global IBI scientific research

We carried out a systematic quantitative literature review (after Pickering and Byrne (2014)) to quantify the amount of agricultural IBI research that has been carried out in each country globally. The search terms used were: "index-insurance" OR "weather derivative" OR "parametric insurance" OR "weather insurance". Using these search terms, we retrieved all related peer-reviewed scientific publications from Scopus (n = 313), Web of science (n = 423) and Google scholar (n = 693) making a total of 1429 publications. From these 1429 publications all duplicates were removed, non-journal articles like books and working papers were removed, and the titles and abstracts were read, with only papers related to agriculture kept for further analysis. Other publications like reports and books were removed because they were not referred for reviews and may limit the extent of their reliability.

Similarly, we believe that although some initiatives might have taken place beside those captured in the journals, they may not be in the public space, hence the limitation of using journal articles as the basis of our metrics. In addition, where such publications exist, there is no designated database like Scopus and web of science for grey-literature on insurance.

Often current journal articles published in this space were based on previous practical initiatives, for example in Ethiopia and Kenya (Belissa et al., 2019; Chantarat et al., 2013) while some of them have been more of theoretical conjectures (Vedenov & Barnett 2004). We hope that future evaluation of agricultural climate IBI will address some of these limitations and capture projects that have been implemented but are not currently within the body of scientific literature.

Finally, although we used Google Scholar as part of our data search efforts, it was only a supplementary database to Scopus and Web of Science because it has been considered only as a supplementary database due to it's lack of the required reproducibility for a scientific research (Gusenbauer & Haddaway, 2020). That is, it returned different searches at different times for the same set of search terms. The main databases for systematic literature reviews are Scopus and Web of Science and these do not include grey literature. After the exclusion of grey literature and non-agricultural journals, we found 253 publications. The Preferred Reporting Items for Systematic Reviews and Meta – Analyses (PRISMA) is in Fig. 1 showing the process in arriving at the papers analysed in the study.

Each of the 253 publications was read and categorised as design, survey or review papers. Design papers are those where the author (s) designed agricultural climate IBI options based on data from sources like weather stations and satellites. The survey papers focused on the use of questionnaires and interviews to gather information about the perspectives of farmers on agricultural climate IBI. It should be noted that these survey papers were restricted to assessing the perspectives of farmers, with complementary perspectives of civil society organisations, local authorities, and respective agricultural ministries being absent in the literature. Finally, we classified review papers as those that did not carry out primary research.

2.2. Assessing global scale IBI research effort and mismatches

The 253 publications were categorized as follows; (1) climate risks (e.g. drought, flood, heat, humidity, cold and others), (2) crops assessed (categorized based on FAO's crop classification (FAO 2000) and (3) data sources used (satellite, station, modelled/grid or other) in each paper were documented. Within each grouping climate risk breakdowns for each of these categories (i.e. study type, crop assessed, and data source used) were then summed across all research papers to assess the amount of IBI research effort dedicated to each area within each climate risk group. When assessing research effort by climate risk review papers were not analysed because this would have led to duplication.

2.3. Mapping IBI research need based on indicators of climate risk, food insecurity and agricultural GDP and employment dependence

We assessed the amount of IBI research carried out in each country against four indicators that reflect the need of, or possible benefit that, IBI could have. The four indicators assessed were (1) climate risk (Eckstein et al. 2020), (2) food insecurity (The Economist Intelligence Unit 2018), (3) agricultural contribution to GDP (The World Bank 2020) and (4) agricultural contribution to employment (Roser 2013). These four indicators were chosen because they reflect the range of risks that IBI is purported to help farmers financially manage. The climate risk index reflects the level of exposure and vulnerability to extreme weather events (Eckstein et al. 2020). It measures the extent to which countries and regions have been historically affected by the impacts of climate-related events. The climate risk indicator is based on mortality rates, the sum of losses in US dollars in purchasing power parity, as well as losses per unit of Gross Domestic Product (GDP) resulting for extreme weather events. We investigated other possible indicators of climate risk, but these are all restricted to one risk (e.g. drought, such as the standardized precipitation index (SPI) and importantly are not linked to economic losses, which is a critical component to consider for climate risk insurance. Furthermore, the data did not capture projections on climate parameters, but we believe that future indices will do so. As such, at the moment the climate risk indicator from Eckstein et al. 2020 is, to the best of our knowledge, the most suitable global scale and inclusive standardized metric of economic climate risk.

However, we do acknowledge that in the future our approach should be tested alongside any newly developed climate risk metrics (including those that may account for shifts in risks under climate change) relevant for insurance.

Food insecurity was measured using the Global Food Security Index (GFSI), which is a composite of four core measures of food security namely affordability, availability, quality and safety and natural resources and resilience (The Economist Intelligence Unit 2018). It measures the risk to food security as a result of exposure to climate change and other natural resource challenges. Agricultural contribution to gross domestic product (GDP) measure is the value, as a percentage, agriculture adds to a countries GDP. It is the summed net output of a sector minus its intermediate inputs. No deductions for depreciation of fabricated assets or depletion are made (The World Bank 2020). Agricultural contribution to employment measures the percentage of employed persons in a country engaged in activities that produce agricultural goods (Roser 2013). We note that these indicators are not available in all countries and only serve as proxies. They are however amongst the best available standardized indicators widely available across most of the world's countries and so suitable for the global scale assessment carried out here.

Taking these indicators, we developed a score that reflects the relative need or benefit of IBI research. Countries with high values of an indicator (e.g. high climate risk), but little or no IBI research would receive a high IBI research need score, while those with low values (e.g. a low climate risk), but have had a lot of IBI research would receive the lowest IBI research need scores. Each indicator was standardized by its standard deviation, to allow comparisons across indicators, and divided by the number of IBI research papers in that country. For each indicator then IBI research need was assessed as;

$$IBIresearchneed_i = \frac{\left(\frac{x_i - \mu}{\sigma}\right)}{\sum p_i + 1}$$

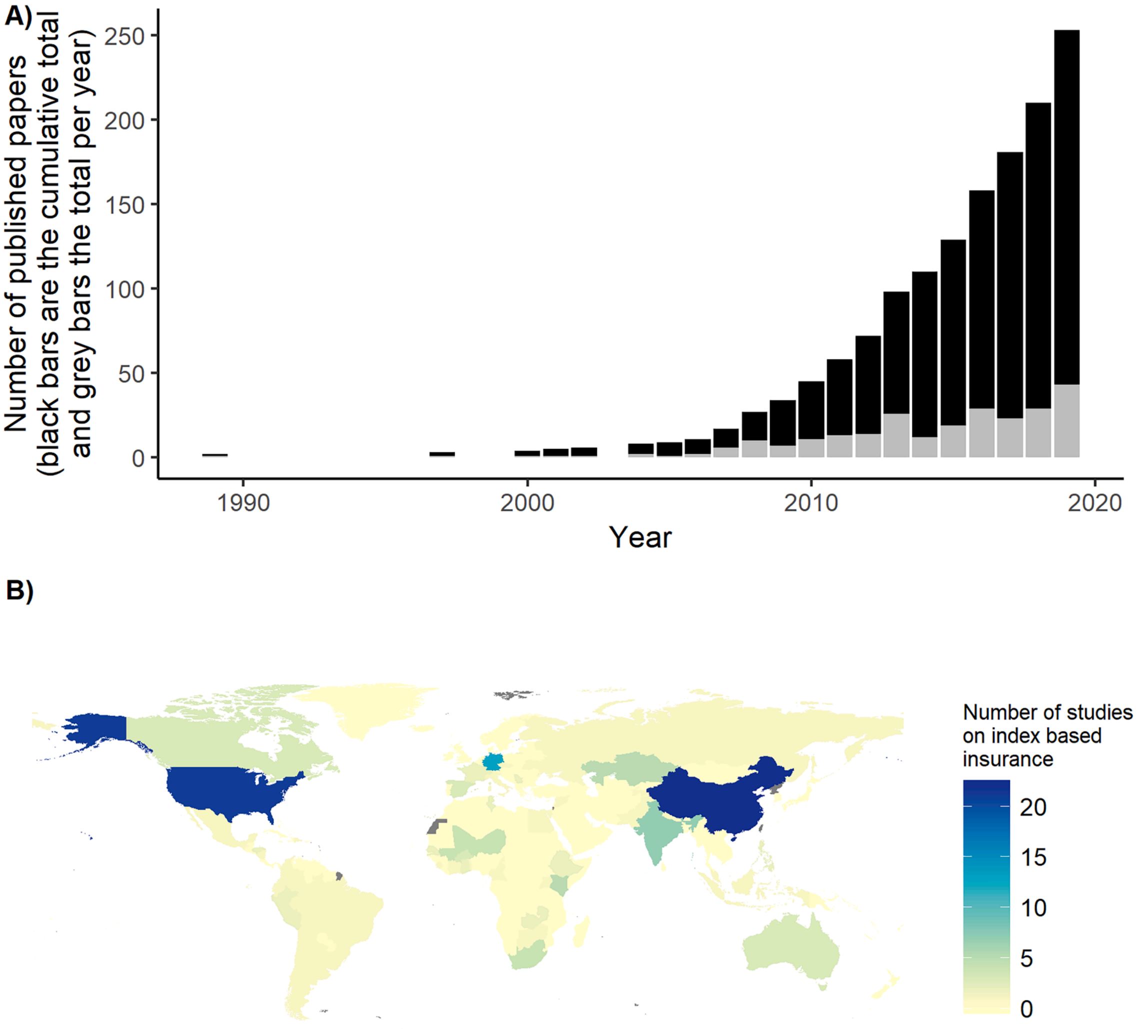

Fig. 2. (A) The number of publications on agricultural climate index-based-insurance per year and (B) the total number of papers across each country.

where x is the values of the indicator of interest for each country (i), μ and σ is the mean and standard deviation of the indicator and p is a research paper. The IBI research need for each indicator was then mapped globally to identify 'hot spots' of IBI research need globally.

2.4. IBI research need priority groupings

We carried out k-means clustering to identify groupings of countries that showed similarities in relation to each indicator (climate risk, food insecurity, agricultural GDP and employment dependence) as well as the amount of IBI research that has been undertaken. These groupings account for the fact that some countries may have related scores of each indicator (e.g. they may have high climate risk, high food insecurity and low IBI research). The groupings derived from this clustering thus represent clusters of similar countries around which research could be targeted. Missing data were removed from clustering resulting in a total of 96 country-level observations. The data were then rescaled so that large values did not bias the clustering. The optimal number of clusters was identified using the gap statistic method (Tibshirani, Walther, & Hastie, 2001). K-mean clustering with the algorithm of Hartigan and Wong (1979) is applied. The weightings of each variable in each group were optimized automatically. All analyses were carried out in R (R Core Team 2019)

3. Results

3.1. Agricultural climate index-based-insurance research is increasing exponentially, but unevenly spread across the world

Based on the 253 publications that were selected a sharp increase in the number of publications is evident from the year 2008 when

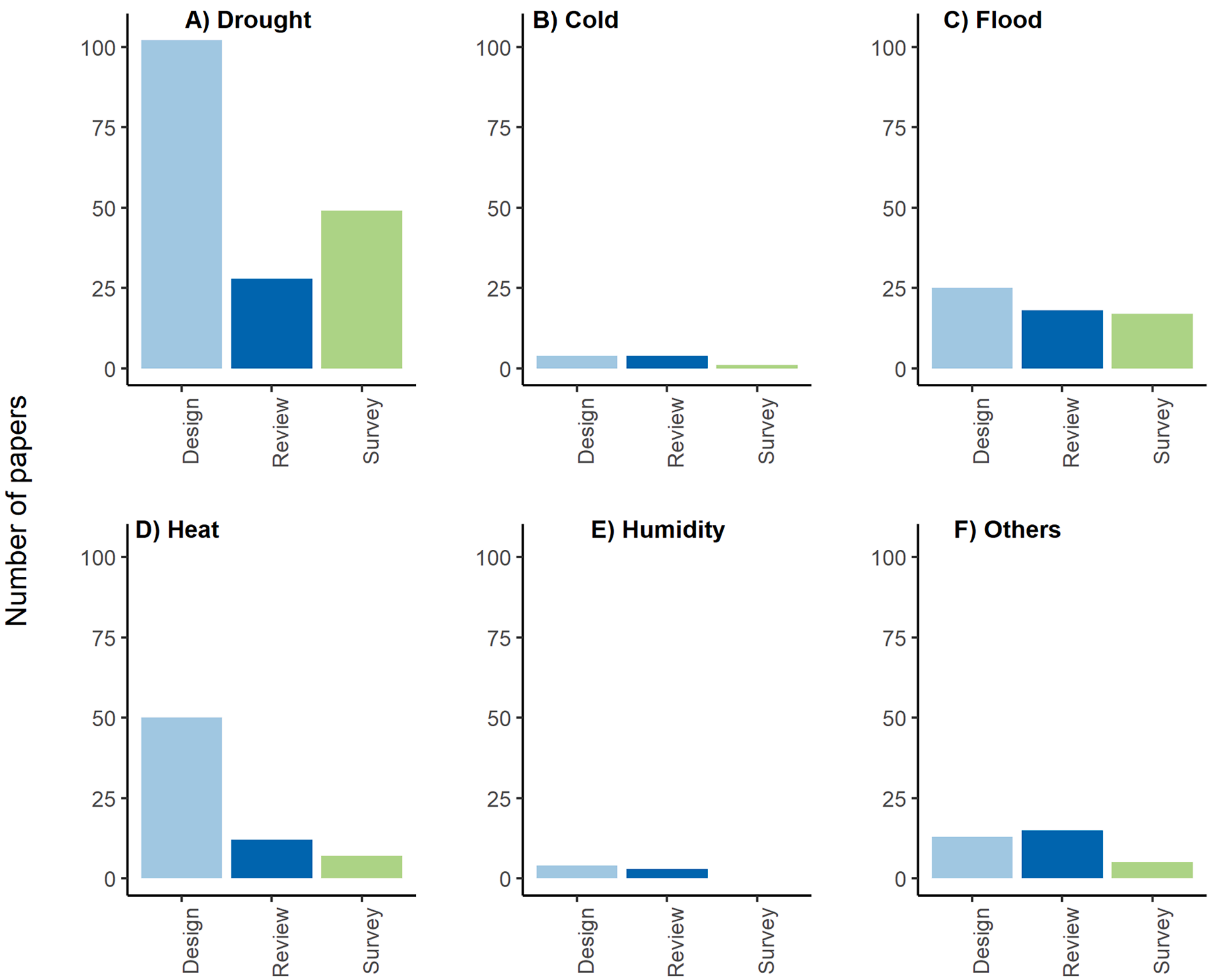

Fig. 3. The number of papers on agricultural climate index-based-insurance for each of the climate risks assessed. The "Others" category includes risks such as cyclones, storms and hail.

the number of published articles on agricultural climate IBI entered the double digits (n = 10). Over 90% of publications have occurred since 2008 (Fig. 2A). The steep rise in the number of publications considered in this study (32.14% growth rate per annum) from 2008 to 2019 is a demonstration of the increasing interest in agricultural climate IBI as a tool for managing the financial consequences of climate variability and change on agriculture.

IBI research has been concentrated in a few countries (Fig. 2B). China and the United States of America account for the majority of research with 31 and 29 publications respectively. India has also seen a recent surge in research on agricultural climate IBI with 25 publications, as has Germany and Kenya with 18 publications each. Although, it should be noted that the type of research between these countries is not even (e.g. Germany has more empirical papers, while Kenya is dominated by survey type papers). Most other countries have little (<5 papers) to no research on agricultural IBI (Fig. 2B). The literature counts were done by counting the specific country where data was collected for the publication. Where multiple countries were involved, all countries were counted. However, where the publication is a literature review, we did not consider it in the count because it is based on publications that have already been counted.

3.2. *Most agricultural climate index-based-insurance research has focused on drought risk*

The majority of IBI research has focused on drought risks to agriculture, accounting for over 50% (n = 179) of studies (Fig. 3A). Studies on heat and flood risks were the next most prevalent, making up 20% and 17% of all studies respectively (Fig. 3). Studies on cold, humidity and other hazards (i.e. storm, hail, etc.) were less common and collectively accounted for the remaining 13% of studies. Across all the risk categories design papers were the most common (56%), followed by review (22%) and survey (22%) papers (Fig. 3). The prevalence of drought studies is not surprising because it is the most significant risk farmers face relative to other risks (Lesk et al. 2016).

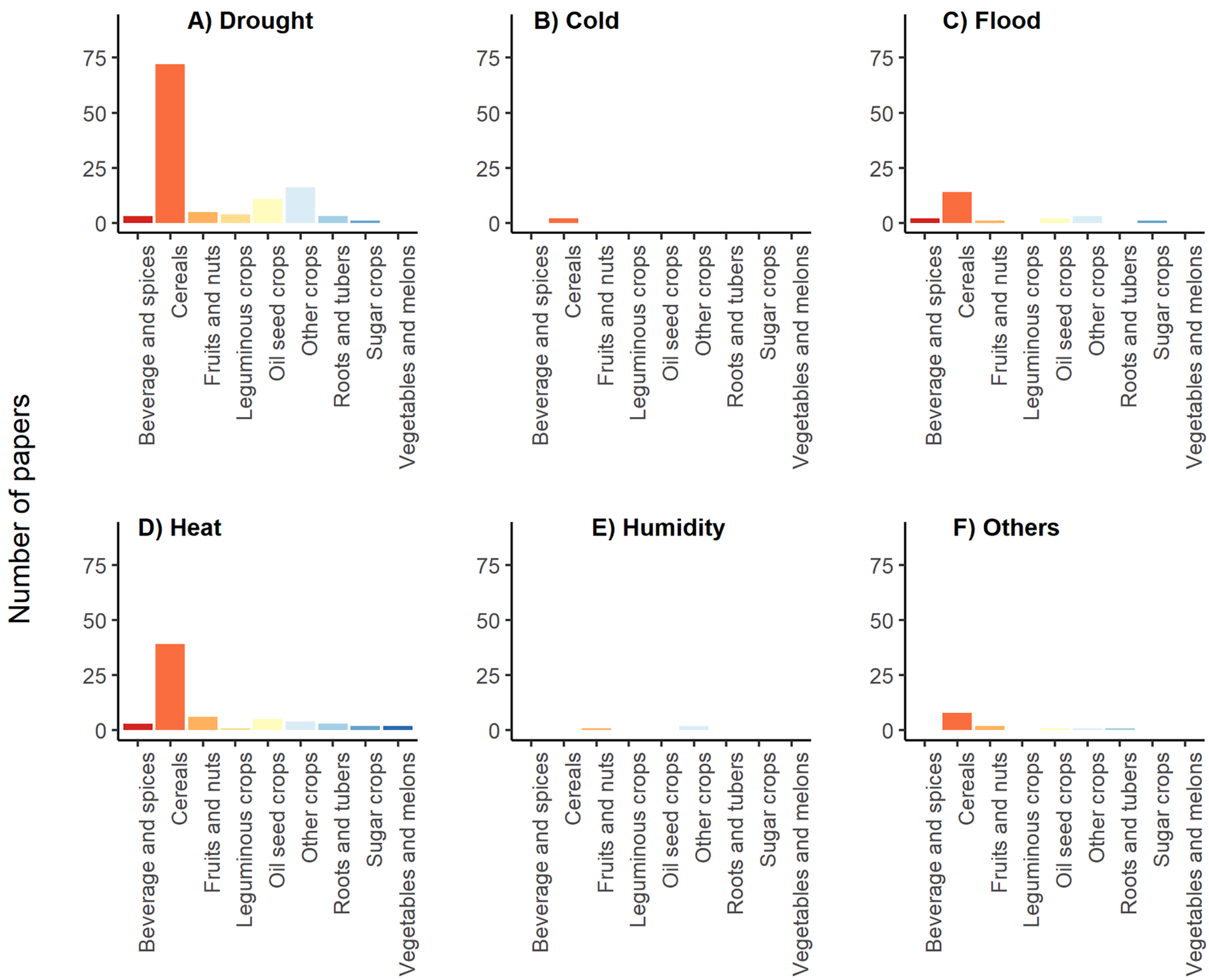

Fig. 4. The number of papers on agricultural climate index-based-insurance for each of the climate risks assessed across major crop groupings (based on FAO classifications). The “Others” category includes risks such as cyclones, storms and hail.

3.3. Cereals dominant in agricultural climate index-based-insurance research

Over 60% (n = 135) of all agricultural climate IBI studies focused on cereals. Within cereal-based studies, 53% (n = 72) are focused on drought risk (Fig. 4A). These cereal studies were predominantly on wheat (n = 29) and maize (n = 19). Cereals dominated the studies in agricultural climate index insurance across all the risk types as could be seen in Fig. 4. For studies focusing on drought, 62.61% (n = 72) were based on cereals like wheat and maize. The two studies based on cold risk were focused on cereals All two studies based on cold risk were on cereals but no study on humidity was on cereals rather on fruits and nuts (1) and other crops (2). For studies based on heat, there were 60% (N = 65) on cereals, fruits and nuts 9.23% (N = 6) followed by five studies on oilseed (7.69%). Cereals equally dominated the flood risk categories with 60.87% (N = 14) of all crops in the risk category being cereals. Oilseed and beverage crops (coffee and cocoa) were 8.70% (N = 2) in each case. Other crops were 13.04% (N = 3) while fruits and nuts were 4.35% (N = 1).

3.4. Agricultural climate index-based-insurance relies largely on point level station-based weather data

Three-quarters of all studies utilized weather station data (n = 144) (Fig. 5). Satellite and other sources of data were the next most used data sources accounting for 10% and 12% of agricultural climate IBI studies respectively. Across all risk types, gridded/modelled climate datasets were only used in 4 studies (Fig. 5).

Of the drought studies, seventy percent (n = 70) were based on data from weather stations (Fig. 5A). Satellites (16%), other data sources, such as irrigation water flow (11%) and modelled data (2%) were the data sources used in the remaining drought studies. Proportions were similar across other risk types. Flood studies had data from weather stations (n = 17, 65%), modelled (n = 1, 4%), satellite (n = 3, 12%) and other sources (n = 5, 19%) (Fig. 5). For studies on heat, 98% (n = 45) of papers were based on data collected from weather stations with only one study using data from satellites. The four publications on humidity were based on weather station data.

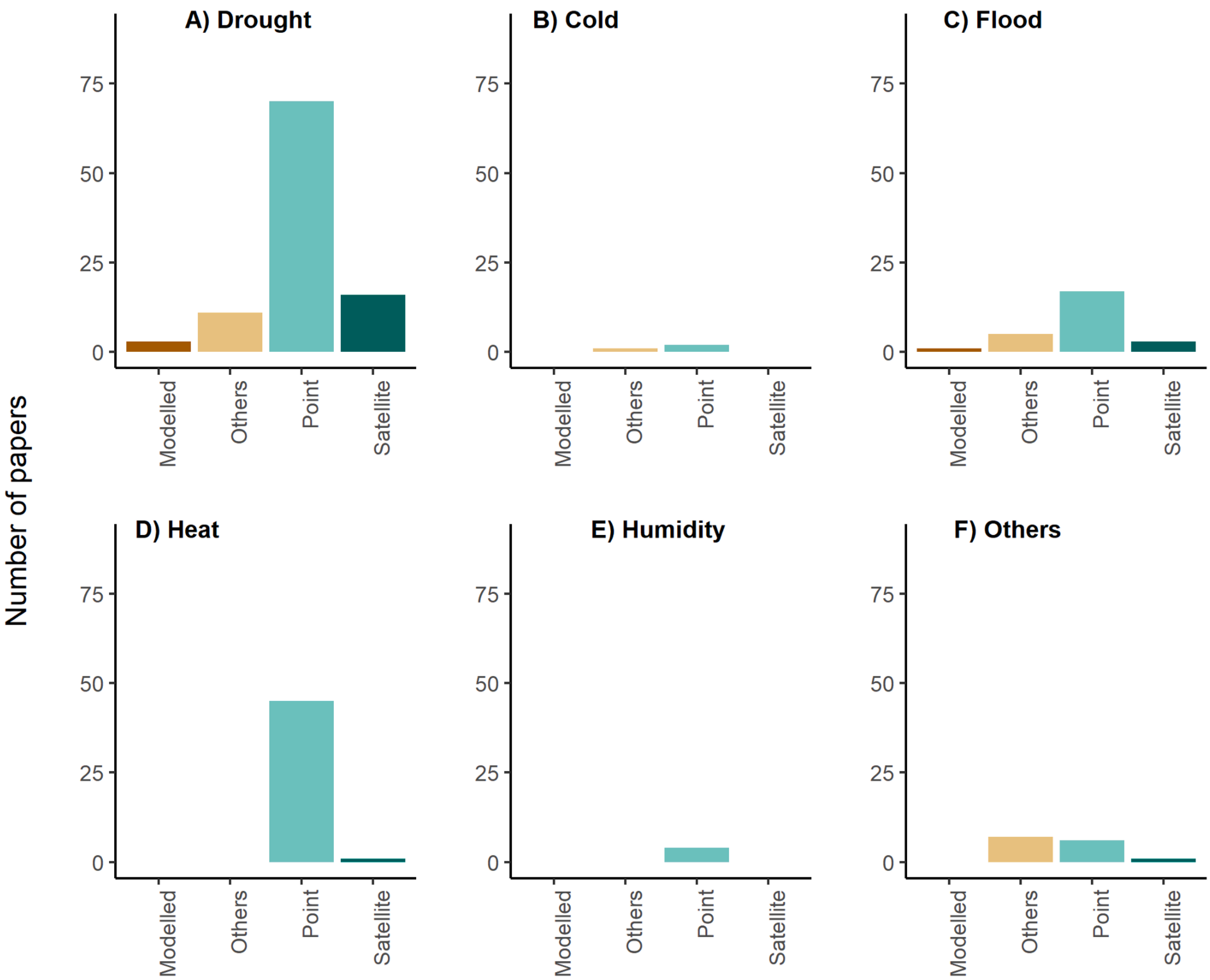

Fig. 5. The number of papers on agricultural climate index-based-insurance for each of the climate risks assessed across different data sources. Point data refers to data from on-ground weather stations). The "Others" climate risk category includes risks such as cyclones, storms and hail.

3.5. Many countries with high climate risk, food insecurity and/or a high dependence on agriculture have no agricultural climate index-based-insurance research

When taking into account climate risk, food insecurity and dependence on agriculture there are clear inequalities, or mismatches, in how agricultural climate IBI research is distributed globally (Fig. 6). Countries with high levels of climate risk have little to no IBI research and as such have the highest IBI research needs based scores – shown as orange or red and with a score > 1 (Fig. 6A). IBI research needs in relation to climate risks are high for Caribbean, Central American and Southeast Asian countries (e.g. Haiti, El Salvador, Myanmar), but is also high for countries in southern Africa (e.g. Mozambique), and the Middle East (e.g. Afghanistan) (Fig. 6A).

When looking at food insecurity IBI research was also unevenly distributed, with countries at highest risk often receiving no or little research (Fig. 6B). Based on the food insecurity index IBI research needs are concentrated in and around central Africa, with Burundi and Democratic Republic of the Congo showing the highest IBI research needs score (Fig. 6B). Other countries with a high IBI research need based on food insecurity included Madagascar, Yemen and Chad (Fig. 6B).

Countries in Africa also had the highest IBI research need scores when considering agricultural contribution to GDP and employment (Fig. 6C & D). Guinea-Bissau had the highest scores based on agricultural GDP (Fig. 6C), while Burundi has the highest need when looking at agricultural employment (Fig. 6D). Outside of Africa, the relative need for IBI research based on agricultural contribution to GDP and employment was low, except for Papua New Guinea which also had a relatively high IBI research need score based on agricultural employment (Fig. 6D).

3.6. Research groupings and priorities based on country level clustering

Six discrete clusters, or groupings, were identified based on the climate risk, food insecurity and agricultural dependence indicators we assessed (Fig. 7, Table 1). Cluster 4 is dominated by African countries with high dependence on agriculture in terms of percentage of employment in agriculture and contribution of agriculture to GDP. They also have relatively low food security and a moderate climate risk. It should however be noted that the benchmarks for these classifications were the lower quartiles (Low), interquartile range (Moderate) and upper quartile (High) for each of the variables as could be seen in Appendix 1. Although, the countries in Cluster 4 had 1.64 papers on average, it is based on the average of those countries in the cluster that had complete data available, but the benchmarks were calculated based on the overall data for each variable. Cluster 5 showed similar characteristics to Cluster 4 but it has a high climate risk with a moderate amount of publications.

When the risk levels of Cluster 4 are compared with Cluster 6 in the Table 1, it is evident that they were reasonably moderate, but the number of papers were much higher than those from all the other clusters. Cluster 6 countries are not shown in the graph because it is an outlier in terms of the number of publications and it's presence in the graph makes the other five clusters unclear. The first three clusters had moderate risks in terms of food security and dependence on agriculture as well as moderate number of publications. However, climate risks are high in Cluster 3, moderate in Cluster 1 (which is dominated by European countries) and low in Cluster 2

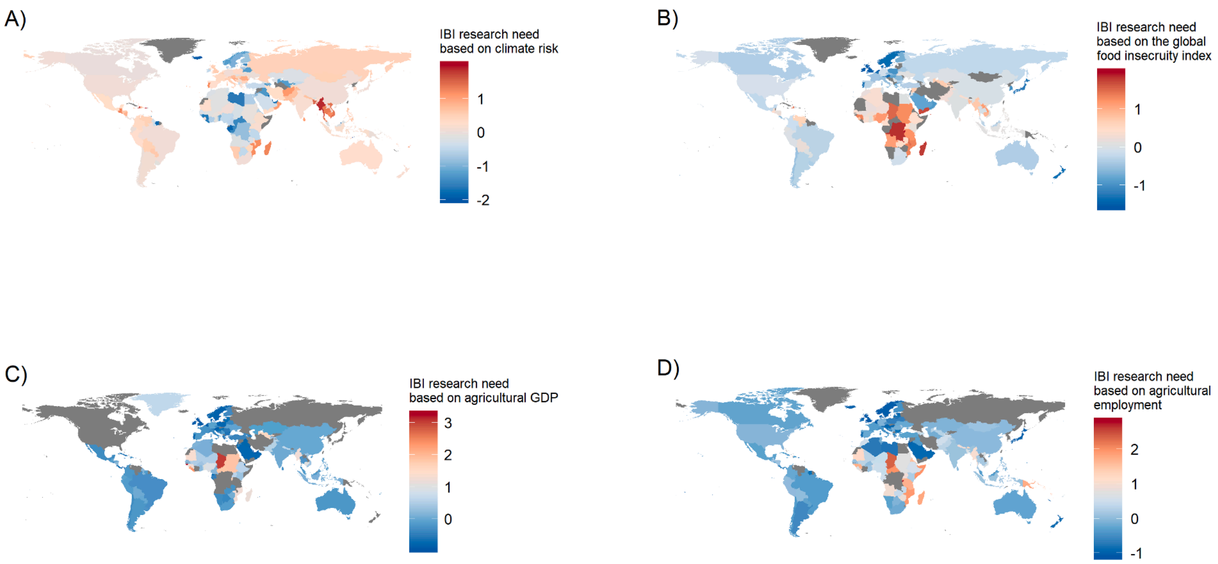

Fig. 6. Global research needs for index-based-insurance based on the number of publications and four different indicators (see section 2.3 for method details) related to the potential benefit the index-based-insurance could have. (A) Climate risk (Eckstein, Künzel et al. 2020), (B) Food insecurity (The Economist Intelligence Unit 2018), (C) Agricultural contribution to GDP (The World Bank 2020) and (D) Agricultural contribution to employment (Roser 2013).

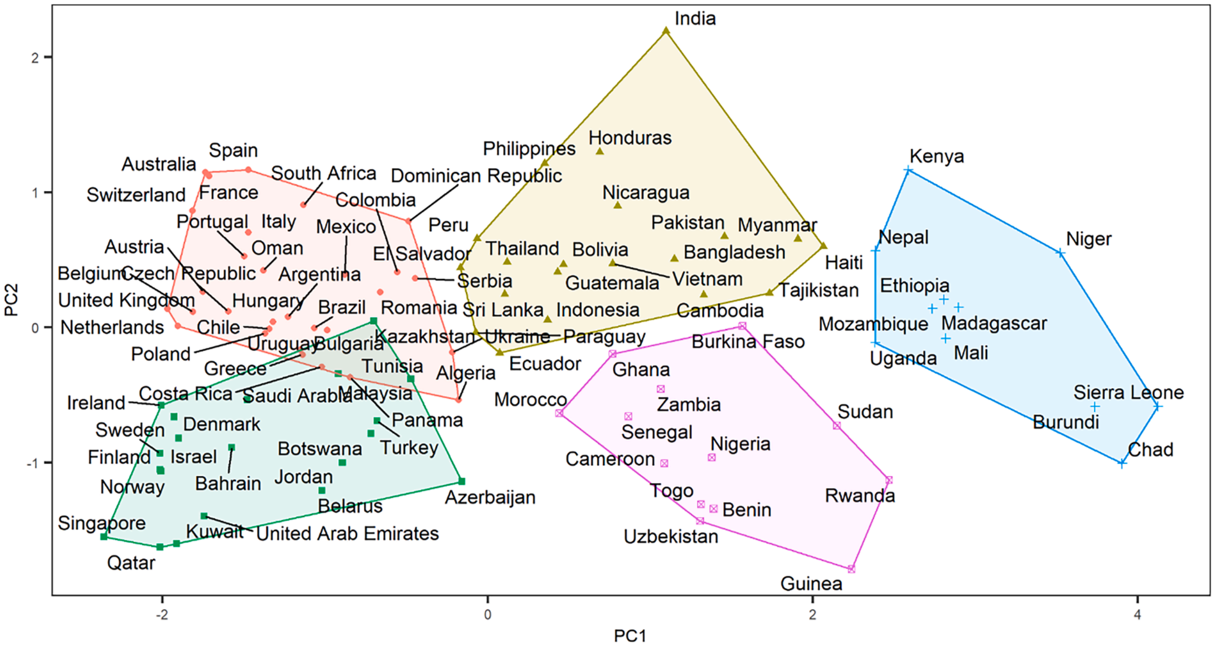

Fig. 7. 6-Mean clustering without a specific weighted variable (see section 2.4 for method details). The plot shows the first and second principal components (PC1 and PC2) of five clusters. Good grouping results where all groups are distinguished from each other. The weightings of each variable in each group were optimized automatically. Note Germany and China, which both have exceptional high numbers of research articles are not shown.

Table 1
Countries within each of the clusters and their associated characteristics and mean number of index-based insurance (IBI) research papers. See Fig. 7 for clusters.

*Cluster	Mean by cluster IBI papers	CRI Score	GFSIIn percentage	Agricultural GDP as % total GDP	Percentage of citizens employed in agriculture	Countries
1	0.87 Moderate	68.61 Moderate	71.83 Moderate	3.63 Moderate	7.76 Moderate	Algeria, Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Czech Republic, Dominican Republic, France, Greece, Hungary, Italy, Mexico, Netherlands, Oman, Panama, Poland, Portugal, Romania, Serbia, South Africa, Spain, Switzerland, Ukraine, United Kingdom, Uruguay
2	0.95Moderate	39.69 Low	50.40 Moderate	13.40 Moderate	33.40 Moderate	Bangladesh, Bolivia, Cambodia, Ecuador, El Salvador, Guatemala, Haiti, Honduras, India, Indonesia, Myanmar, Nicaragua, Pakistan, Paraguay, Peru, Philippines, Sri Lanka, Tajikistan, Thailand, Vietnam
3	0.50 Moderate	135.26 High	71.76 Moderate	3.00 Moderate	8.08 Moderate	Azerbaijan, Bahrain, Belarus, Botswana, Denmark, Finland, Ireland, Israel, Jordan, Kazakhstan, Kuwait, Malaysia, Norway, Qatar, Saudi Arabia, Singapore, Sweden, Tunisia, Turkey, United Arab Emirates
4	1.64 High	69.76 Moderate	35.24 Low	34.00 High	70.38 High	Burundi, Chad, Ethiopia, Kenya, Madagascar, Mali, Mozambique, Nepal, Niger, Sierra Leone, Uganda
5	0.85 Moderate	122.44 High	41.14 Low	21.00 High	42.36 High	Benin, Burkina Faso, Cameroon, Ghana, Guinea, Morocco, Nigeria, Rwanda, Senegal, Sudan, Togo, Uzbekistan, Zambia
6	17.5 High	48.08 Low	73.90 Moderate	3.98 Moderate	13.91 Moderate	China, Germany

(dominated by Asian countries).

Some countries like USA, Malawi and Mongolia are missing in Fig. 7 and Table 1 because the data sets used for the cluster analysis were not complete for them

4. Discussion

We carried out a systematic quantitative literature review on agricultural climate IBI globally to assess (1) what climate risks, crops and data sources have been examined, and overlooked in agricultural climate IBI research to date and (2) to investigate possible systemic biases in where agricultural climate IBI research has been undertaken so as to identify what countries would benefit most from future agricultural climate index research. In total we surveyed 253 scientific publications which covered 62 countries and 42 different crops. The overwhelming majority of studies focused on drought and cereals. Most studies were also in countries (e.g. Germany, USA and China) with levels of climate risk, food insecurity and economic dependence on agriculture that are at the lower end of the distribution across the other countries we assess. In contrast, countries with the highest levels of climate risk, food insecurity and economic dependence on agriculture had little to no research into agricultural climate IBI. Current published research has largely overlooked climate risks and different crops, aside from drought and cereals, and is not being undertaken in countries that may benefit the most from agricultural climate IBI research.

4.1. Agricultural climate insurance research has mostly focused on drought, but other climate risks are also important

Over sixty percent of agricultural climate IBI studies we surveyed focused on cereal crops. This is not unexpected given the importance of cereal crops (e.g. rice, wheat, maize) for world food supply and in terms of how widely they are grown (e.g. maize is one of the most widely grown crops in the world, Aguiar et al. 2020). Relatively, speaking the effects of climate on cereals, such as drought, have also been well studied and quantified globally (Ray et al. 2015, Lesk et al. 2016) and in detail for several regions and countries (Welch et al. 2010). This provides a strong information base and justification from which to investigate agricultural climate IBI options for cereal crops.

While cereals, such as maize, rice and wheat are undeniably important crops there are numerous other crops that are also of great importance and sensitive to climate but have had little to no agricultural climate IBIresearch. Plantain, numerous root and tuber crops (e.g. yam and cassava) as well as a range of economically important beverage and spice crops, such as tea, pepper and coffee are of great socio-economic importance for millions of farmers globally, yet we find no evidence of agricultural climate IBI research for these crops. The risks of adverse climatic events on these crops are well documented (coffee, Kath et al. (2020); tea, Nowogrodzki (2019) cassava, Brown et al. (2016), root crops and banana, Adhikari et al. (2015)). Our results suggest there is a clear need for agricultural climate IBI to be carried out for these and other overlooked crops.

Reflecting the focus on cereals, the majority (over 70%) of agricultural climate IBI has focused on the risks most important for these crops – namely drought and heat stress. Although, it should be noted that the effects of extreme rainfall events on cereal crop production are also well documented in many parts of the world (e.g. maize, Li et al. 2019). Agricultural climate IBI on risks important for non-cereal crops, such as excess rainfall, flooding, cyclones and hail events are largely absent from the literature. Our findings suggest there is a need for agricultural climate index researchers to cover a broader range of crop types and risks beyond the current focus on drought, heat and cereals.

4.2. Research has largely relied on station data, but satellites could offer many benefits

Another notable bias in agricultural climate IBI unearthed by our systematic review was the overwhelming use of station data. However, this is changing as access to satellite data and modelled datasets improves over time (Brahm et al. 2019). The use of satellite data could be particularly advantageous for agricultural climate IBI in developing countries, which often lack extensive and long-term station data (Miranda & Farrin 2012). With satellite and modelled/gridded data becoming more widely available, research in countries that have been overlooked by researchers due to a lack of climate data, will become more viable. An example of the use of satellite data in building resilience to climate risk where station data may be lacking, is the African Risk Capacity project, which uses Africa Risk View, an advanced satellite weather surveillance and software developed by the UN World Food Programme (WFP).

Additional to making research more viable in a wider range of countries the use of satellite data could allow a greater range of risks to be quantified more accurately and thus allow a greater range of agricultural climate IBI options to be investigated. Satellite measurement for excess rainfall, flooding, storms, hail and cyclones is well advanced globally (Liu et al. 2019). Researchers have also shown some advantages of these satellite measurements in the context of designing climate risk insurance (Mendelsohn et al. 2007). Consequently, a shift towards the more widespread use of satellite data could help foster agricultural climate index research in many developing countries where a lack of station-based records has hampered research in the past.

4.3. There is a mismatch between agricultural climate insurance research and country level climate risk & food security

The historical focus on cereal crops and drought risk coupled with the use of station data has also been associated with clear geographical biases on where agricultural climate index research has been undertaken. Relatively well-developed countries (Germany, China, India and the United States) with large proportions of cereal production and station data have been the overwhelming source of most agricultural climate index-based-insurance studies (averaging over 20 papers in each country). The exceptions to this are Kenya and Ethiopia where extensive research on pasture IBI using satellite data for livestock has been undertaken (Chantarat et al. 2013, Hochrainer-Stigler et al. 2014). The presence of Kenya in Cluster 4 therefore increases the number of publications for the countries in the cluster in comparison to the other countries. Outside of these countries, agricultural climate IBI has been non-existent for most developing countries like Burundi.

The geographical disparity in agricultural climate IBI has important consequences for many countries, particularly those at high climate risk, low food security and high dependence on agricultural production. We identified thirteen countries as having high climate risk index, low food security and highly dependent on agriculture (Please see Table 1 – Cluster 5), Benin, Guinea, Morocco, Rwanda, Sudan and Uzbekistan had no publication on the application of agricultural climate index-based insurance in agriculture based on our search, however, they may have some other forms of agricultural risk management options. In Cambodia alone, floods in 2011damaged up to 10% of all rice fields and led to agricultural losses in the vicinity of $180 million USD (ADB, 2012). Most, if not all of these losses are likely to have been uninsured, with the potential benefit or otherwise of insurance in helping Cambodian farmers cope with such flood disasters yet to be investigated. Our results suggest these high-risk countries identified by this review (Please see Fig. 7 and Table 1 particularly Clusters 3 to 5) should be the highest priority for future agricultural climate IBI research.

Furthermore, Burundi in Cluster 5 has a moderate climate risk index but food security is evidently low with a high dependence on agriculture. The high dependence on agriculture could mean that climate events impact on agricultural production could have disproportionately large consequences for such countries. For example, 92% of total employment in Burundi is based on agriculture, therefore climate events that impact production could have disproportionally large consequences (Roser 2013). Again, and despite, Burundi's high dependence on agriculture we found no research on agricultural climate index-based insurance. We would argue therefore that these countries should also be seen as a high priority for future agricultural climate index-based insurance research. We however do not presume that these countries have no agricultural climate risk management strategies in place, however, given the failure of multiple peril crop insurance that is often subsidized in western countries, the move towards agricultural climate index-based insurance, particularly in developing countries, remains a viable option.

4.4. Implications: What is the role of global initiatives in insurance on driving IBI research to address potential 'mismatches'?

Governments and global aid agencies have recognised the important role of insurance in building resilience, sustainable growth, and societal welfare, especially in developing countries. As a result, a number of global insurance initiatives and facilities have been established. For example, The World Bank has set-up the Global IBI Facility (GIIF), which facilitates access to finance for smallholder farmers, micro-entrepreneurs, and microfinance institutions through the provisions of catastrophic risk transfer solutions and agricultural climate index-based insurance in developing countries as well as a forum for the collection of best practices and practical experiences. Similarly, the InsuResilience Investment Fund by InsuResilience Global Partnership (IGP), which was established by KfW, the German Development Bank, on behalf of the German Ministry for Economic Cooperation and Development (BMZ), aims to contribute to the adaptation to climate change by improving access to and the use of insurance in developing countries. Also, there are other important programs and initiatives, such as Munich Climate Insurance Initiative (MCII), the United Nations Environment Programme Finance Initiative (UNEP FI). IGP promotes the scaling up of agricultural climate index-based insurance and disaster risk finance through an inclusive, global, multi-stakeholder governance, comprising many programmes, including GIIF, IIF and many more. There is also the UNDP Insurance and Risk Financing Facility and more recently, the Asia-Pacific Climate Finance Fund (ACliFF), a multi-donor trust fund established with the financial support of the German government. The ACliFF supports the development and implementation of financial risk management products, which can help facilitate capital for climate investments and enhance resilience to the impact of climate change. In addition, the International Fund for Agricultural Development's (IFAD) programs on insurance, and other similar initiatives aim to improve resilience of poor rural people.

Our analysis shows that several of the aforementioned projects and initiatives have been implemented in countries with high agricultural IBI research needs based scores, for example, countries with high levels of climate risk have little to no IBI research (Fig. 6A), such as Kazakhstan, Norway and Tunisia. Whether the lack of peer-reviewed research on IBI research undermines the effectiveness of such projects remains to be seen. Importantly, we also show that there is a notable lack of attempts (and projects) for other countries with the same high agricultural climate index-insurance research need scores like Mozambique and Burundi. Moreover, some projects were conducted in countries where the IBI research needs were not in the priority, countries with needs-based scores equal to or less than zero. Examples include the 'Investigating the Feasibility of Municipal Risk Pooling as an Adaptation Finance Measure (MuRP)' in South Africa (MuRP), ECA in Ethiopia, or the Advancing Climate Risk Insurance Plus in Barbados, China, Ghana and Morocco (ACRI +), among others.

The aforementioned projects coupled with the commercialization and intellectual aspect of the IBI product design and establishment of insurance programs and publication of research consequences are often potholed against each other as if they were mutually exclusive options. This implies that a large volume of high-quality research is not available for generating knowledge and public benefits. Furthermore, as a limitation of the PRISMA approach, we did not review technical reports.

We acknowledge the limitation of our study in that we used academic journals only. Academic literature is not required to develop agricultural IBI programs. However, academic research, which is lacking in some high-risk countries and crucial for wider uptake, is necessary for a better understanding (quantifying) of the risks and impacts, to, for example, examine the performance of the indices (e.g. income smoothing effects at different trigger rates), allowing for the building of the credibility and transparency of the agricultural IBI products/program (see Vedenov and Barnett, 2004). While some commercial-in-confidence (and grey literature) may not be available easily, academic research builds knowledge, facilitating learning, and increases public awareness, which is crucial for building stakeholders' confidence in insurance schemes in order to develop more innovative agricultural IBI programs, and produce new data, which may otherwise be unavailable.

Additional to this, while there may be research existing outside of academia (e.g. in private consulting firms and insurance companies) this research is largely inaccessible to the communities that need it most – in this case countries at high climate risk, where there is little or no evidence of publicly available peer-reviewed research that could help inform them about the benefits, or otherwise, of index insurance for helping manage the economic impacts of climate risk. To this end we believe that the FAIR guiding principles for scientific data and stewardship (Wilkinson et al. 2016) could play an important role in making research on IBI that is currently largely inaccessible more widely available. If data and research on agricultural IBI not currently available in the scientific literature or in searchable databases was made more widely available than this of course would allow for a more holistic assessment of the mismatch between agricultural IBI research and climate risk globally. We believe that Multiple Peril Crop Insurance (MPCI) may be available in some of these countries but given the limitations of MPCI and its' failure and recent trends in the acceptance of agricultural climate IBI, we believe that this study is worthwhile.

Finally, as pointed out by Cole and Xiong (2017), it may be too early to investigate deeper, welfare-related questions since both developed and developing countries have rarely achieved high take-up without substantial government subsidies. In addition, such analysis requires a large sample of farmers over a long time period to build convincing evidence of income smoothing effects; data collection just for this purpose is quite costly. It is thus perhaps not surprising that there has been very little research on these topics as we have aimed to carry out in this study which we consider as a major step forward in the evaluation of agricultural climate index-based insurance across the globe. One notable exception is the work of Mobarak and Rosenzweig (2014), who estimate the general equilibrium labour market effects of randomly offering rainfall insurance to both cultivators and agricultural wage laborers in rural India. A point to note is that Cole and Xiong (2017) were largely focused on broader agricultural insurance, not agricultural climate index-based insurance in particular. Hence, we believe future researchers will consider the effectiveness agricultural climate IBI.

4.5. Conclusion

Our analyses indicated that the recent rapid increase in agricultural climate index-based insurance research is lacking in countries with the highest need. Several countries at high risk based on four indicators, have had no agricultural climate index-based insurance research undertaken, nevertheless, we acknowledge that they may have other strategies in place, but our aim is to evaluate the use of agricultural climate IBI which has been considered as a major risk management option for agricultural risk management. Further, research to date has largely focused on cereal crops and drought risk, which while important, only represent a fraction of the crops and climate risks that agricultural climate IBI could be beneficial in helping to manage. Our analysis provides evidence-based recommendations for which countries should be focused on to redress the current disparities in agricultural climate IBI research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1:. Percentile cut-offs for the number of publications and risk metrics.

Low	Moderate	High
CRI ≤ 56.96	56.96 < CRI ≤ 120.67	CRI > 120.67
GFSI ≤ 42.3	42.3 < GFSI ≤ 74.4	GFSI > 74.4
GDP ≤ 2.22	2.22 < GDP ≤ 14.62	GDP > 14.62
EMP ≤ 5.01	5.01 < EMP ≤ 41.17	EMP > 41.17
PPS = 0	0 < PPS ≤ 1	PPS > 1

References

Adhikari, U., Nejadhashemi, A.P., Woznicki, S.A., 2015. Climate change and eastern Africa: a review of impact on major crops. Food Energy Secur. 4 (2), 110–132.
Aguiar, S., Texeira, M., Garibaldi, L.A., Jobbágy, E.G., 2020. Global changes in crop diversity: Trade rather than production enriches supply. Global Food Secur. 26, 100385. https://doi.org/10.1016/j.gfs.2020.100385.
Asian Development Bank, 2012. Flood Damage Emergency Reconstruction Project (RRP CAM 46009) Asian Development Bank Flood Damage Emergency Reconstruction Project Preliminary Damage and Loss Assessment March 2012.
Bandara, J.S., Cai, Y., 2014. The impact of climate change on food crop productivity, food prices and food security in South Asia. Econ. Anal. Policy 44 (4), 451–465.
The World Bank, 2020. Agriculture, forestry, and fishing, value added (% of GDP). accessed 30 March 2020. https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/
.
Barnett, B.J., Mahul, O., 2007. Weather index insurance for agriculture and rural areas in lower-income countries. Am. J. Agric. Econ. 89 (5), 1241–1247.
Barnett, J., Dessai, S., 2002. Articles 4.8 and 4.9 of the UNFCCC: adverse effects and the impacts of response measures. Climate Policy 2 (2-3), 231–239.

Belissa, T., Bulte, E., Cecchi, F., Gangopadhyay, S., Lensink, R., 2019. Liquidity constraints, informal institutions, and the adoption of weather insurance: A randomized controlled Trial in Ethiopia. J. Dev. Econ. 140, 269–278.
Binswanger-Mkhize, H.P., 2012. Is there too much hype about index-based agricultural insurance? J. Dev. Stud. 48 (2), 187–200.
Brahm, M., Vila, D., Martinez Saenz, S., Osgood, D., 2019. Can disaster events reporting be used to drive remote sensing applications? A Latin America weather index insurance case study. Meteorol. Appl. 26 (4), 632–641.
Brown, A.L., Cavagnaro, T.R., Gleadow, R., Miller, R.E., 2016. Interactive effects of temperature and drought on cassava growth and toxicity: implications for food security? Glob. Change Biol. 22 (10), 3461–3473.
Carter, M., de Janvry, A., Sadoulet, E., Sarris, A., 2017. Index insurance for developing country agriculture: a reassessment. Ann. Rev. Resour. Econ. 9 (1), 421–438.
Chantarat, S., Mude, A.G., Barrett, C.B., Carter, M., 2013. Designing index-based livestock insurance for managing asset risk in northern Kenya. J. Risk Insur. 80 (1), 205–237.
Clement, K.Y., Wouter Botzen, W.J., Brouwer, R., Aerts, J.C.J.H., 2018. A global review of the impact of basis risk on the functioning of and demand for index insurance. Int. J. Disaster Risk Reduct. 28, 845–853.
Collier, B., Skees., Barnett, B., 2009. Weather index insurance and climate change: opportunities and challenges in lower income countries. The Geneva Papers on Risk and Insurance-Issues and Practice 34(3): 401-424.
Croppenstedt, A., Knowles, M., Lowder, S.K., 2018. Social protection and agriculture: Introduction to the special issue. Global Food Secur. 16, 65–68.
Demirgüç-Kunt, A., Klapper, L., Singer, D., Ansar, S., Hess, J., 2020. The Global Findex Database 2017: Measuring Financial Inclusion and Opportunities to Expand Access to and Use of Financial Services. World Bank Econ. Rev. 34 (Supplement_1), S2–S8.
Eckstein, D., Kunzel, V., Schäfer, L., Winges, M., 2020. Global climate risk index 2020: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2018 and 1999 to 2018.
Garnett, T., 2014. Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? J. Cleaner Prod. 73, 10–18.
Gusenbauer, M., Haddaway, N.R., 2020. Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. Res. Synthes. Method. 11 (2), 181–217.
Hazell, P., Varangis, P., 2019. Best practices for subsidizing agricultural insurance. Global. Food Secur. 25, 100326. https://doi.org/10.1016/j.gfs.2019.100326.
Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A k-means clustering algorithm. Journal of the royal statistical society. series c (applied statistics), 28(1), 100-108.
Hellmuth, M.E., Osgood, D.E., Hess, U., Moorhead, A., Bhojwani, H., 2009. Index insurance and climate risk: Prospects for development and disaster management. International Research Institute for Climate and Society (IRI).
Heltberg, R., Siegel, P.B., Jorgensen, S.L., 2009. Addressing human vulnerability to climate change: toward a 'no-regrets' approach. Global Environ. Change 19 (1), 89–99.
Hochrainer-Stigler, S., van der Velde, M., Fritz, S., Pflug, G., 2014. Remote sensing data for managing climate risks: Index-based insurance and growth related applications for smallhold-farmers in Ethiopia. Clim. Risk Manage. 6, 27–38.
Hudson, P., De Ruig, L.T., de Ruiter, M.C., Kuik, O.J., Botzen, W.J.W., Le Den, X., Persson, M., Benoist, A., Nielsen, C.N., 2020. An assessment of best practices of extreme weather insurance and directions for a more resilient society. Environ. Hazards 19 (3), 301–321.
Kath, J., Byrareddy, V.M., Craparo, A., Nguyen-Huy, T., Mushtaq, S., Cao, L., Bossolasco, L., 2020. Not so robust: Robusta coffee production is highly sensitive to temperature. Glob. Change Biol. 26 (6), 3677–3688.
Kath, J., Mushtaq, S., Henry, R., Adeyinka, A., Stone, R., 2018. Index insurance benefits agricultural producers exposed to excessive rainfall risk. Weather Clim. Extremes 22, 1–9.
Kath, J., Mushtaq, S., Henry, R., Adeyinka, A.A., Stone, R., Marcussen, T., Kouadio, L., 2019. Spatial variability in regional scale drought index insurance viability across Australia's wheat growing regions. Clim. Risk Manage. 24, 13–29.
Lesk, C., Rowhani, P., Ramankutty, N., 2016. Influence of extreme weather disasters on global crop production. Nature 529 (7584), 84–87.
Li, Y., Guan, K., Schnitkey, G.D., DeLucia, E., Peng, B., 2019. Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. Glob. Change Biol. 25 (7), 2325–2337.
Liu, X., Tang, Y., Ge, J., Miranda, M.J., 2019. Does experience with natural disasters affect willingness-to-pay for weather index insurance? Evidence from China. Int. J. Disaster Risk Reduct. 33, 33–43.
Mendelsohn, R., Kurukulasuriya, P., Basist, A., Kogan, F., Williams, C., 2007. Climate analysis with satellite versus weather station data. Clim. Change 81 (1), 71–83.
Miranda, M.J., Farrin, K., 2012. Index-insurance for developing countries. Appl. Econ. Perspect. Policy 34 (3), 391–427.
Mobarak, A.M., Rosenzweig, M.R., 2014. Risk, insurance and wages in general equilibrium. NBERWork Pap. 19811.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Prisma Group, 2009. Reprint—preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Physical therapy, 89(9), pp.873-880.Müller, B.,Johnson, L., Kreuer, D., 2017. Maladaptive outcomes of climate insurance in agriculture. Glob. Environ. Change 46: 23-33.
Mushtaq, S., Kath, J., Stone, R., Henry, R., Läderach, P., Reardon-Smith, K., Cobon, D., Marcussen, T., Cliffe, N., Kristiansen, P., Pischke, F., 2020. Creating positive synergies between risk management and transfer to accelerate food system climate resilience. Clim. Change 161 (3), 465–478.
Nowogrodzki, A., 2019. How climate change might affect tea. Nature 566 (7742), S10–S11.
Ntukamazina, N., Onwonga, R.N., Sommer, R., Rubyogo, J.C., Mukankusi, C.M., Mburu, J. and Kariuki, R., 2017. Index-based agricultural insurance products: challenges, opportunities and prospects for uptake in sub-Sahara Africa.
Pickering, C., Byrne, J., 2014. The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. Higher Educat. Res. Dev. 33 (3), 534–548.
Pielke, R.A., Rubiera, J., Landsea, C., Fernández, M.L., Klein, R., 2003. Hurricane vulnerability in Latin America and the Caribbean: Normalized damage and loss potentials. Nat. Hazard. Rev. 4 (3), 101–114.
Ray, D.K., Gerber, J.S., MacDonald, G.K., West, P.C., 2015. Climate variation explains a third of global crop yield variability. Nat. Commun. 6 (1), 1–9.
Roser, M., 2013. Employment in agriculture. Our world in data.
Shi, H., Jiang., Z., 2016. The efficiency of composite weather index insurance in hedging rice yield risk: evidence from China. Agricult. Econom. 47(3): 319-328.
Skees, J., 2011. Innovations in index insurance for the poor in low-income countries. Financial inclusion, innovation, and investments: Biotechnology and capital markets working for the poor, ed. RD Christy, and VL Bogan: 73-100.
R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Tibshirani, R., Walther, G., Hastie, T., 2001. Estimating the number of clusters in a data set via the gap statistic. J. Roy. Statist. Soc.: Ser. B (Statist. Methodol.) 63 (2), 411–423.
Tirivayi, N., Knowles, M., Davis, B., 2016. The interaction between social protection and agriculture: A review of evidence. Global Food Security 10, 52–62.
The Economist Intelligence Unit, 2018. Global Food Security Index: Exploring Challenges and Developing Solutions. accessed 20 July 2019. https://foodsecurityindex.eiu.com/.
Vedenov, D.V., Barnett, B.J., 2004. Efficiency of weather derivatives as primary crop insurance instruments. J. Agricult. Resour. Econom. 387–403.

Welch, J.R., Vincent, J.R., Auffhammer, M., Moya, P.F., Dobermann, A., Dawe, D., 2010. Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. Proc. Natl. Acad. Sci. 107 (33), 14562–14567.

Wilkinson, M.D., Dumontier, M., Aalbersberg, IJsbrand.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brookes, A.J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C.T., Finkers, R., Gonzalez-Beltran, A., Gray, A.J.G., Groth, P., Goble, C., Grethe, J.S., Heringa, J., 't Hoen, P.A.C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S.J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., Mons, B., 2016. The FAIR Guiding Principles for scientific data management and stewardship. Sci. Data 3 (1). https://doi.org/10.1038/sdata.2016.18.

Zavatta, G., 2014. Agriculture Remains Central to the World Economy. 60% of the population Depends on Agriculture for Survival. http://www.expo2015.org/magazine/en/economy/agriculture-remains-central-to-the-world-economy.html. (Accessed 10 February 2020).