World Meteorological Organization
Weather • Climate • Water

Report of the CAgM Expert Team on Weather and Climate Extremes and Agricultural Needs

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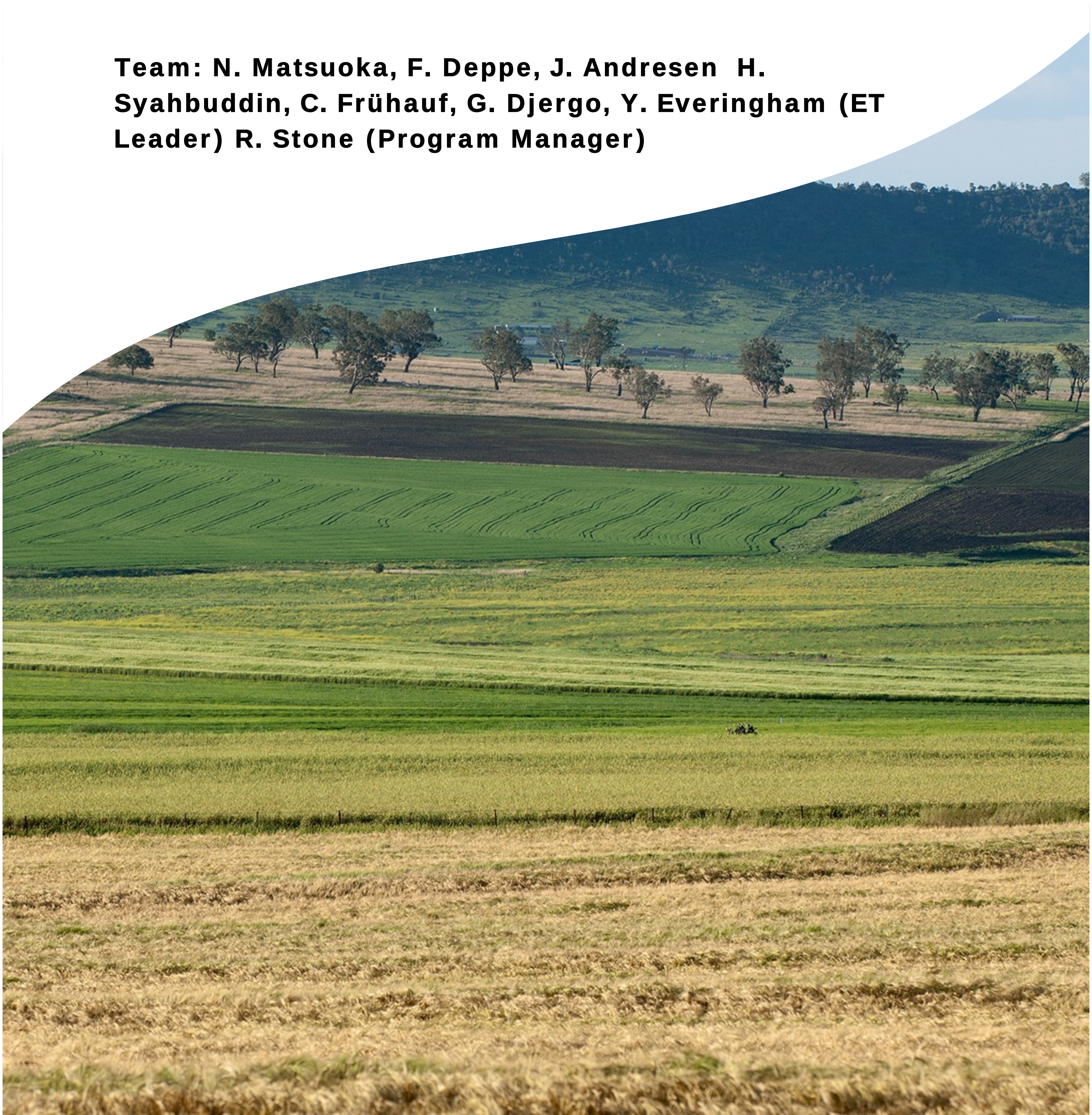

Contents

Introduction

Deliverables

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The following provides a summary of key work performed and outputs against the required Terms of Reference. A bibliography is provided at the conclusion of the report.

TOR1: Identify weather and climate extremes with consideration to outputs from CCL team on definition of extreme events in commission for climatology.

What is an Exteme Event?

Evidence that climate is changing is now irrefutable (PDO, IPCC 2014a). Global mean temperatures have already risen by about 0.8°C above preindustrial levels while scientific reviews published in the last few years indicate that recent greenhouse gas emissions and future 21st century emissions trends are higher than previously projected. In the absence of further mitigation there is a 40 % probability that global mean temperatures will exceed 4°C above preindustrial levels and a 10 percentage chance that they will exceed 5°C (WorldBank 2013).

"Climate describes the long-term weather patterns for a specific area and time of the year" (Fraisse and Jones 2013) (e.g., average monthly or annual rainfall, average minimum temperature for the winter months), whereas weather is the state of the atmosphere at a particular time, as defined by the various meteorological elements (e.g., hot/cold, wet/dry, calm/stormy, clear/cloudy). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) defines an extreme weather or climate event as

> "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable"

For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes' (IPCC 2012b). However, what actually defines a climate extreme is by no means straightforward and is very much dependant on location, among other factors (Stephenson et al. 2008). Some climate extremes such as droughts and floods may be the result of an accumulation of weather events that, in themselves, are not defined as extreme (Climate and Development Knowledge Network 2012). Many climate extremes are a result of natural climate variability but their frequency, intensity, spatial extent, duration, and timing are being affected by global climate change, leading to unprecedented extremes (IPCC 2012b; Easterling et al. 2016). For example, climate change may result, on average, in a region getting wetter; however, if the variance is also increasing, it is possible for both floods and droughts to become more common. An important message put forward by the SREX is that even without taking climate change into account, disaster risk will continue to increase in many countries as more vulnerable people and resources are exposed to climate extremes. Extreme events have greatest impacts on sectors that are closely linked with or dependent on the climate, such as agriculture.

Purpose of this Report

The purpose of this report is to i) provide an introduction to climate extremes and their impacts or projected impacts on agriculture; ii) summarise some of the successful management strategies and tools that have been or are currently being developed and implemented to mitigate risks associated with climate extremes; and iii) deliver recommendations incorporating agricultural industry needs into weather and climate services in regards to monitoring and forecasting weather and climate extremes.

Extreme Events, ENSO and Climate Change and Impacts on Agriculture

Agricultural land covers an estimated 38% (12% crops, 26% pasture) of the Earth’s terrestrial surface (Foley et al. 2011). Food production of the world’s most valuable commodity crops (maize, wheat, rice and soybean) comes from just a few major producing countries (Bailey et al. 2015) (**Error! Reference source not found.**). In fact, an analysis of data from the Foreign Agricultural Service (FAS), United States Department of Agriculture (USDA) shows that for the most important agricultural crops of the world, more than 60% of total global production comes from five or less countries (Table 1).

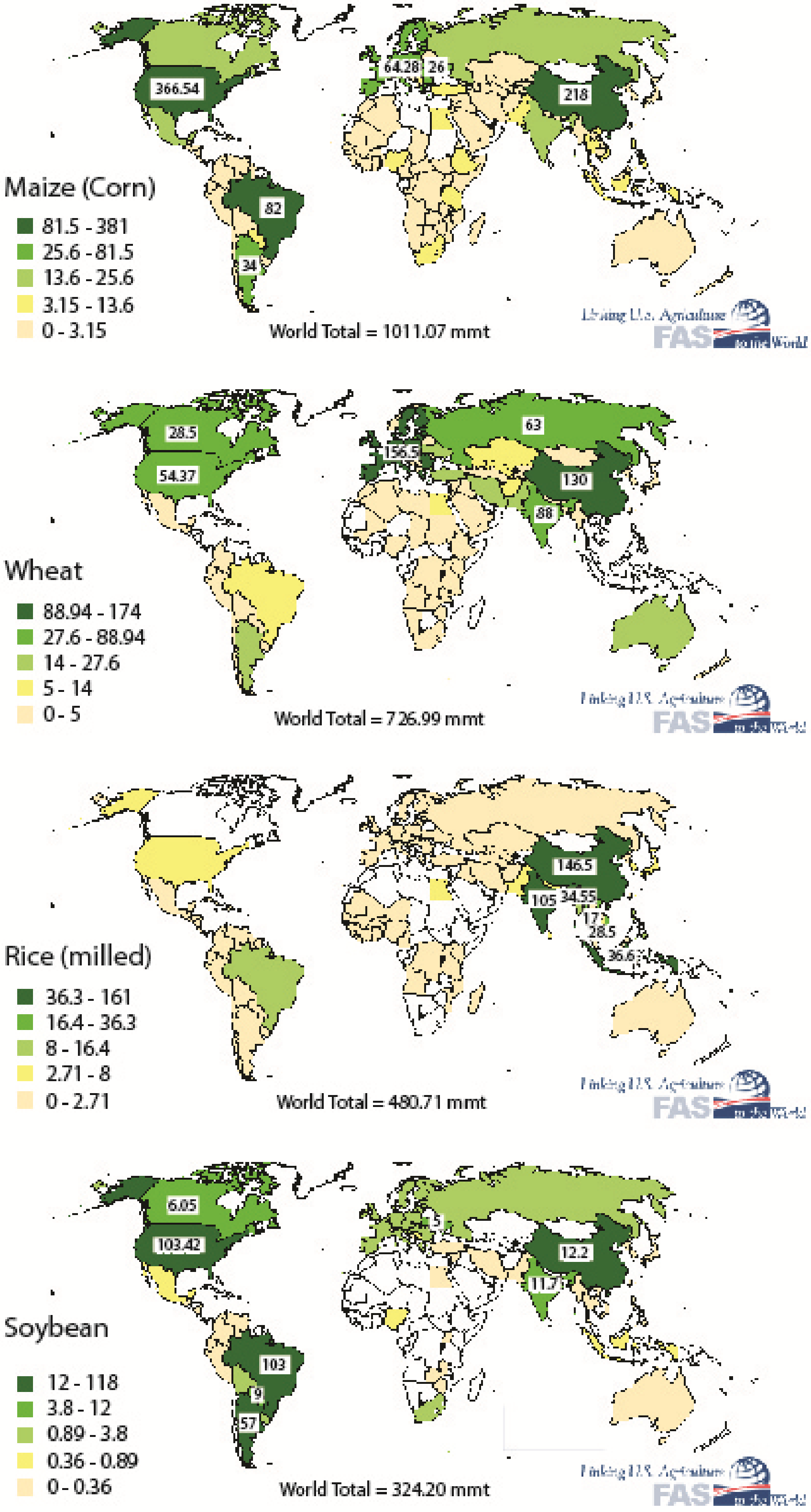


Figure 1 2016/17 projected production (million metric tons) of the world's major crops. Sourced from FSA, USDA (http://www.fas.usda.gov/psdonline).

Table 1 Global production estimates (million metric tons) for the 2015/16 growing season of the world's most important agricultural crops. Numbers in parentheses are percentages of total global production for each crop. Only countries are listed that contribute more than 5% towards total global production. Data from FSA, USDA (http://www.fas.usda.gov/psdonline).

Crop	Country/Region	Production (million metric tons)
Maize (Corn)	**World Total**	**968.86**
	USA	345.49 (36%)
	China	224.58 (23%)
	Brazil	81 (8%)
	EU	57.98 (6%)
Wheat	**World Total**	**734.05**
	EU	160.01 (22%)
	China	130.19 (18%)
	India	86.53 (12%)
	Russia	61.04 (8%)
	USA	55.84 (8%)
Rice	**World Total**	**470.49**
	China	145.77 (31%)
	India	103 (22%)
	Indonesia	35.3 (8%)
	Bangladesh	34.5 (7%)
	Vietnam	28.1 (6%)
Soybean	**World Total**	**315.86**
	USA	106.93 (34%)
	Brazil	99 (31%)
	Argentina	56.5 (18%)
Sugar (cane and beet)	**World Total**	**164.92**
	Brazil	34.65 (21%)
	India	27.7 (17%)
	EU	16.5 (10%)
	Thailand	9.74 (6%)
Barley	**World Total**	**147.92**
	EU	61.35 (41%)
	Russia	17.08 (12%)
	Ukraine	8.75 (6%)
	Australia	8.7 (6%)
	Canada	8.23 (6%)
	Turkey	7.4 (5%)
Sorghum	**World Total**	**61.66**
	USA	15.16 (25%)
	Nigeria	6.15 (10%)
	Mexico	5.7 (9%)
	India	5.05 (8%)
	Argentina	3.6 (6%)
Millet and Mixed Grains	**World Total**	**45.38**
	EU	15.81 (35%)
	India	10.68 (24%)
	Nigeria	4.8 (11%)
	Mali	4.09 (9%)
	Australia	2.56 (6%)
	Iran	2.56 (6%)
	Burkina	2.52 (6%)
Oats	**World Total**	**22.19**
	EU	7.52 (34%)
	Russia	4.53 (20%)
	Canada	3.43 (15%)
	Australia	1.3 (6%)
	USA	1.3 (6%)
Grapes	**World Total**	**21.07**
	China	9.6 (46%)
	India	2.5 (12%)
	Turkey	2.01 (10%)

	EU	1.68 (8%)
	Brazil	1.46 (7%)
Cotton	**World Total**	**20.77**
	India	5.59 (27%)
	China	4.97 (24%)
	USA	2.69 13%)
	Pakistan	1.46 (7%)
	Brazil	1.36 (7%)
Rye	**World Total**	**12.14**
	EU	7.82 (64%)
	Russia	2.08 (17%)
	Belarus	0.8 (7%)
Coffee	**World Total**	**9.01**
	Brazil	2.96 (33%)
	Vietnam	1.76 (20%)
	Columbia	0.8 (9%)
	Indonesia	0.64 (7%)

Contemporary agriculture faces enormous challenges as the world's climate is changing. There is now very extensive and convincing evidence that extreme weather events, such as intense floods, droughts and heatwaves, are increasing in frequency and severity at an alarming rate (Challinor et al. 2014; Bailey et al. 2015; Coumou and Rahmstorf 2012; Hansen et al. 2012; WorldBank 2013; Mallya et al. 2016). The past decade as a whole has seen an exceptional number of unprecedented extreme weather events, some causing human suffering and widespread economic damage (Coumou and Rahmstorf 2012). Warm temperature extremes continue to increase while cold temperature extremes continue to decrease, despite the warming hiatus/slowdown in global mean surface temperature over the last 18 years (Fyfe et al. 2016; Hay et al. 2016). In India, research has shown that the severity and frequency of drought has increased over recent decades (1972-2004) irrespective of the data and methodology used (Mallya et al. 2016). Of particular concern is that droughts are becoming more regional and are showing a general shift to more agriculturally important regions of India (Mallya et al. 2016). Globally, rainfall extremes also appear to have increased in more regions than they have decreased (Hay et al. 2016). This is somewhat expected as warmer air can hold more moisture (for each 1 °C of warming, saturated air contains 7% more water vapour), which is available to precipitate out if conditions are right (Coumou and Rahmstorf 2012).

In August 2010, the World Meteorological Organization (WMO) issued a statement on the "unprecedented sequence of extreme weather events" that had occurred over recent years, stating that it "matches IPCC projections of more frequent and more intense extreme weather events due to global warming". It is very likely that there will be an increase in frequency and magnitude of warm daily extremes, warm spells and heat waves in most regions (**Error! Reference source not found.**). This will lead to more evaporation, and thus surface drying, increasing the intensity and duration of drought in some regions such as southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa (Coumou and Rahmstorf 2012; IPCC 2012b). Drought is the second costliest type of disaster (behind tropical cyclones), averaging 9.4 billion USD in losses per event since 1980 (NCEI 2015). In parts of southern and west Africa, annual precipitation and groundwater recharge rates are projected to decrease by up to

30 % and 50-70 %, respectively, by the end of this century leading to an increase in drought in much of southern and central Africa (WorldBank 2013). The total area of arid land in southern Africa is also expected to increase by about 10 % reducing crop yields as growing seasons shorten by more than 20 % (WorldBank 2013). There will also be significant impacts on livestock (Climate and Development Knowledge Network 2012).

Globally, climate variability accounts for about a third of the global crop yield variability and more than 60% in some regions (Ray et al. 2015). Significant impacts to crop yield are already being experienced under current global temperatures (increase of 0.8°C since preindustrial levels) (WorldBank 2013). For example, global maize and wheat production declined by 3.8 and 5.5%, respectively as a result of temperature extremes between 1980 and 2008 (Lobell et al. 2011). In the Netherlands, increases in the number of extreme high temperatures and extreme precipitation events since 1901 has led to a decline in wheat production (Powell and Reinhard 2016). In much of the Sub-Saharan Africa region, the annual average temperature is already above optimal values (15-20°C) for wheat during the growing season and is expected to increase further (WorldBank 2013). Non-linear reductions in maize yield above certain temperature thresholds have also been reported (WorldBank 2013). For example, each day in the growing season spent at a temperature above 30°C reduces yields by one % compared to optimal (i.e., drought-free) conditions. Drought poses a continuing threat to agriculture and Africa is expected to be the region most affected by drought-caused yield reductions in the future (Dai 2013; WorldBank 2013). It is estimated that by mid-century 15-20% reductions in yields may occur across all crops and regions of sub-Saharan Africa (WorldBank 2013). In 7 of the 10 years between 2000 and 2009, drought caused on average more than 4.7 billion USD in agricultural losses annually across portions of the United States in crops such as maize and soybean (NCEI 2015). About 15% of Asia's rice fields experience yield losses due to drought (Climate and Development Knowledge Network 2012). In China, the annual average crop area suffering from drought has increased by nearly 120% since the 1950s, along with an increase in the number of flood events (Huang et al. 2015).

Globally, precipitation extremes are expected to increase in all regions even in those where mean precipitation is expected to decline (Hay et al. 2016), therefore a higher proportion of total precipitation will come from extreme events although uncertainty is higher for some regions such as Africa (Climate and Development Knowledge Network 2012; WorldBank 2013). Excessive rainfall can create waterlogging in the root zone, reduce plant growth and hinder field operations. Flooding has caused major impacts to agriculture over the last two decades. For example, in 1993 heavy precipitation flooded 8.2 million acres of soybean and maize crop in America mid-west, decreasing maize yields by up to 50% in some states (Climate and Development Knowledge Network 2012). Extreme rainfall also resulted in a 50-70% loss of agriculture in Haiti in 2004, and 462 million USD loss of crops and livestock in southern Mexico in 2007 (Shannon and Motha 2015). More recently in 2014, major flooding in Pakistan led to an estimated 1 million acres of crop damage and significant reductions in the production of rice, sugarcane and cotton. Loss of seed stocks and agricultural tools, destruction of irrigation channels and land erosion further deteriorated the agriculture sector.

Increased atmospheric moisture content along with increased sea surface temperatures will also provide more latent energy to drive more intense, yet less frequent, storms and tropical cyclones (IPCC 2014a, 2012b; Coumou and Rahmstorf 2012; Kang and Elsner 2015). With projected rise in mean sea level and increase in strong ENSO (discussed below), more frequent extreme sea levels are expected. Extreme sea levels will affect coastal agricultural crops in two major ways: saltwater intrusion and loss of coastal land due to inundation (IPCC 2012b). Meanwhile, more extreme heat waves and flood events may also pave the way for pests (e.g., weeds, insects) and/or plant and animal disease vectors, increasing their spatial distribution. For example, climate extremes can alter the ecology of plant pathogens, while higher soil temperatures can promote fungal growth that kills seedlings (Pavan et al. 2011). A severe disease outbreak in Ethiopia in November 2013 caused farmers to lose on average 50 % of their wheat crops. In 2010, an epidemic of Yr27 (an aggressive strain of stripe rust) hit wheat fields in Central and West Asia and North Africa, and caused crop losses up to 40% in the region.

ENSO

Unabated global warming is also expected to increase the frequency of extreme ENSO (El Niño/Southern Oscillation) events and associated weather extremes. ENSO is the most dominant climate phenomenon causing year-to-year fluctuations of the world's climate system and affecting extreme weather conditions worldwide (Cai et al. 2015). The dynamics and properties of ENSO are closely linked to the background climate state of the equatorial Pacific Ocean (Cai et al. 2015). In the broadest terms, ENSO can be characterised as a fluctuation between a "normal" or neutral phase and two extreme phases: El Niño and La Niña that occurs at a semi-regular interval of 2-5 years and usually lasting 9-12 months. Globally, 7 of the 10 hottest years on record have been during El Niño years or the subsequent year (Australian Government Bureau of Meteorology 2016). The 1997/98 El Niño event was regarded as one of the most powerful ENSO events in recorded history, rivalling the strong El Niño of 1982/83, and resulting in widespread extreme weather such as drought and flooding, and raising global air temperatures by about 1.5°C compared to the usual increase of 0.25°C associated with ENSO (Trenberth et al. 2002). Catastrophic floods occurred in the eastern equatorial region of Ecuador and northern Peru, widespread floods and droughts throughout south Pacific nations, and shifting extreme cyclones to regions normally not affected (Cai et al. 2012; Cai et al. 2015). Furthermore, an extreme La Niña in the subsequent year generated droughts in the southwest United States and eastern equatorial Pacific regions, floods in the western Pacific and central American countries, and increased land-falling western Pacific tropical cyclones and Atlantic hurricanes (Cai et al. 2015). In Australia, 17 of the most recent 26 El Niño events have brought widespread drought while 7 of the 10 driest years on record were during El Niño (Australian Government Bureau of Meteorology 2016). There are now a robust set of climate model projections that extreme El Niños and La Niñas will occur more frequently in the future due to global warming in response to accelerated equatorial Pacific warming, particularly in the eastern Pacific (Cai et al. 2015). ENSO-related catastrophic weather events are thus likely to be more common in the next few decades, affecting ecosystems and agriculture worldwide (Table 2).

The physical effects of ENSO are felt throughout the world's agricultural sector. For instance, significant reductions in the production of strawberries in California, due to flooding associated with the 1997/98 El Niño, resulted in losses to consumers of about $15 million compared to 1997 prices and $100 million compared to average prices of the previous decade (Adams et al. 1999). During the 2002 and 2006 growing seasons, El Niño-related droughts greatly impacted upon the Australian wheat belt, cutting national wheat production by nearly 50% compared to the previous year (Johansson et al. 2015). In southeast US, ENSO significantly influences corn (Maize) and tobacco yields and can explain an average shift of 26% of the value of maize as yields are typically lower than historic values during El Niño years (Hansen et al. 1998). In Alabama, wheat yield can be about 47% greater in El Niño years compared to La Niña years (Figure 2) whereas peanut yield in Florida can be about 48% lower (Figure 2). No interactions between ENSO and wheat yield were found in Argentina (Podesta et al. 1999), whereas studies in the neighbouring countries of Brazil (Alberto et al. 2006) and Paraguay (Ramirez-Rodrigues et al. 2014) show higher wheat yields during the La Niña phases. In a global meta-analysis, Iizumi et al. (2014) found that El Niño likely increases global-mean yield of soybean by 2.1-5.4% but decreases the yields of maize, rice and wheat by -4.3 to -0.8%. On the other hand, La Niña tends to decrease the yields of all four crops by up to -4.5% (Figure 3). Such cases highlight the potential value of using ENSO forecasts to predict local and regional crop yields, yet caution should be used because the relationship between ENSO events and crop yield anomalies, although strong in some regions worldwide, is not perfectly correlated in others (Johansson et al. 2015). Hammer (2001) presents a series of key lessons learnt from successful case studies from ENSO in Australia, Africa, America and Argentina. These key lessons include: (i) better understanding and communicating risk; (ii) applying forecasts for a range of scales from on farm through to marketing; and (iii) an interdisciplinary approach in that seasonal climate forecasts must be integrated with specific agricultural actions to better inform decisions.

Given the sensitivity of crop and livestock production to climate, the agricultural sector and producers will be disproportionately impacted. Most agriculture is climate dependent as the weather's variability determines the relative productivity of the seasons and therefore governs the spatial distribution of agriculture and impacts upon the global food market (Bailey et al. 2015; WorldBank 2013). Furthermore, the Food and Agriculture Organization of the United Nations (FAO) estimates that by 2050 demand for food will increase over 60% above the current level, meaning crop production systems will also be under increasing pressure to meet growing global demand in the future (Bailey et al. 2015; WorldBank 2013; Foley et al. 2011). Even if producers are not directly impacted by climate change and/or climate extremes, they will feel their effects on other producers through the interconnected global market for agricultural commodities.

Adaptation to climate change

The use of weather and climate data influences many decisions in agricultural planning and impact agricultural related outcomes. Farmers most vulnerable to climate change and increased frequency of climate extremes will be those unwilling or unable to respond to changing agronomic conditions by altering their production systems. Decisions made by farmers based on weather monitoring and forecasting include tactical decisions such as:

- Applying agrochemicals (e.g., herbicides, pesticides, fertilizers)
- Whether to plant or harvest a crop

However, more meaningful adaptive strategies undertaken by farmers/producers to mitigate risks associated with climate extremes will include:

Changing planting or harvest dates	Regenerative agriculture (e.g., cover crops, fire)
Diversifying crops	Weather Index Insurance
Crop relocation	Forward selling, hedging
Increased use of irrigation, herbicides, pesticides and fertilizers	Development and implementation of improved Integrated Pest Management (IPM) programs
Investment in new irrigation or drainage systems (Increasing water use efficiency and conserving soil moisture)	Changing crop species or livestock to varieties more conducive to changing conditions (e.g., drought and heat resistant/tolerant types)
Integrating livestock production and/or forestry (agroforestry) with crop production	Changing crop varieties to disease resistant types (including GM crops)
Changes in tillage practices	Early warning and early response systems
Changing cultural practices	Using climate forecasting to support farm planning

The extent of adaptation will depend mostly on the affordability of proposed strategies, the rate of climate change, and access to know-how and technology (Fraisse et al. 2009).

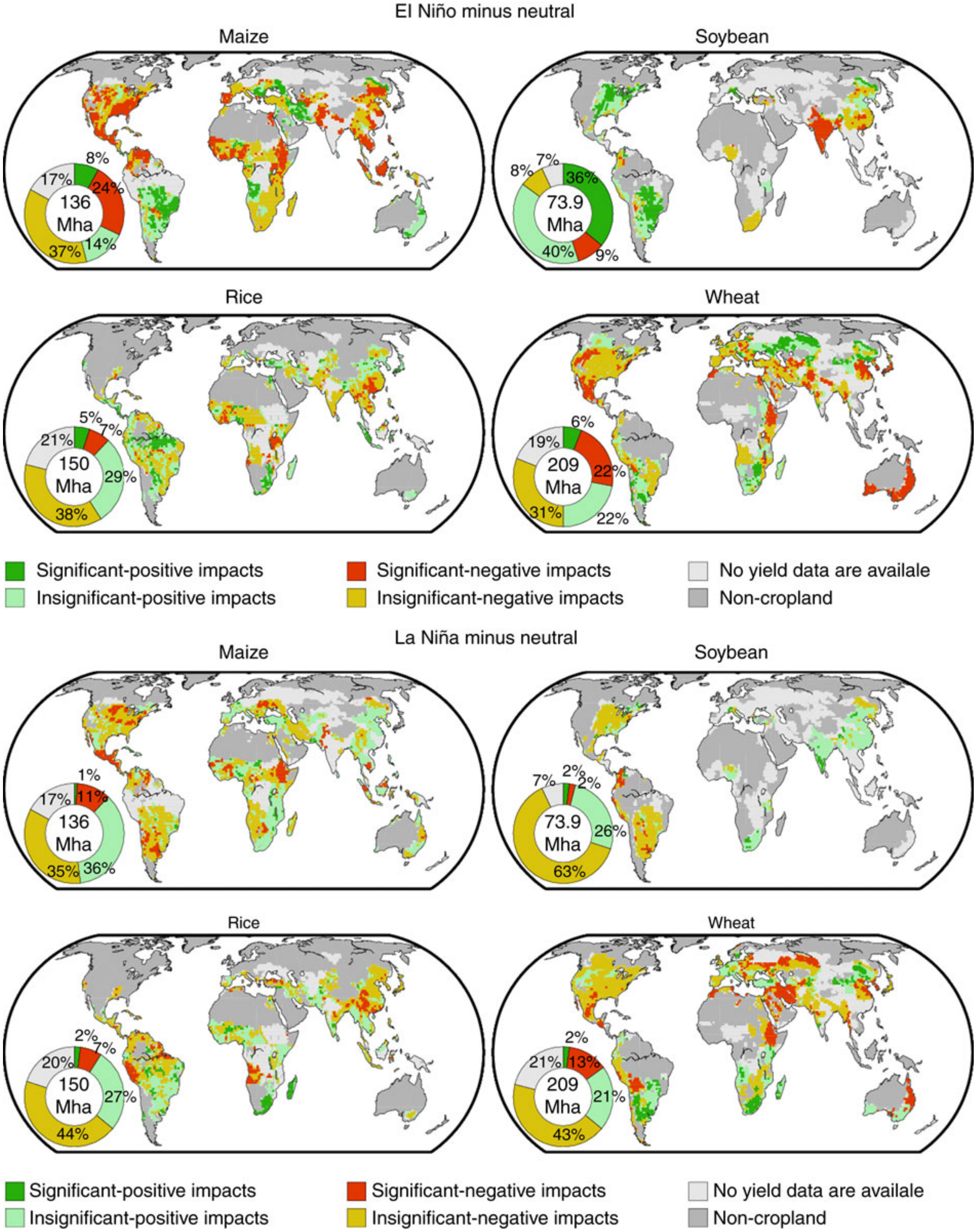


Figure 2 Impacts of El Niño/La Niña on crop yield anomalies for four major crops of the world. The pie diagrams indicate the percentages of harvested area normalized to the global harvested area in 2000 (source: Iizumi et al. (2014)).

Table 2 Climate extremes, future projections, and impacts on agriculture (data compiled from IPCC 2012, WorldBank 2013, a variety of literature from this report).

Climate Extreme	Future Projections	Confidence	Potential Agricultural Impacts
Droughts	-Increased intensity in some seasons and areas such as southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa	*Medium*	-Immediate fall in crop production (e.g., Maize) -Possible failure of entire crops such as cotton, corn, sorghum, wheat and hay -Farmers forced to sell off transport and draft livestock -Reduction in pasture production and fodder for livestock (starvation) -Reduction in availability of manure (an important source of fuel in some countries) -Increased dependency on groundwater supplies to maintain crop production leading increased need to dig deeper wells and/or find alternative drinking water sources - Increased prices for hay, feeds and even grocery produce - Increased operational costs for farmers (e.g., new irrigation or wells, higher prices for livestock feed) -Increased risk of wildfires
Extreme rain events + Floods	-Increased frequency of heavy precipitation -Increased proportion of total rainfall from heavy rainfall events	*Likely (especially high latitudes and tropical regions)*	-Flooding of lowland crops -Increased occurrence of crop diseases
Hot extremes and heat waves	-Increased frequency and magnitude of warm daily extremes and decreases in cold extremes -Increased frequency, and/or intensity of warm spells or heat waves	*Virtually Certain* *Very Likely*	-More rapid transition through developmental phases of annual crops -Increased water requirements -Reduced photosynthesis and shortened growing period -Overall reduction in crop yield -Increased insect populations -Increased occurrence of crop diseases Heat stress of dairy cattle (temperature optimum for milk production is between 4.5-24ºC)
Tropical Cyclones	-Increased intensity of tropical cyclones in some ocean basins -Decreased or unchanged frequency of tropical cyclones	*Likely* *Likely* *Medium*	-Despite decreased frequency of tropical cyclones, damage to farm infrastructure and crops may still increase as greatest impacts are

	-Decreased frequency of mid-latitude cyclones -Poleward shift in mid-latitude storms	*Medium*	caused by more intense storms -Increased extreme rainfall and associated flood risk in some regions
ENSO	-Most model indicate increase frequency of extreme ENSO events.	*Low*	Varies by region e.g., extreme El Niño is linked to failed monsoons in India, drought in Indonesia, flooding rains in southwest USA, and drier-than-normal conditions in Australia
Sea Level Rise	Increased frequency of coastal inundation events due to contribution of rising mean sea level	*Very Likely*	-Inundation and/or saltwater intrusion into coastal lowland crops (e.g., rice in the Mekong Delta)

TOR2: Report on existing material on agricultural industry needs, including information from CCl ETUIP, in regards to managing weather and climate extremes.

TOR3: Compile lists of successful case studies and risk management strategies in linking agricultural industry needs and their management capabilities in preparing for weather and climate extremes. Include case studies of useful applications in agricultural insurance

Agricultural Industry Needs

Here we discuss several successful management strategies and tools that have been or are being developed and implemented to mitigate risks associated with climate extremes such as reductions in crop yield, shortened growing periods, increased occurrence of crop diseases and pests, or complete crop failures. We consider a case study/management tool to be successful if it delivers a benefit to at least one element of the triple bottom line in some way shape or form – the triple bottom line being the social, economic, and environmental aspects of agriculture. This most often relates to profitability, use and conservation (Harrison 2007). We also include several key recommendations for incorporating agricultural industry needs into weather and climate services in regards to monitoring and forecasting weather and climate extremes.

Decision Support Tools and Crop Simulation Models

Crop Simulation Models are increasingly being used worldwide to explore food security and adaptation to climate change and climate extremes (Cabrera et al. 2010; Dias et al. 2016; Jones et al. 2000; Ngwira et al. 2014; Chauhan et al. 2013; Everingham 2008a; Hochman, van Rees, et al. 2009; Phung et al. 2013;

Ramirez-Rodrigues et al. 2014). Two of the most popular CSM's in agriculture are APSIM (Keating et al. 2003) and DSSAT (Jones et al. 2003).

APSIM (https://www.apsim.info/)

APSIM (Agricultural Production Systems sIMulator) was developed by the Agricultural Production System Research Unit (APSRU) in Australia to analyse the biophysical processes involved in a farming system. It includes modules that simulate growth, development and yield of crops, soil water balance, mineralization and immobilization of soil nitrogen (Keating et al. 2003). It has been evolving over the last 23 years and over the last decade has exploded into new domains such as social media, web and mobile application (Holzworth et al. 2014). APSIM is open-source which encourages collaboration while being relatively transparent. APSIM has been used to explore on-farm management practices, climate risk/change adaptation strategies, land use strategies, agro-forestry, nutrient leaching, gene trait expression and many other applications. As of 2014, APSIM contained 41 different crop models, 12 soil models, 4 livestock models, and 3 climate models (Holzworth et al. 2014). According to Web of Science (accessed on 27/05/2016), 557 journal articles contain APSIM as a topic indicating its broad use throughout the world. In recent studies in Australia, APSIM has aided in increasing the accuracy of yield forecasts for sugarcane (Everingham et al. 2016) and improving water management on wheat fields by demonstrating that deficit irrigation of larger areas of wheat was generally more profitable and risk-efficient than smaller areas of full irrigation (Peake et al. 2016). Both studies delivered better environmental and economic outcomes. In China, Liu et al. (2016) used the APSIM model to quantify the contributions of soil physical properties, cultivar selections, and management practices to maize yield gaps, while Bai et al. (2016) used APSIM to discover that sowing/transplanting date did not significantly affect rice and wheat yield in a rice-wheat rotation system but did alleviated some of the negative impact of climate change.

DSSAT (http://dssat.net/)

DSSAT (The Decision Support System for Agro technology Transfer) was a multi-collaborative development led by the University of Florida, among others, and has been in use for more than 25 years by researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 100 countries worldwide (Cabrera et al. 2010; Dias et al. 2016; Jones et al. 2003; Ngwira et al. 2014; Jing et al. 2016; Liu, Asseng, et al. 2016; Vianna and Sentelhas 2016). Like APSIM, DSSAT is open-source software and comprises of crop simulation models for over 42 different crops simulating growth, development and yield. These crop models require daily weather data, soil surface and profile information, and detailed crop management as input. According to Web of Science (accessed on 27/05/2016), 443 journal articles contain DSSAT as a topic. DSSAT also includes application programs for seasonal, spatial, sequence and crop rotation analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate variability, climate change, soil carbon sequestration, and precision management (Jones et al. 2003). DSSAT also contains algorithms which can stimulate the influence of farm management practices such as crop residue cover and tillage on soil surface properties and plant development (Ngwira et al. 2014). Recent studies have used DSSAT to assess the effects of management practices on crop yields and soil water balance in China (Liu et al., 2013; Nangia et al., 2010), show positive benefits of no-till systems (over 5 years) for maize crops in Malawi (Ngwira et al. 2014), estimate gap yield for rice in Pakistan, demonstrating that delayed sowing decreases rice yield in the studied regions (Singh et al. 2016), and project changes in wheat yield on the Canadian Prairies under climate change revealing average increases of 26-37% by 2070 under elevated CO_2 (Qian et al. 2016).

Case Study: Yield Prophet (http://www.yieldprophet.com.au/) – Improved management of Australian grain crops.

Yield Prophet acts as an interface to the crop production model APSIM providing a user-friendly online crop production model with some of the advanced features of APSIM but without its complexity (Hochman, van Rees, et al. 2009). It was developed through a partnership between CSIRO and BCG (The Birchip Cropping Group – a not for profit farmer-driven research organisation) to suit farmer and consultant needs. It incorporating soil test results, growing season rainfall, crop management and over 100 years of historic climate data to allow farmers and consultants to manage climate risk water resources, and nitrogen fertilizer application, forecast yield, assess the effects of changing sowing dates, and explore possible effects of climate change (Holzworth et al. 2014). Yield Prophet has become the most successful decision support tool for grain farmers in Australia. Between 2003 and 2012 it was used by over 2000 grain growers in a wide range of environments throughout the Australian wheat belt (Holzworth et al. 2014). It has advantages over more traditional DSS's because solutions to problems can be flexibly configured and locally situated. A similar but somewhat less successful tool based on APSIM and aimed at farmers and consultants is WhopperCropper (Nelson et al. 2002).

In 2004, one farmer in northern NSW, Australia, was able to use Yield Prophet to predict yield based on what-if scenarios of nitrogen fertiliser top-dressing (a practice not common in the region). The farmer was able to calculate that for an approximate yield increase of 1.0 t/ha, a farm-gate price of 140 AUD/t for an outlay of 56 AUD/ha, the profit from an additional 50 kg nitrogen/ha was 84 AUD/ha (Hochman, van Rees, et al. 2009).

In 2006 early rains spurred many grain farmers in South Australia to plant their crops early. However, the latter half of the year turned out to be one of the driest on record. Many farmers cut their grain for hay when this occurs as yields are expected to be low. Yield Prophet was used by one farmer to predict that yield would still be significant even under a driest year on record, thus convincing the farmer not to "cut hay" and saving him A$20,000 (Carberry et al. 2009).

In 2009, a total of 334 wheat fields were analysed and Yield Prophet used to simulate crop growth and water use (Hochman, Holzworth, et al. 2009). Yield Prophet's what-if scenarios indicated that further improvement in water use efficiency may be achieved with an early sowing strategy or a higher nitrogen input strategy. Water use efficiencies equivalent to best crop yield were attained using a strategy including an optimal plant density, early sowing, and higher nitrogen inputs.

To assess the potential for Australian farmers to increase water-limited yield, the long-term farm production records of individual wheat fields of three leading farmers in South East Australia were analysed over a 16-20-year period using APSIM (van Rees et al. 2014). Average yield on the three farms was found to be 74-82% of the water-limited yield (small yield gap), and unlikely to be economically exploitable using current management techniques. Yield Prophet was used to assist farmers in deciding when to apply in-crop nitrogen fertiliser. In 82% of cases Yield Prophet proved to be correct in its recommendation to apply or not apply further nitrogen (van Rees et al. 2014). This equated to a benefit in gross margin of up to A$71/ha/yr.

Case Study: AQUAMAN – A tool for improved irrigation management for peanuts

Peanuts (*Arachis hypogaea* L.) are an economically important crop in irrigated production areas of northern Australia. However, most growers typically only obtain about 50-65% of the potential pod yield largely due to poor irrigation management (Chauhan et al. 2013). Irrigation management will be an important strategy in mitigating some of the impacts of climate extremes (particularly drought). This will require better information and tools that are easy to use, accurate and cost-effective. AQUAMAN is a web-based decision support tool that was developed by the Department of Employment, Economic Development and Innovation (DEEDI) in response to continued decline in dryland peanut cultivation due to reoccurring droughts (Chauhan et al. 2013). It was initially released during the 2004/05 growing season and by 2008/09, over twenty growers used the program to various extents (Chauhan et al. 2013). AQUAMAN integrates the FAO-56 guidelines on the timing and depth of future irrigations (Allen et al. 1998) with the accuracy of the APSIM model (Keating et al. 2003; Holzworth et al. 2014) to predict crop water use and deliver this information via the internet (http://www.apsim.info/aquaman/). The user interface allows the user to input data on irrigation, rainfall and temperature, on a daily interval, and importantly keeps the APSIM modelling complexity in the background, which is a key requirement for a successful online DSS. It typically takes 5-15 minutes for the entire process, i.e., opening the website to receiving a report (Chauhan et al. 2013).

Researchers conducted case studies on the effectiveness of AQUAMAN on seven peanut farms in Bundaberg, Australia, over five growing seasons. Results showed that the use of AQUAMAN enabled irrigation water savings of up to 50%, and a 38% increase in crop yield per unit of irrigation (Chauhan et al. 2013). AQUAMAN also delivered environmental benefits by reducing runoff and deep drainage water losses due to application of smaller irrigation depths. A survey was conducted to approximately one third of the farmers in the Bundaberg region. The survey revealed, that farmers were particularly satisfied with the features of AQUAMAN, especially the ability of AQUAMAN to predict when irrigation should next be applied, but were less satisfied with the slow transmission of results and the unreliability of internet access. With the increased global adoption of smartphones that allow web access (Ericsson 2015) it should be possible to increase the uptake of such DSS's by incorporating smartphone compatibility. Similar online DSS's for irrigation scheduling in Australia include IrriSAT for cotton (Montgomery et al. 2015; Vleeshouwer 2015), WaterSense for sugarcane (Inman-Bamber et al. 2005) and Yield Prophet for wheat and barley (Hochman, van Rees, et al. 2009).

Recommendations:

- A key to successful online DSS's is to keep the complex models in the background.
- Wider adoption requires faster transmission of results via the internet and more reliable internet access.
- Growers dislike the idea of using different DSS's for different crops, therefore, development of a whole-farm irrigation scheduler is a desirable longer term objective.
- Increase adoption of DSS's by incorporating smartphone technology where possible.

Case Study: Optimizing deficit irrigation schedules for cotton in Uzbekistan using AquaCrop and HYDRUS-1D models.

Limited fresh water supplies and the increase in demand for irrigation water is becoming an issue in the Khorezm region of Uzbekistan, which is projected to worsen in the near future. Therefore, farmers have to achieve their crop yield targets with less water. A model was developed using AquaCrop (Steduto et al. 2009) and the HYDRUS-1D model (Simunek et al. 2008) to optimize deficit irrigation schedules for cotton in the Khorezm region. The input parameters used in the HYDRUS-1D model were daily groundwater levels (cm), precipitation (cm day^{-1}), daily transpiration (cm day^{-1}) and daily evaporation values (cm day^{-1}) which were derived from FAO guidelines (Allen et al. 1998).

Results from model simulations show that reducing water supply by 20% increased yield by 2% and the impact of reducing water by 40% on yield could be kept in the range of 14-29% yield loss. Introducing water stress at a late developmental stage would introduce water savings of 12-13% and increase yields by 7-8%. Overall, the model revealed that cotton yield can be raised by about 74-78% by adopting an optimized irrigation schedule that incorporates groundwater. Water stress introduced during late vegetative and early boll formation stages in cotton would provide adequate and feasible irrigation options for water saving.

Recommendation:

- Deficit irrigation at specific vegetative stages can be risky due to non-reliable water supplies at the right times. This can be overcome by small decentralized water storage facilities that can be utilized during high demand stages.

Case Study: IrriSAT – Climate-smart irrigation for cotton, Australia

A reoccurring theme throughout this report is the importance of climate-smart irrigation especially as irrigation water is expected to become scarce. A weather-based irrigation management tool (IrriSAT) has been trialled in northern NSW, Australia by two cotton producers in 2009/10, 10 cotton producers over 20,000 ha. in 2010/11, and in 2011/2012, was used for over 75,000 ha. (~23% of Australia's total) (Vleeshouwer 2015; Montgomery et al. 2015). It has also been successfully used in the Murrumbidgee Irrigation Area by grape and citrus irrigators to estimate daily crop water use and provide irrigation scheduling information to growers (Hornbuckle et al. 2009). IrriSAT uses satellite imagery (LandSat 7 and 8) to provide site specific crop water management information across large spatial scales and at a useful resolution of 30 m (Montgomery et al. 2015). LandSat images are free, and are at a suitable temporal (6-18 days) and spatial (30 m pixel) scale. An app is being developed to deliver data to any web enabled platform including smart phones, tablets and desktops. A delivery platform is being developed using the Google App Engine (https://irrisat-cloud.appspot.com/).

Main advantages of IrriSAT:

- Low cost (economical benefit)
- Complete spatial coverage
- Ability to benchmark crop productivity between farms – key to improving water management

Case Study: WaterSense – Smart irrigation for Australian sugarcane

Irrigation management strategies are critical to minimize the impact of swings in climate. Watersense (Haines et al. 2008; Inman-Bamber et al. 2008; Haines and Attard 2010) has undergone a series of field trials as part of intense participatory action research project in sugarcane growing regions in Australia that rely on irrigation. WaterSense is a web based tool for optimising water management that uses daily weather data (real-time) to improve water use efficiency and minimize deep drainage and runoff losses of both water and agrochemicals making it possible to interpret different management strategies on water use efficiency. As well as offering better environmental outcomes improved efficiencies can be converted to increased yields and profits for canegrowers.

Case Study: Artificial Intelligence Systems – GENIE: A web-based expert system for frost warnings.

In the United States, and many regions worldwide, frost damage is responsible for more economic losses than any other weather related phenomenon (Chevalier 2012). Georgia's Extreme-weather Neural-network Informed Expert (GENIE) is a web-based java tool for use by Georgia producers to provide warning levels of frost and freeze for blueberries and peaches based on predicted air and dew point temperatures and observed wind speeds from a network of weather stations. Growers have the ability to see how the frost risk will change over the next 12 hours. The accuracy of GENIE was verified using 570 different scenarios, whereby 100% were correctly classified. By providing five warning levels compared to the textual warnings made by the National Weather Service, GENIE presents a value-adding opportunity for producers. Although GENIE focusses on frost prediction for blueberries and peaches in Georgia, the USA, the technology can easily be extended to other crops and regional networks around the world.

Early Warning/Response Systems and Integrated Pest Management

Case Study: ClimateMinder – Oranges in USA

The ability to respond quickly to changes in the environment is important for agricultural producers to minimize risk and maximise opportunities. Climate Minder is a wireless sensor-based monitoring and control system that allows growers to access information about their soils, climate and environment in real time from their mobile phone (Ersavas and Roth 2010). The ClimateMinder system helps increase crop yields and quality, reduce water, fertilizer and chemical application costs and immediately respond to frost conditions/frost risk. Using ClimateMinder, a citrus grower in California was able to improve his water efficiency by 30-40% by reducing watering time and frequency during a record breaking drought, thanks to the real-time soil moisture data. During this time the citrus grower was also able to increase his crop yield by 15-20%. The citrus grower also receives frost alerts as phone calls or text messages during cold months, saving him time and money on fuel and potential saving a crop failure due to frost damage.

Case Study: BlightPro – Forecasting potato and tomato late blight (USA)

BlightPro is a web-based tool for potato and tomato late blight which links several models into a system that enables prediction of disease dynamics based on weather conditions/forecasts, crop information, and management tactics. Growers identify the location of their production unit of interest (latitude and longitude of field) and the system automatically obtains observed weather data from the nearest available weather station, and location-specific forecast weather data from the National Weather Service – National Digital Forecast Database. An integrated alert system also allows users to receive notification of upcoming critical thresholds via e-mail or text message. BlightPro was evaluated by researchers in field experiments conducted each year from 2010 to 2014 and in computer simulation experiments, as well as by extension personnel, crop consultants and commercial farms. The use of BlightPro reduced fungicide usage by up to 50% when conditions are not favourable for late blight, while maintaining successful disease suppression, while simulation experiments demonstrated the potential of the system to reduce fungicide usage by up to 91%. As a comparison, the potato blight forecasting tools PLANT-Plus (South Africa) and VNIFBlight (Russia) reduced the use of fungicide by up to 50% and 62%, respectively (Filippov et al. 2015; van der Waals et al. 2003)

Case Study: An early warning system for controlling grapevine mildew – Italy

Downy mildew of grapevine, can be very destructive to grape-growing regions in Europe. In northern Italy, to minimize environmental damage and better target the fungicide application to prevent potential damage, early warning forecasts of downy mildew of grapevine disease outbreaks are of vital importance. The early warning system combined a mathematical model (Rossi et al. 2008), short-term weather forecasts, and a mobile phone short message (Caffi et al. 2010). This early warning forecast system relies heavily on official weather data from the Agro-meteorological service of the Emilia-Romagna Region (http://www.arpa.emr.it/sim/) consisting of hourly values of air temperature (T, in °C), relative humidity (RH, in %), rain (R, in mm), and presence of wetness (yes or no) for each node of the grid (5 by 5 km) that covers the region.

Experiments were carried out at three locations in Northern Italy between 2006-2008. Use of the warning system reduced applications by about one-half to two-thirds leading to an average saving of 174-224 €/ha, respectively. Savings could be as high as 300 €/ha. Environmental benefits include a reduction of 4.9 litres/ha in fuel consumption and 12.5 kg/ha in CO_2 emissions, per fungicide application saved.

Despite its potential, this early warning system can be improved by removing unjustified alarms due to inaccurate weather forecasts – inaccurate weather forecasts are a common problem in early warning systems for crop diseases (Shtienberg 2013).

To be accepted by grape growers in Italy, the disease early warning system must:

- have assurance that increased risks of crop damage will be minimal
- be affordable
- be easy to use

Recommendation:

- More accurate weather forecasts offer the opportunity to better help farmers target the right amount of application to the crop.

Case Study: SISALERT – Local and regional disease and pest control for the apple and wheat industry in Brazil

Plant diseases account for at least 10% of the loss of valuable food crops throughout the world An important step in developing forecast systems for plant disease and pests is to provide an easy and comprehensive way to either run the models or deliver results to the users. SISALERT (Pavan et al. 2006) is a web-based disease warning system using simulation models and near real-time weather data with local weather forecasts to support analysis and decision by researchers, crop consultants and growers in the Brazilian apple and wheat industry. The primary focus is on model implementation and delivery. SISALERT forecasts disease and pest outbreaks/epidemics by retrieving weather data from both weather stations and a remote database with 7-day weather forecasts. Forecast models are run on a daily basis giving information on past or recent disease behaviour as well as predicted disease risk. These results are generated in real-time, assessed by experts, and made available on the web portal or sent out to farmers by email or sms. The main advantages of SYSALERT are:

- increased accuracy and site-specificity of disease forecasts
- real-time delivery of forecast data
- effectiveness of data dissemination
- cost efficiency (uses public domain software and programming tools)

The system is currently being used in Brazil to forecast two wheat diseases (fusarium head blight) and five apple diseases and has enabled growers to increase profit and efficiency, and reduce unnecessary dependency on fungicides (Fernandes et al. 2011).

SYSALERT was the original design for the Strawberry Advisory System (SAS) that is now used in Florida, USA (Pavan et al. 2011). There is potential in scaling up the system to more extensive crops (e.g., wheat, rice and soybean) and would require developing disease cycle models specific to those crops (Fernandes et al. 2011), but also the inclusion of novel GIS and remote-sensing technologies.

Case Study: Strawberry Advisory System (SAS) – Disease forecast system for strawberries in southeast USA

Anthracnose and Botrytis fruit rot are the most important diseases for production of annual strawberries in Central Florida and worldwide. In Florida, growers may need up to 20 pesticide applications and spend up to $800 per acre due to the high costs of fungicides, labour, and machinery. Anthracnose is favoured by warm temperature (>18°C) and wet weather and can cause up to 50% loss, while Botrytis requires moist but cooler conditions (15-22°C) (Pavan et al. 2011). High rainfall associated with El Niño in Central Florida may result in a much higher incidence of fruit rots in the future.

The Strawberry Advisory System (SAS) is a web-based disease forecasting system for Strawberries in Florida that uses leaf wetness and temperature during wet periods to predict disease outbreaks. Growers can thus apply fungicides only when conditions are favourable for disease, reducing the number and costs of applications while keeping strawberries healthy. The tool consists of a weather database to store data from different sources and formats, disease models for Anthracnose and Botrytis, and a web-based interface. The database consists of current and recent weather data (temperature, precipitation, relative humidity, wind speed, and solar radiation) collected from the Florida Automated Weather Network (FAWN) and short-term weather forecasts were obtained from the National Weather Service-National Digital Forecast Database (NWS-NDFD). The user interface is based on the hugely popular Google Maps API – a free and widely supported web mapping technology. There is also an automative sms/email message service. The design of the SAS system originated from SISALERT, developed in Brazil to forecast disease in the wheat and apple industry (Pavan et al. 2006).

SAS was made available to commercial strawberry growers in 2009/2010 which, in general, were able to reduce the number of fungicide applications by about half, saving about $400 per acre without affecting disease control and yield, therefore representing a significant cost benefit. During the 2009/2010 growing season, 15 growers adopted the system into their crop management. It is now one of the most popular and sophisticated tools on the AgroClimate website (http://agroclimate.org/).

SAS has been successful in eliminating many unnecessary fungicide applications and has proven user friendly. If all growers in Central Florida use the system for their 7,500 acres of winter strawberries, they can potentially reduce costs by up to $3 million per year and significantly decrease the environmental risks associated with pesticide use (SECC 2014).

Recommendation:

- Scale up the SAS system to more extensive food crops such as wheat, maize, soybean and rice

Case Study: SmartVinyard – Grapes in Hungary and Slovakia

The rapid evolution of Information Communication Technologies (ICT) and Geographical Science offers enormous potential for the development of optimized solutions for distributed information for precision viticulture. SmartVinyard is an open source web-GIS application designed to store, manage, access and disseminate data through web-GIS applications and advanced research in precision viticulture (De Filippis et al. 2013). Specifically, it was developed to support operational applications for agronomic treatments and grape harvesting and to provide digital images for mobile devices that can also be integrated on farm machinery. SmartVinyard makes use of distributed and integrated agro-meteorological data, remote sensing, chemical and physical analysis data, soil and morphological data to forecast local grape diseases at a microclimate scale of 5-8 Ha. It was initially tested on experimental vineyards in the Tuscany region of Italy and has been successfully used by wine producers in Hungary and Slovakia.

Success stories

1. Kovacs Nimrod winery in Hungary – The aims of the project were to deploy four stations to capture data on three separate locations covering 30 Ha. and to support the winery with a solution that helps remote data access from all three locations using a simultaneous monitoring system. The customer could monitor all of his vineyards remotely without having to travel, monitoring the weather parameters and disease forecasts from his mobile phone, regardless of where he is. The use of four SmartVineyard™ devices enables the customer to make decisions hours before grape protection activities should be started. This helps the customer save a great amount of money spent on workforce and fuel.

2. Biocentrum Ltd in Slovakia – The aims of the project were to deploy a station to capture reliable data and provide accurate forecasts on major

diseases, and to support the winery by providing a solution that helps with prediction of common diseases and therefore make decisions on appropriate spraying/protection. The V40 SmartVineyard™ models were deployed to provide reliable information on microclimatic conditions. Disease alerts and predictions were displayed on an intuitive web-based interface to enable fact-based decisions and optimize spraying processes, saving the customer money on unnecessary pesticides and allowing the farmer to continue labelling wines as organic.

3. Winery estate in Northern Hungary – In order to produce the world famous high quality tokaji wine grapes they need to get infected by botrytis. However, the quality of this wine depends on when and in what amount it is affected with the fungus. The aim of this project was to provide the customer with reliable information on botrytis and predicts the intensity of the fungal disease. The SmartVineyard™ user interface provided the customer the opportunity of monitoring those weather parameters that play a key role in the development of botrytis. Moreover, due to the algorithms implemented in the system, the customer gets accurate predictions on the disease.

Case Study: Integrated Pest Management for Australia cotton

Australia produces around 3% of the world's cotton grown by about 900 cotton growers on 1,250 farms, but is the third largest exporter, behind the USA and India (CRDC 2015). Decision support systems/tools are widely accepted in the Australian cotton industry for assisting with integrated pest management (IPM), crop nutrition and other aspects of farm management. Australian cotton growers receive no government subsidies, and must achieve high yields to remain profitable. One major production issue that these growers face each season is the protection of the crop against a range of insect pests (Bange et al. 2004). To control these pests they rely strongly on the use of chemical pesticides, which are both costly (up to Aus$ 400-100 per ha.) and potentially ecologically/environmentally problematic (Fitt 2000).

The cotton crop is vulnerable to a range of insect and pests. Bange et al. (2004) discuss how Australian cotton growers can use a decision support tool called EntomoLOGIC. EntomoLOGIC is a software tool that is part of the CottonLOGIC software suite, first released back in 1994 and developed for Palm OS handheld systems in 2002 by the CSIRO/Cotton CRC. EntomoLOGIC supports the cotton industry's efforts in adopting IPM which is important given the increases in certain agricultural pests and diseases associated with climate extremes. The tool uses average or forecasted daily maximum and minimum temperatures for specific regions to predict *Helicoverpa* spp. specifically, *Helicoverpa armigera* and *Helicoverpa puntigera* caterpillars. Users select sample areas in cotton fields and collect information on the types of beneficial and 'pest' insects present, their stage of development and quantity (building a database). The EntomoLOGIC software is then used to predict future pest numbers and densities, and indicates when pest numbers exceed standard or user-defined economic thresholds (Bange et al. 2004; Moore et al. 2004). Cotton pest managers can then use this information to make their own decisions on when and how to control pests. The ability to predict pest outbreaks helps farmers determine how much pesticide they should apply. In a case study involving 18 large-scale commercial cotton field trials in Australia, the number of insecticide sprays was reduced on average by 16% when EntomoLogic was used.

The number of registered users of the CottonLOGIC software suite increased steadily from 200 in 1995 to over 1100 in 2004. However, over the last decade, the software appears to have become redundant with the introduction of insect-resistant genetically modified (GM) cotton varieties, which according to the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) have reduced insecticide use by 85 %. However, the reduction in insecticide use against *Helicoverpa* has allowed other pests to survive and emerge as important pests including aphids, mirids, whitefly, thrips and jassids requiring an improved Integrated Pest Management (IPM) strategy.

IPM seeks to manage pests using a wide range of management strategies:

- using pest resistant plants, such as Bt-cotton
- destroying over-winter food sources of pests (e.g., weeds)
- managing over-winter forms (e.g., the pupae of *Helicoverpa*)
- using “trap crops” that are more attractive to pests than cotton
- conserving "beneficials" (predators or parasites that destroy pests)
- effective sampling to understand the abundance of pests versus beneficials
- using pest thresholds to decide when control is needed
- preferentially using selective insecticides that preserve beneficials
- using broad spectrum insecticides as a last resort
- tolerating non-economic damage
- adopting strategies that limit exposure of pests to selection from insecticides
- using strategies to dilute resistance, such as creating nurseries of susceptible insects (source: CSIRO, http://www.csiro.au/en/Research/AF/Areas/PlantScience/Cotton/Cotton-pest-management).

The IPM research conducted at CSIRO over recent years has led to the development of the Cotton Pest Management Guide (Mass 2014) which provide growers with core information to support improved pest management, and a collection of continually updated management tools delivered through an online decision support system called CottASSIST (https://www.cottassist.com.au/). Developed by CSIRO and the Cotton Research and Development Corporation CRDC (along with the former Cotton Catchment Communities CRC), the tools can help growers refine their management decisions by analysing specific crop information using the latest climate data and research knowledge. The main tools include:

- Crop development tool – uses daily temperature data (day degrees) to predict cotton development.
- Day degree report – predicts crop progress throughout the season using local weather data and sowing time, and compares to previous years.
- Last effective flower tool – predicts the data after which a flower is no longer likely to have sufficient time to complete development into an open boll (seed capsule).
- *Helicoverpa* diapause induction and emergence tool -- predicts the

percentage of *Helicoverpa armigera* pupae going into diapause and when they're like to emerge as moths.

Case Study: Ecologically Based Rodent Management – Southeast Asia rice fields

Rodent outbreaks can significantly reduce crop yield and have been estimated to be attributable to losses of about 77 million tonnes (John 2014). Climate extremes are expected to increase the impacts of rodents on food production in the future by changing the length of breeding seasons and therefore the ecology of rodents, which is likely to become more unpredictable (John 2014). A case study reviewed the research on rodent outbreaks and chronic yield losses due to rodents in rice cropping systems, with particular focus on Southeast Asia (John 2014). Rodent outbreaks are expected to become more serious and destabilizing for food security in this region in the future, but ecologically-based rodent management (EBRM) can act as an effective tool in addressing this issue to:

- Reduce farmers' dependence on rodenticides (EBRM project in Vietnam led to >50% drop in use of rodenticides (Palis et al. 2011)) – Environmental benefit.
- Promote farmers to work as a community.
- Include setting traps continuously and community rat hunting.
- Other management techniques include synchronized planting of rice crops among neighbouring farms, rat catching campaigns prior to transplanting, clearing weeds, reducing size of embankments, destroying rat burrows and constructing trap barrier systems – Trap Barrier Systems are found to be effective at reducing rodent damage up to 200m away (~15 Ha.).

A Number of studies have shown EBRM is effective at combating rodent destruction, e.g. (TBS increased rice production by 10-25% and increased average rice yields by 380kg/Ha. in West Java (Singleton et al. 2005; Singleton et al. 2003) and average yield loss in rice fields in Vietnam was reduced from 30% with traditional methods to 18% using EBRM (Phung et al. 2013).

Case Study: Long-lead ENSO prediction models to enhance Australian sugarcane harvest management.

The Australian sugarcane industry generates about $2 billion AUD annually (WMO 2014; Inman-Bamber et al. 2008) and one 'average La Niña event' can easily cost this industry in excess of $175 million AUD (Everingham 2008b). The particularly strong La Niña event of 2010 cost the industry close to $500 million AUD of which a large proportion could have been avoided if farmers had been made aware and were able to implement their management systems (Stone et al. 2012). In Australia, the decision about when to start the harvest season (June-November) must be made no later than March to allow sufficient time for farmers to complete mill maintenance (Everingham 2012). Using a long-lead ENSO prediction model (Everingham 2008b) combined with the sugarcane payment scheme, Everingham et al. (2012) compared a ENSO-forecast-driven harvest strategy with a standard and perfect strategy (maximum potential). The authors found that the region could save up to 1.9 million AUD per annum by starting the harvest season later than that conventionally practiced when warm ENSO conditions were predicted for the end of the harvest season. In a more recent study Everingham et al. (2016) showed that in >86 % of years, it was possible to determine if sugarcane production would be above median as early as September in the year before harvest. This accuracy improved to >95% for January in the year of harvest. Results demonstrate strong potential climate forecast technologies can improve adaptive management of sugarcane systems and deliver economic benefits.

Recommendations:

- Crop simulation models such as APSIM and DSSAT should be incorporated into such studies to detect the potential effects of other factors such as soil types, farmer management strategies, and trends in climate variability due to climate change.
- The value of these types of forecasts can be significantly increased by releasing more refined forecasts and educating agricultural producers how to use them (Chen et al. 2002).

Case Study: ENSO-based forecasts for Nitrogen fertilizer management of wheat in Paraguay

Wheat is one of the most important food crops covering about 22% of the world's cultivated land (Licker et al. 2010) with 2015/16 production exceeding 734 million metric tons (Table 1). It is grown in a wide range of growing conditions, and yields often vary from year to year due to seasonal variability in rainfall and temperature (Powell and Reinhard 2016; Licker et al. 2010; Lobell et al. 2011). The study used the widely tested APSIM wheat model (Keating et al. 2003) and three different forecast methods: an ENSO-persistence-based forecast, a global climate model (GCM) with a lead time of 2 months, and the same GCM with a lead time of 1 month.

The ENSO-persistence-based forecast resulted in higher net returns compared to the GCM-based forecasts. Model simulations indicated that by applying more fertilizer (2-3 times as much) and sowing in optimal dates, farmers could increase their gross margin (accounting for increased cost of fertilizer) by up to 61% during El Niño, 41% during neutral, and 58% during La Niña. By understanding ENSO phases and associated rainfall and temperature, farmers in Paraguay are able to change their management practices, specifically tailoring their nitrogen fertilizer applications to ENSO forecasts and saving >100 US$/ha when compared to normal practices (Ramirez-Rodrigues et al. 2014).

Education and Service

Case Study: AgroClimate – A web-resource for proactive decision-support and learning

The majority of crop failures in the USA are associated with either a lack or excess of rainfall (Fraisse et al. 2006). As discussed throughout this report, climate forecasts can be used to reduce risks posed against agriculture but simply providing more accurate climate forecasts in not enough. Climate information is only useful when there is a clearly defined adaptive response and benefit(s) (Fraisse et al. 2006). AgroClimate is an innovative web-resource for proactive decision-support and learning (http://agroclimate.org/), providing climate forecasts combine with interactive tools. It helps the agricultural community, extension services, forest managers, crop consultants, and policy makers in the southeastern USA make more informed decisions to save money, increase production and prepare for climate extremes.

The first version of AgroClimate was developed in 2005 in collaboration with other institutions under the Southeast Climate Consortium (SECC) and funding from the USDA–RMA (Fraisse et al. 2006). AgClimate, as it was formerly named, started out as a website established for the dissemination of climate information, crop management tools, and associated decision support systems. The website allowed for easy and rapid updating of information, such as climate outlooks and forecasts (Sivakumar and Hansen 2007; Fraisse et al. 2006). The first step for implementing AgClimate was the development of a climate database for the region. Weather observations were compiled from the National Weather Service's Cooperative Observer network. The crops initially selected for crop production risk based on climate forecasts were peanut, potato, and tomato (Fraisse et al. 2006). This was done using the crop simulation model DSSAT-CSM (Jones et al. 2003). The website was purposely designed for easy modification and updating by personnel of the SECC, rather than having to rely on professional programmers. In addition, the design of AgClimate could also be easily migrated to other regions and/or counties as long as the underlying database was populated (Fraisse et al. 2006; Sivakumar and Hansen 2007; Pavan et al. 2011). AgroClimate is currently maintained and operated by the University of Florida. It includes climate forecasts and outlooks combined with dynamic risk management tools linking climate, crop development, crop diseases, crop yield and drought data, including information on selected agricultural crops, trees, livestock and fodder. Dynamic tools always default to the current ENSO phase for the evaluation of climate-associated risks. However, the user can also evaluate the results for alternate ENSO phases and various management scenarios (Pavan et al. 2011). Many of the University of Georgia forage extension agents regularly consult AgroClimate for guidance in making strategic planting and fertilization decisions as well as decisions on whether to purchase additional feed ahead of a forecasted bad winter or spring. Tools such as the Strawberry Advisory System (SAS) have led to up to a 50% reduction in dependence of fungicides (Pavan et al. 2011). In Paraguay, ENSO data from AgroClimate has been used to make decisions on whether to leave cattle in low-land areas and has saved thousands of dollars in transportation and land leasing costs (SECC 2014).

Due to the fact that regional agents are less likely to be familiar with the concept of climate and its applicability in agriculture, it is imperative that several workshops be held during the developmental phase (Fraisse et al. 2006). During early development of AgroClimate (previously AgClimate), an import aspect of the design methodology was a strong interaction with regional institutions to ensure that the information provided in the system is relevant for user needs and that the language and formats used are appropriate. Of particular importance is strong interaction with end users for testing and evaluation of layout design and functionalities.

Although AgroClimate is restricted to use in the south-eastern US, its modularity and decentralised administration make it applicable to other regions. Prototypes are currently in development or operational in several countries in Africa (e.g., Mozambique) and South America (e.g., Brazil and Paraguay). For example see http://fecoprod.agroclimate.org/ for Paraguay and http://mz.agroclimate.org/ for Mozambique.

Take home messages:

- Climate forecasts can be used to reduce risks posed against agriculture but simply providing more accurate climate forecasts in not enough. Clearly defined adaptive response(s) and benefit(s) must be included.
- There is great potential in the use of online web portals such as AgroClimate to combine climate forecasts and crop management risk tools. However, there are a few requirements:
    - Easy and rapid updating of climate data in real-time, preferentially automated
    - Designed for easy modification and updating limiting the need for dedicated professional programmers
    - Workshops to be held in early phases of development and a strong interaction with regional institutions
    - Strong interaction with end users for testing and evaluation of layout design and functionalities

Biotechnology for Agriculture

Case Study: Genetically modified (GM) crops

Significant opportunities exist to improve crop yield and the resilience of cropping systems to pest and diseases, and drought using genetically modified (GM) varieties. However, the general public remains largely unaware of what a GM plant actually is or what advantages and disadvantages the technology has to offer (Qaim and Zilberman 2003). There is also public concern over environmental and health risks and their use remains controversial (Azadi et al. 2016; Whitfield 2015). A review by Azadi et al. (2016) summarises the advantages GM crops and challenges faced by small-scale farmers.

The most significant advantages of GM crops include:

- independent to farm size
- environment protection
- improvement of occupational health issues
- potential of bio-fortified crops to reduce malnutrition

Challenges faced by small-scale farmers for adoption of GM crops include:

- availability and accessibility of GM crop seeds
- seed dissemination and price
- lack of adequate information
- high research and development (R&D), and production costs
- intellectual property right regulations
- concerns on socio-economic and environmental safety

A recent meta-analysis (Klumper and Qaim 2014) of all the relevant literature since 1995 revealed that, on average, production of GM crops reduced chemical pesticide input by 37%, increased crop yields by 22%, and increased farmers' profits by 68%. Yield and profit gains are higher in developing countries than in developed countries. These numbers are significant and compelling considering the accumulated land area planted with GM crops in 2015 was approximately 179.7 million ha (James 2015). According to the ISAAA (James 2015), profit gains from GM crops in 28 countries amounted to more than US$150 billion since 1996. Between 1997 and 2014, GM cotton brought an estimated US$17.5 billion worth of benefits to Chinese cotton farmer. In summary, the literature reveals conclusively that there are considerable benefits of GM crops for both the environment and for the economic well-being of farmers, particularly in developing countries.

Recommendation:

- Focus on how to make biotech crops accessible and affordable in developing countries

Financial Tools

Case Study: Risk pooling at regional and national level to reduce financial exposure to drought - Africa RiskView (ARV)

Drought is a recurring and increasing threat to the population of rural farmers in Africa. Over the past decade, sub-Saharan African countries have faced some of the most catastrophic droughts in history (WorldBank 2013). Africa RiskView (ARV) is an innovative and flexible desktop application and online tool established for the sub-Saharan region of Africa (www.africariskview.org). It was designed by the World Food Programme's (WFP) Climate Disaster and Risk Solutions (CDRS) unit in 2008 to translate real-time globally-available rainfall data, crop parameters and livelihood information into food security outlooks, and was the first platform of its kind. It combines existing operational rainfall-based early warning models on agricultural drought in Africa with data on vulnerable populations to estimate food insecurity response costs across the continent. Such information is critical for financial preparedness for drought and for providing the basic infrastructure needed to establish and manage a parametric risk pool and trigger early disbursements of aid.

To estimate the risk of a region becoming food-insecure due to drought, ARV uses satellite-derived rainfall data for the entire sub-Saharan Africa measured against a Water Requirement Satisfaction Index (WRSI), considered a better indicator than cumulative rainfall (Verdin and Klaver 2002). The WRSI monitors water deficits throughout the growing season, and captures the impact of timing, amount and distribution of rainfall on staple annual rain-fed crops (Verdin and Klaver 2002). The index is based on a model developed by the United Nations Food and Agriculture Organization (FAO) to determine if a given piece of farmland has received enough rainwater to support its staple crops. The results yield a colour-coded map identifying areas which have received adequate rainfall and areas that have not. Once the magnitude and extent of the impacts of weather shocks on food crops and rangelands are estimated, ARV accurately estimates the number of people in the area potentially affected who depend on rain-fed agriculture and their ability to endure a bad harvest to predict how hard a dry spell is likely to hit them. Finally, the range of potential response costs at the continental, regional and country scale are determined. Thus, ARV determines beneficiary numbers and intervention costs before the spending actually needs to occur. A user-friendly interface and rendering over GoogleMaps means the basic functions of ARV are accessible to users without computer or climate expertise, although experts may utilize more advanced features. During its beta-testing phase, ARV demonstrated a 90% correlation between estimated number of people affected and actual number of people requiring assistance. However, without good data, it is impossible for the Africa Risk View software to function appropriately.

Upon completion of the software in November 2009, the project team both realised the great savings potential of ARV in combination with a pan-African contingency fund for African countries. This encountered great interest from the African Union (AU). Traditionally, the international humanitarian community responds to drought disasters on an ad hoc basis whereby limited contingency funds are made available, a damage assessment is made, a funding appeal launched, and finally intervenes once funds become available. The delay in response caused by these processes is about 7-8 months (Lung 2013). The African Risk Capacity (ARC) is a groundbreaking project of the African Union established in 2012 and designed to improve the current response to drought by transferring risk away from communities most threatened by oncoming drought to a risk pool and then on to international financial markets that can better handle the financial burden. This effectively reduces the time between EVENT and RESPONSE so that appropriate assistance can be mobilized quickly and efficiently to those in need. Knowing ahead of time the potential amount of funds available also allows for direct cost savings (evidence from Ethiopia shows $1 spent on early response can save $4 in the cost of intervention once a crisis has escalated), while in general it is estimated to be 3 USD for every 1 USD spent, when compared to traditional humanitarian response mechanisms (Lung 2013).

ARC currently (as of Feb 2016) has 32 signatories out of 54 countries and plans to have 1.5 billion dollars of coverage for 30 countries by 2020. The country of Senegal has been the first to benefit from participation in the ARC. Senegal is the drought-prone Sahel region but is heavily reliant on rain fed agriculture (only 5% irrigated). Major crops include millet and peanuts. In 2014/15 the country experienced late and poor rains which led to a 40% decrease in the cereal production compared to 2013/14 and a 45% decrease compared to the average for the previous five years. The Africa Risk View (ARV) software detected that the December harvest in Senegal would be affected by the late onset of rain, and the Senegalese government was therefore able to respond by beginning to plan its response as early as September. The ARC made its first payout, totalling $25 million USD, to three participating countries in 2015, of which $16 million USD was made out to Senegal. The payout was focused on three kinds of activities: livestock relief; food assistance; and supplementary feeding for mothers and children and was made out even before relief agencies had fully mobilized resources to respond to the unfolding drought, highlighting its effectiveness and ability to function as anticipated.

The ARC and the software Africa RiskView provide an important step forward in creating a sustainable African-led strategy for managing extreme climate risks. However, in addition to supporting ARC, the information produced by Africa RiskView has broader applications.

Summary:

- ARV could help to target early food security assessments in specific geographic areas or help with contingency planning and emergency preparedness for future shocks in a country.
- The tool could also be helpful in guiding planning and investment decisions aimed at enhancing agricultural productivity or market development.
- To date the tool focuses on drought, but could be applied to other climate extremes such as flood risk.

Final remarks

Over the last two decades, there have been significant advances in seasonal predictions, and their methods, delivery and applications in various sectors, especially agriculture. The technological advances including the widespread availability of cheap and powerful computers and software, as well as the evolution of mobile technology. The use of mobile phones in agricultural areas is causing a revolution in the way information is provided to farmers around the world, including in developing countries where Information and communications technologies (ICTs) have spread rapidly in the recent years. Mobile phones are an effective way to reach farmers at the time tactical decisions are made in the field and nicely complement information and tools available on the web that provide a more in depth analysis of climate-related risks and can be used as planning tools for strategic decision making. It is estimated that about 70% of the world's population will be using a smartphone by 2020 and about 26 billion mobile devices will be connected to the internet (Ericsson 2015). It will be developing countries that experience the greatest increase. Therefore, there is great potential for improved awareness and mitigation of climate extremes using smart technology in developing countries over the next few years. Agrometeorological Advisory Services can increase nationwide crop yield while reducing costs of cultivation (Maini and Rathore 2011). The key to achieving this is to improve the link between climate information and agricultural practices, especially those of smallholder farmers in developing countries (Mberego and Sanga-Ngoie 2014; Oyekale 2015; Winarto et al. 2011). The technological improvements of satellites may provide the opportunity of using remote sensing imagery for real-time soil moisture and temperature data (Chew et al. 2016) that could feed into national drought-warning systems or assist in the irrigation of crops. Finally, there is great potential in the use of biotech crops to reduce the need for agrochemicals and increase crop yield and profits, especially in developing countries, although several challenges will have to be overcome (Azadi et al. 2016; Klumper and Qaim 2014; Qaim and Zilberman 2003). Transformational approaches will be required in the management of natural resources, including new climate-smart agriculture policies, practices, and tools such as those discussed in this report. Better use of climate data in assessing risks and vulnerability, and increased financing for food security will also be important (IPCC 2012b).

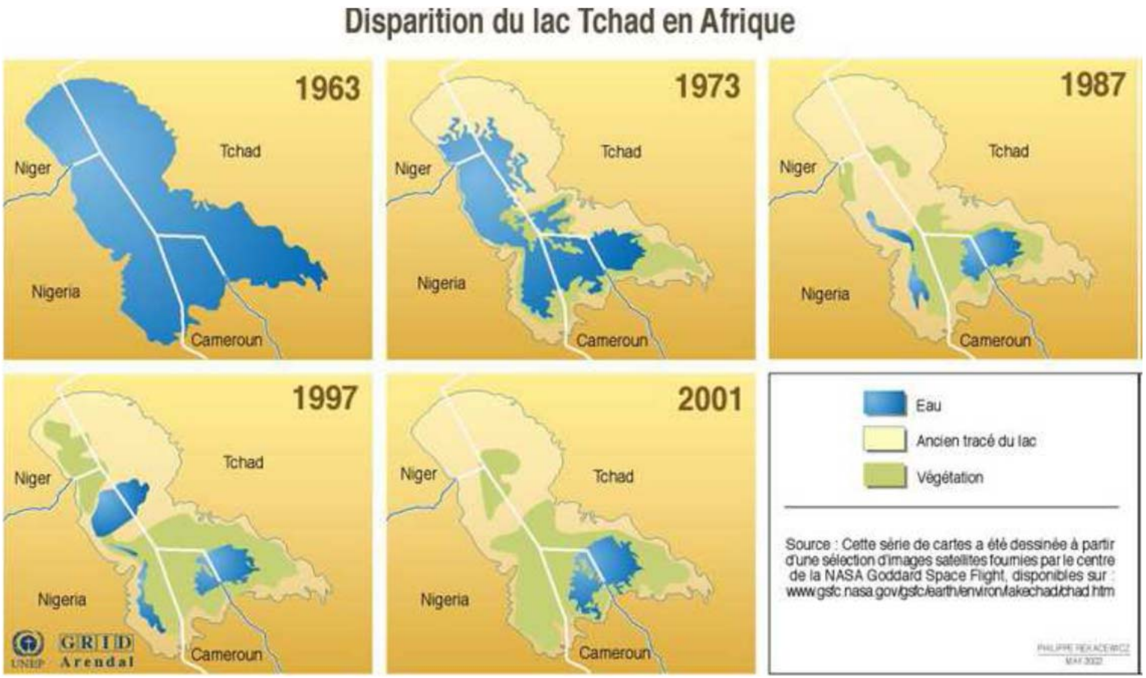
Case Study: Climate and weather events, consequences and farmers adaptation strategies on agriculture in Chad

Introduction

Many countries in tropical and sub-tropical regions are expected to be more vulnerable to global warming because additional warming will affect their marginal water balance and harm their agricultural sectors. The problem is expected to be most severe in Africa where current information is the poorest, technological change has been the slowest, and the domestic economies depends the most heavily on agriculture. African farmers have adapted to a certain amount of climate variability, but climate change may well force large regions of marginal agriculture out of production in Africa (Robert M.; Ariel D.; Arne D. July 2000)

Like other sub-Saharan countries, Chad is highly vulnerable to climate variability and climate change. Climate change and extreme weather events such as droughts, floods, heat waves, and high winds create a serious problem to natural resources including, water resources (surface and groundwater), land resources, and, agro-pastoral and fisheries resources. Chad has 39 million hectares of arable land of which 5.6 million is irrigated, and the livestock has been estimated, to be more than 19 million heads (across all species) Jean Ngamine, Caritas Suisse in Chad, june 2012

Of enormous concern to agricultural industries is the severe decline in area of Lake Chad (Figure 3).


Disparition du lac Tchad en Afrique

Source : Cette série de cartes a été dessinée à partir d'une sélection d'images satellites fournies par le centre de la NASA Goddard Space Flight, disponibles sur : www.gsfc.nasa.gov/gsfc/earth/environ/lakechad/chad.htm

Figure 3 In 1963 to 2001 the Lake Chad has lost her area (from 25000 km^2 to 2500 Km^2)

The agriculture and the cattle sectors are major contributors to the economy of Chad. In Chad, natural climate variability causes droughts which change the regime of rivers, declines farming production and the loss of lives both human and animal. Under a changing climate these events are likely to become more frequent (Abessolo Amougou Patrice, August 2013). For example, in 2008 Chad has experienced severe? flooding although the rainfall is unevenly distributed. Where was the flooding experienced? In the south of Chad. The consequence of this flooding event are: - Destruction of yields - fall in yield production – coming out cattle epidemic. In 2011, the combination of deficit and poor distribution of rainfall caused 43% reduction in plantings in the Sahel region and 18% in the Sudan region. The cereal deficit recorded was 455,000 tons.

To combat the adverse effects of climate change, the country's authorities have set up a national adaptation program (NAAP).

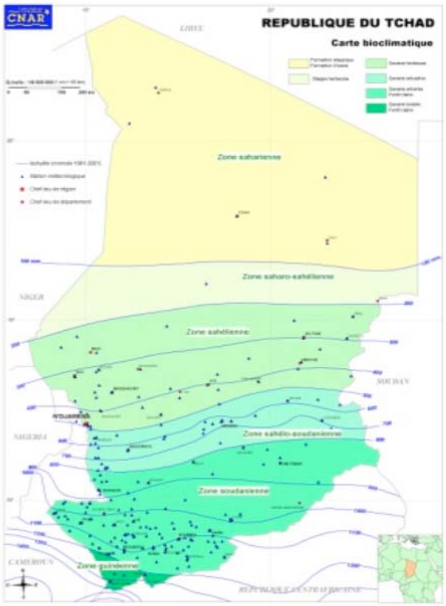
Agro ecological Situation and Production Systems

Chad is divided into three distinct areas (Jean N. Caritas Suisse au Tchad, 2012

- The Saharan region (47% of the territory), with an average annual rainfall of less than 100 mm, is characterized by a complex system combining oasis date production, irrigated subsistence agriculture, small and sedentary livestock rearing transhumant camel;

- The Sahel region occupies 43% of the country with rainfall of between 100 and 600 mm. Production systems are agro pastoral and pastoral kind, characterized by the combination of rain-fed agriculture to livestock transhumance consists of small ruminant flocks of cattle and to a lesser extent, camels. The Sahel is a livestock area par excellence. However, agriculture is also practiced there;

- The Sudan region (10% of the country with average annual rainfall exceeds 800mm). It is characterized by diversified production systems, combining crops of cereals, pulses, oil seeds, tubers and cotton to a small breeding diversified and important livestock development of oxen plus a nomadic grazing. Many nomads come to the region with their animals.



(Source : Centre National d'Appui à la Recherche (CNAR), Tchad 2007)

Climate Change Consequences on Agriculture

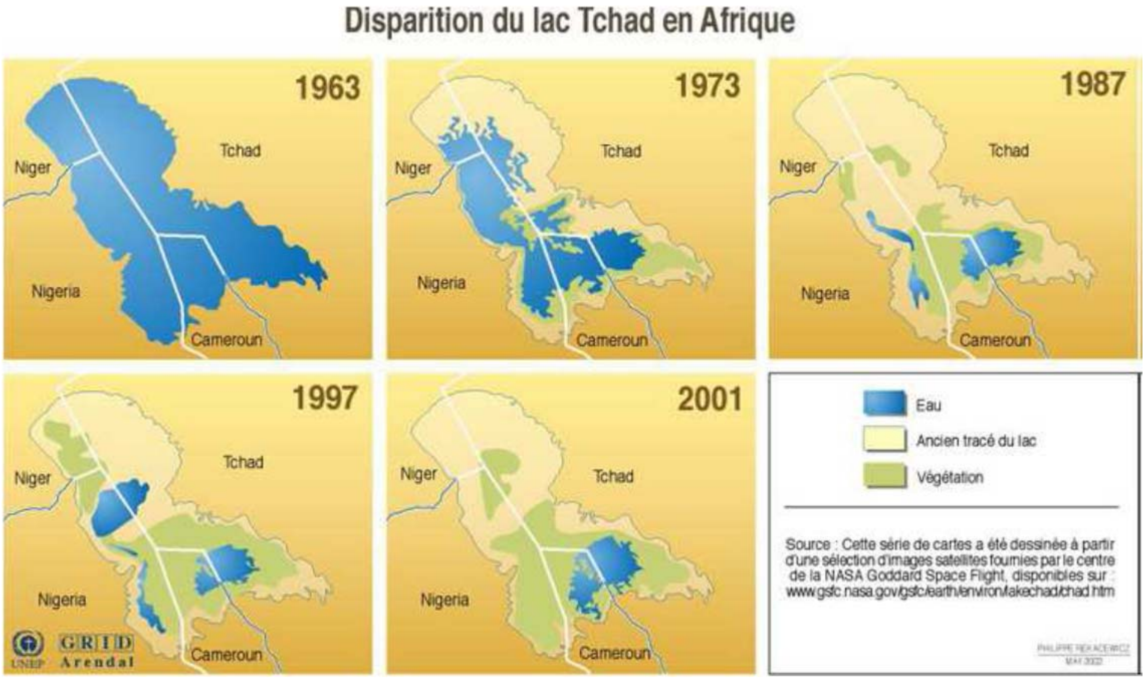
The climate change consequences touch many sectors in Chad. The sectors more concerning to the effects of climate change are: agriculture, livestock, peach and economic sector.

The table under saw how climate stimuli and their effects to millet and sorghum.

Despite many technological advances, weather and climate remains a key underpinning factor that impacts agricultural productivity. Climate change is leading to changes in global and regional climates which can have severe impacts on the growth of key crops such as rice, maize, millet, sorghum, and coffee as well as on socio-economic activities associated with agriculture and distribution of food.

In view of this, an impact chain approach analysis was conducted that highlights the consequences induced by climate stimuli, it shows the related implications of climate and identifies the required adaptation measures to counteract the relevant stimuli (see Table 3).

For millet, high temperature rise in the growing season, droughts and strong winds cause major biophysical impacts. Sorghum is sensitive to flooding especially during 30 days after emergence.



Source : Cette série de cartes a été dessinée à partir d'une sélection d'images satellites fournies par le centre de la NASA Goddard Space Flight, disponibles sur : www.gsfc.nasa.gov/gsfc/earth/environ/lakechad/chad.htm

In 1963 to 2001 the Lake Chad reduced from h 25000 km^2 to 2500 Km^2 primarly due to. ..The change due to more humans and animals taking from the lake is secondary.

Table 3 Impact analysis for Millet and Sorghum production in Chad – adaptation measures in response to climate stimuli, biophysical and socio-economic impacts.

Millet and Sorghum impact chain			
Climatic stimuli	**Biophysical impacts**	**Socio-economic impacts**	**Adaptation measures**
Temperature	• Low temperature causes germination inhibition, leading to growth and yield depression. • Can tolerate higher temperatures during the life cycle. If temperatures are too high seed can be affected.	• In general lower yield leads to lower production therefore food insecurity, as well as reduced income for farmers, • Increased demand for millet and sorghum causing higher prices at local markets	• Use of heat tolerant cultivars (region specific) Please explain in more detail Use varieties who resist at higher temperatures.
Rainfall	• High-intensity rains can cause increased erosion. • Millet has a higher drought tolerance than sorghum: absence of rainfall for long periods causes delay in germination and reduced growth. • Absence of rainfall during fruit formation causes reduced yield.		• In case of high rainfall, adopt erosion protection measures • Increasing soil water infiltration rates through soil improvement measures (e.g. increasing the organic matter content, crop rotation with deep rooting plants), • If possible apply additional irrigation during fruit formation throughout dry spells. • Farmers could plant millet instead of sorghm if it was going to be dry ?
Flooding	• Millet can withstand short periods of water logging; • Sorghum is more sensitive especially during 30 days after emergence: prolonged flooding leads to yield reductions.		• Change of fields for growing please explain in more detail • Millett and sorghum in case of repeated flooding, application of soil amelioration measures (e.g. improved drainage). When soil is saturated, farmers can use a drainage system to

			avoid asphyxiate young plant.

Adaptation Strategies

To help farmers build resilience and adaptation strategies, the Meteorological service provides strategies to help farmers respond to situations when seasonal forecasts indicate dry conditions or wet conditions. For example, if the seasonal forecast indicates that the typical rainy season will in fact be dry, farmers must respond to this information by carefully considering the planting area of crops and their likely yield.

In 2009 Chad has developed his National Action Plan for Adaptation (NAPA). This NAPA had made up of ten points:

- Master and water management for adaptation to climate change for pastoral activity.
- Development of intensive and diversified crops adapted to climate risks.
- Implementation of the development, dissemination and sustainability of cropping calendars for small farmers vulnerable to climate change.
- Information, Education, Communication for adaptation to climate change.
- Realization of defense works and land reclamation for development of agricultural activities face to degradation caused by climate change.
- Prevention of land degradation caused by climate change. Improving community grazing areas to reduce the migration of farmers to climate change.
- Minimise the displacement of farmers due to impacts caused by climate change that makes it difficult to farm.
- Improved seasonal forecasting of rainfall and runoff of surface water.
- Creation of a National databases to inform adaptation policies to climate change.
- Creation and popularization of food stock: research to preserve soil health and allow the renewal of pastures to strengthen the capacity of farmers in the renewal of pasture.
- Develop management strategies to minimise Climate Risk

Livestock response to climate change

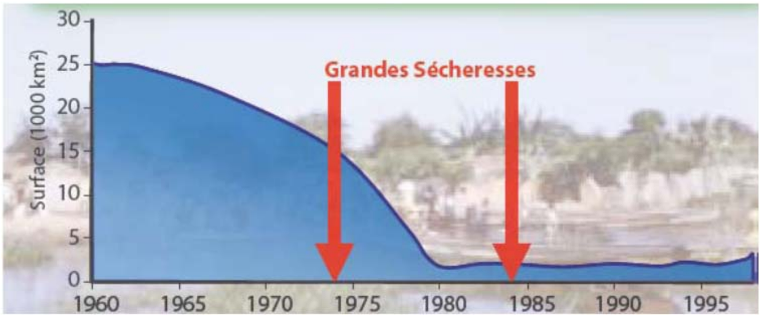
Like agriculture, livestock can also be affected by climate and, hence climate change in Chad. In the dry season, the high temperatures affect pasture land and limit water availability for livestock causing managers to limit the density of livestock in grazing areas.

Precocious descent of transhumant in August. Normally, this descent begins at the end of October or at the start of November. This early descent on south of Chad cause conflict between cattle farmers and agricultural farmer.

Recommendations

Adaptation strategies are short and long-term changes to human activities that respond to the effects of changes in climate. In agriculture, adaptation strategies in Chad, will require cost-effective investments in water infrastructure, emergency preparation for and response to extreme weather events, development of resilient crop varieties that tolerate temperature and precipitation stresses, and new or improved land use and management practices.

Flood at Chad in 2012: Logone basin portion



Red flitch indicate droughts years on Chad

Fields of millet completely destroyed because drought

Insurance Strategies for Reduction of Weather- and Climate-Related Risks in Agricultural Production Systems

Figure 4 2013 severe drought in the US destroys corn field (Bouchard 2014)

Introduction

In recent years and months, the subject of risk and crisis management has been given increased attention by farmers and politicians. This is due mainly to the co-occurrence of three developments: the very recent increased volatility of the markets, the reduction of traditional market support instruments and the growth in the frequency and intensity of extreme climatic events as a consequence of climate change (Scientific Advisory Board for Agricultural Policy 2011). The increase in the frequency and intensity of extreme climatic events as a consequence of climate change speaks in favour of a rise in volatility in the future.

Increased extreme weather events and the subsequent increased yield loss is a significant issue which affects not only farmers and the wider community, but the rest of the world (Lobell and Field 2007). Increased extreme weather events will lead to increased yield loss and reduced income for farmers. Furthermore, increased extreme weather events leads to greater market volatility and reduced food security; more frequent production shocks due to increased temperatures, droughts and floods will cause greater price uncertainty due to rising global food prices and the reliance on imported products (Carter et al. 2016; Swiss Re 2013; Sivakumar et al. 2013; FAO 2011). The Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA) identified climate change as the most important issue in the West Asia and North Africa (WANA) region (Sivakumar et al. 2013). Climate has been found to cause up to 30 % variation in crop yield (Lobell and Field 2007) and extreme weather events can have devastating impacts. Worldwide, floods are the most catastrophic to humans with an estimated 500 million people impacted (Honegger 2016). Droughts in the US in 2012 were expected to cost insurance companies $US10 – 14 billion (NRAC 2012).

Crop insurance is being investigated as a risk management tool to mitigate the impacts of climate change and increase resilience in the agricultural industry (Enjolras et al. 2012; Greatrex et al. 2015; Field et al. 2012; Zaki 2016; Bhushan et al. 2016; Botzen et al. 2010). Crop insurance can sustain farms by recovering losses, allowing farmers to quickly recover (especially in the case of index insurance), and builds resilience in farmers by encouraging them to take more risks with crop diversification, which can lead to higher yields, more robust farming and lower food prices (Enjolras et al. 2012; Greatrex et al. 2015; Isakson 2015). Crop insurance spreads and transfers the financial risk of climate change; risks are spread amongst all clients purchasing insurance products and transferred to the insurer and investors who purchase insurance products as part of their portfolio (Yang 2010; Surminski and Oramas-Dorta 2014). It also places less burden on taxpayers by reducing or eliminating the need for government disaster relief.

Despite the benefits of crop insurance, its popularity varies significantly globally depending on the region, type of insurance and level of government support. Overall, crop insurance is well established in the United States, parts of Europe and Asia but is relatively new and has low uptake in developing countries and Australia (for global distributions of the different types of insurance covered in this report – multi-peril crop insurance, named (or single) peril insurance and index insurance – see Figure 5, Figure 6 and Figure 7) (Barnett 2014; Bielza et al. 2008). It is estimated that in developing nations only 3 % of natural disaster yield loss are insured while in developed nations (except Australia), 40 % are insured (Surminski and Oramas-Dorta 2014).

The primary reasons for low uptake of insurance products are that the products are too expensive. This is particularly the situation for multi-peril insurance with no government subsidies. Many farmers perceive insurance as an unnecessary cost (Farzaneh et al. 2017). Insurance is heavily subsidized by governments in the United States and other countries (Vedenov and Barnett 2004). In contrast, despite Australia being one of the riskiest agricultural countries in the world (due to the variable climate and unreliable market conditions), only 1 % of Australian farmers have insurance cover (NIBA 2017) mostly due to the high cost of insurance premiums (including the excess stamp duty, which is > 10 % of premiums) and the lack of government subsidies (Nguyen et al. 2007). Improving our understanding of insurance products, including their advantages and disadvantages, and the issues faced by farmers in taking up insurance will improve the quality of insurance products which will increase farmers trust in the products and insurance industry and, hopefully, increase uptake. Increased uptake of crop insurance will minimise the impact of climate change on global food security by helping to spread the risk, reduce the burden on the taxpayer, reduce market uncertainty and make the agricultural industry more resilient to climate change.

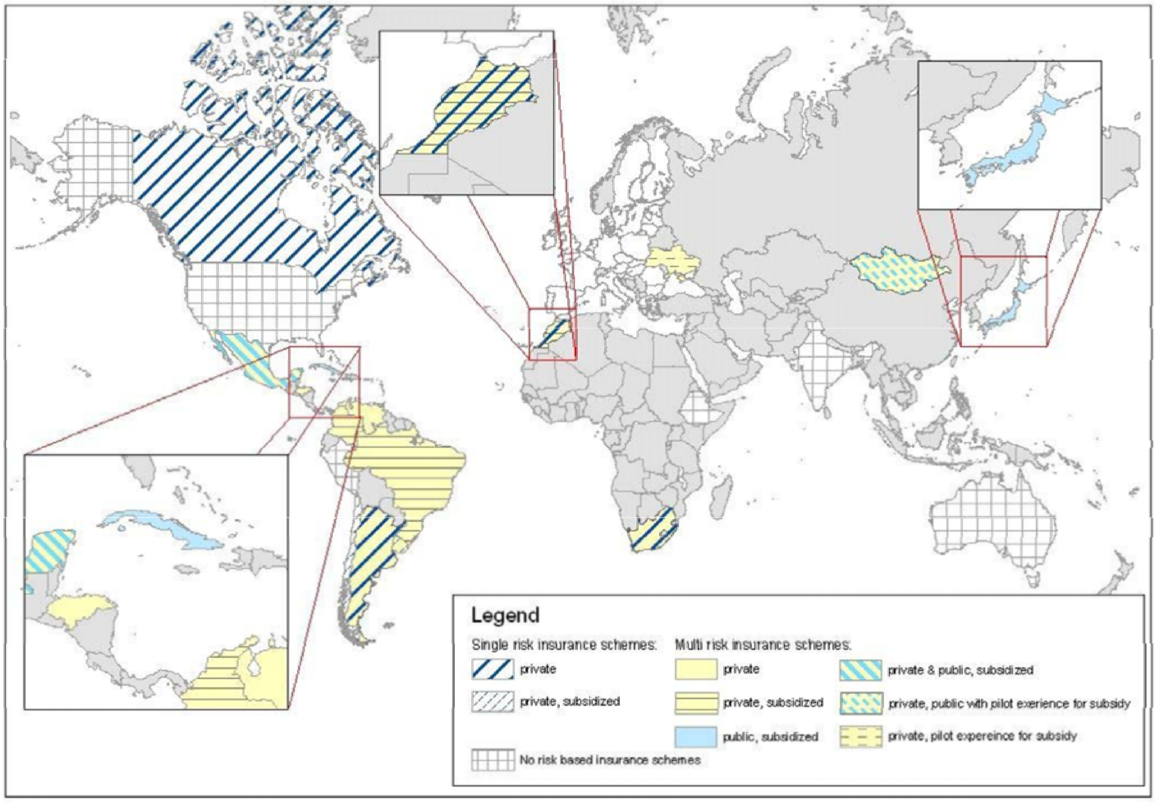


Figure 5 Global distribution of named peril insurance products as at 2008, sourced from Bielza et al. (2008). Named peril insurance products are referred to as single risk in Bielza et al. (2008), and the multi-risk insurance schemes (a combination of several perils but is separate from multi-peril insurance) are not covered in this report.

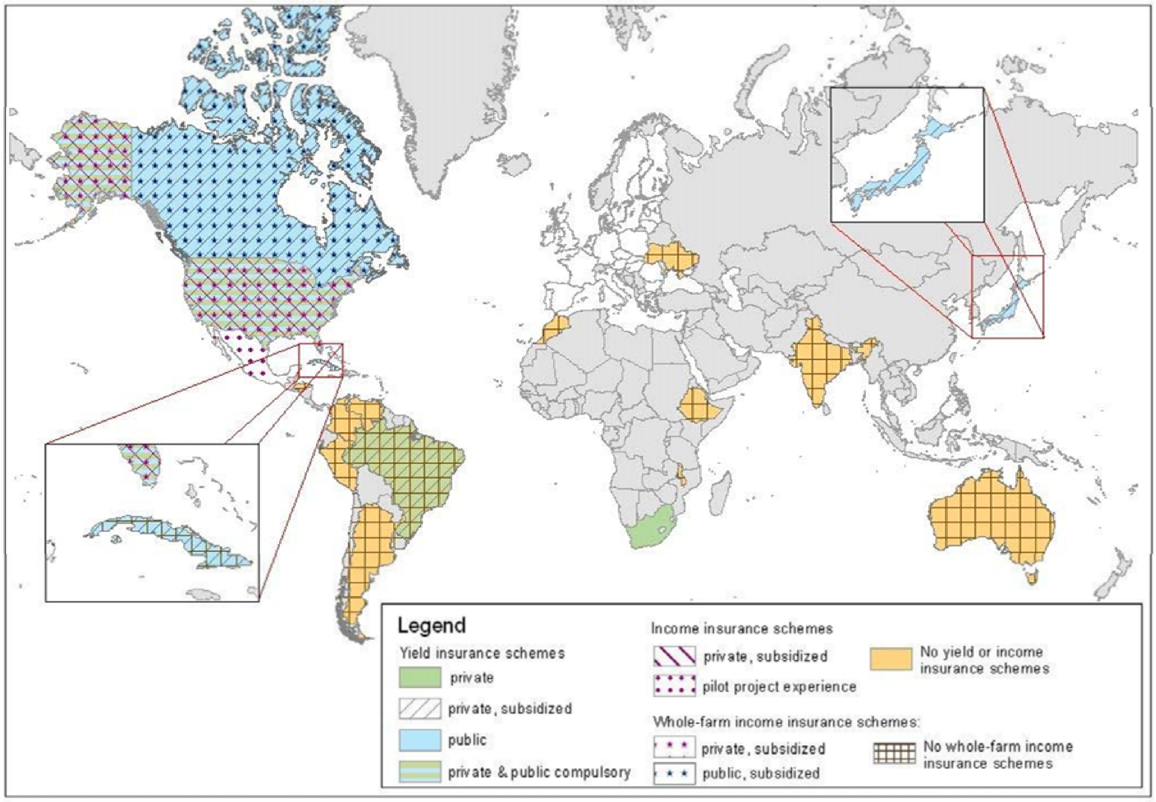


Figure 6 Global distribution of multi-peril insurance products from Bielza et al. (2008). Multi-peril products are referred to as yield insurance schemes in Bielza et al. (2008), and the income insurance schemes are not covered in this report.

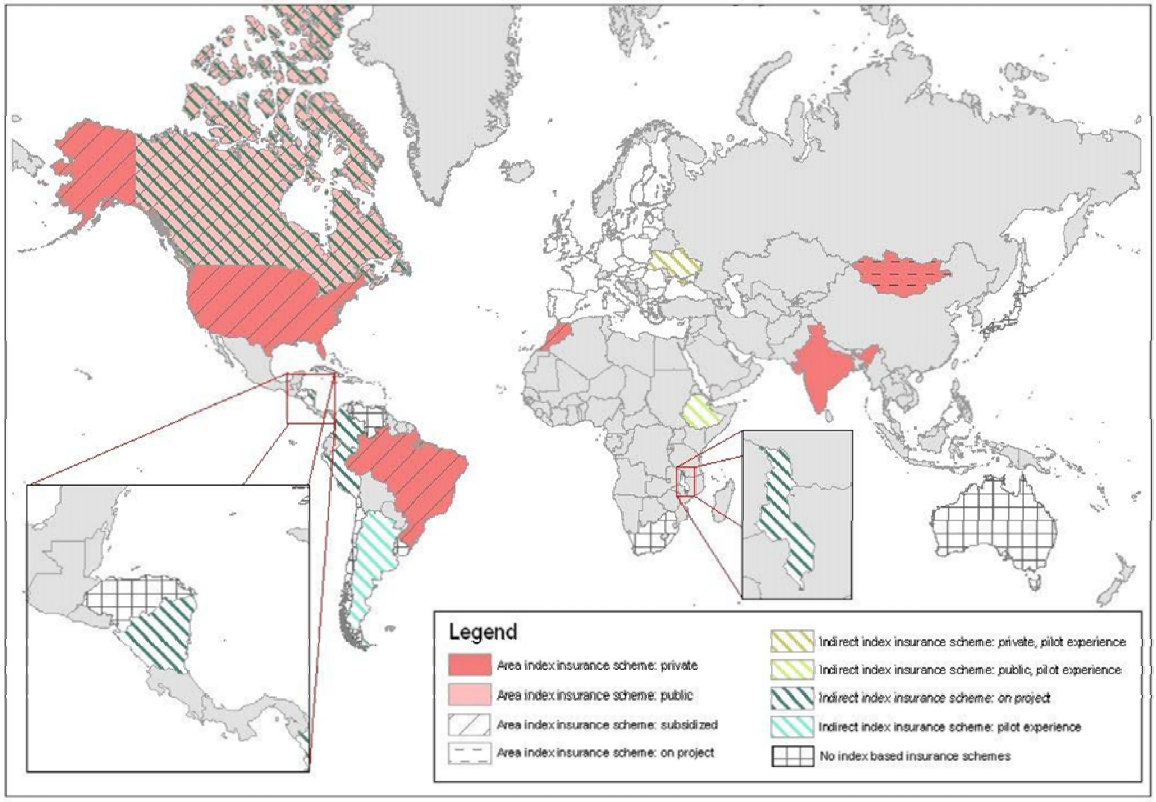


Figure 7 Global distribution of index insurance schemes from Bielza et al. (2008) who have separated index insurance into area index and indirect index. Area index refers to an area average yield or income, while indirect index refers to weather based indices derived from, for example, satellite images of vegetation index) and, as this report does not distinguish between the two, can both be considered as index insurance.

The purpose of this study is to provide recommendations to facilitate the adoption of crop insurance. The major types of crop insurance are presented, as well as their advantages and disadvantages. Successful case studies in each of the United Nations (UN) regions (Africa, Asia-Pacific, Eastern European, Latin American and Caribbean, and Western European) are presented for each type of insurance. From these successful studies, recommendations are made to improve insurance products and provide strategies to insurance companies.

Sources of Weather and Climate Data for and development of Products and Applications to Support the Insurance Industry

Vedenov and Barnett (2004) investigated the hedging efficiency of temperature- and rainfall-based weather derivatives (WD) for corn, cotton and soybeans in the US. Their findings indicate that WD can generally reduce the weather-related risk for farmers. However, the efficiency differs heavily between crops and districts.

Ender and Zhang (2015) found that in developed countries other mitigating mechanisms and governmental funds are more effective than in developing countries. This includes direct compensation as disaster aid, directed credit programs, subsidized lending, investment in research to allow mitigation through advanced agricultural technology or other market intervention systems that are for example common in the European Union. Further, only a small percentage of the population works in the agriculture sector. So it is easier for the whole society to compensate losses. For the farmers themselves, incomes in usual years are comparatively high and allow savings to balance a loss in a year with a bad harvest. In developing countries, a larger proportion of the population works as farmers and incomes are generally lower. These reasons increase the demand of the farmers for efficient risk transfer mechanisms. Because if the income is already low in a good year, it is obviously not sufficient in a year with low yields as for example new seeds for the next year need to be bought instead of producing the seed by themselves. Risk mitigating instruments that reduce the income fluctuations allow farmers to escape from chronic poverty.

Satellite imagery data allows computation of vegetation indices such as the Leaf Area Index or the Normalized Difference Vegetation Index (NDVI). This technique is thus more frequently used for large-scale food crisis early warning, livestock management, and forecasts of forage production. It has been implemented by Agriculture Financial Services Corporation (AFSC) in Alberta (Canada), Spain, and Mexico for grassland and forage insurance (Hartell et al. 2006) and by the Word Bank in 2005 in Mongolia (Mahul and Skees 2007) for livestock.

Types of Insurance Products / Strategies

The three major types of crop insurance products (multi-peril crop insurance, named peril insurance and index insurance), their advantages and disadvantages, and successful case studies of each type are outlined below. The advantages and disadvantages can inform improvements to insurance products by maximising advantages and minimising disadvantages, and the successful case studies will assist in providing recommendations to insurance companies of ways to improve insurance products and ideas on how to increase insurance uptake.

Multi-Peril Crop Insurance (MPCI)

Multi-peril crop insurance and named peril insurance are the two types of traditional indemnity insurance which pay indemnities for actual yield loss. As the name suggests, multi-peril insurance covers multiple peril events, including droughts and floods, and, unlike named peril insurance, does not attribute the loss to a specific peril (World Bank 2014). The coverage provided to farmers under multiple peril policies is generally defined in terms of the farmer’s expected crop yield and normally insure for 50 – 75 % of expected yield (NRAC 2012).

Multi-peril insurance is the most popular insurance product in the US and Canada due to large government subsidies (Barnett 2014; Di Falco et al. 2014), but is relatively new and limited in Australia and developing nations, with few farmers purchasing the product due to the high premiums and lack of government support (IPART 2016; NRAC 2012). The US and Canada have the highest government subsidised support for multi-peril insurance (up to 73 %), followed by Asia and Europe (50 % and 37 %, respectively), Latin America and Africa (36 % and 3 %), while the Australian government offers no subsidies on multi-peril crop insurance premiums (Bhushan et al. 2016). Furthermore, MPCI is relatively new in Australia and, as seen in other countries, new insurance products take time to establish.

Advantages

The advantage of MPCI is the wide range of threat coverage and the inclusion of events such as droughts and floods, which are likely to increase in the future due to climate change.

Disadvantages

The greatest disadvantage of multi-peril insurance is the high premium price. Multi-peril insurance is only popular in developed countries offering large government subsidies such as the US and Canada (Barnett 2014; Di Falco et al. 2014). US farmers pay only an administrative fee while in Canada 50 % of the premiums are subsidized (Bielza et al. 2008). In contrast, in Australia multi-peril premiums are not subsidized, although the federal government offers administration subsidies of $2500 and the NSW government has recently commissioned research into the use of multi-peril insurance (IPART 2016).

MPCI is also prone to moral hazards which contributes to increases premiums. Moral hazard refers to the situation where clients are less likely to adopt risk prevention strategies such as crop spraying, using quality products and improving their timing of planting. Moral hazards requires thorough assessments of claims which increases both the administrative costs and time between claim and payments (Boyd et al. 2011; Greatrex et al. 2015; IPCC 2012a).

Multi-peril insurance is also prone to asymmetric information, risk aversion and systemic risk which affect the ratio of indemnity payments to premiums purchased (also known as loss ratio). Asymmetric information refers farmers using their own information to assess their risk and decide whether or not to purchase insurance. These decisions leads to risk aversion, where only the highest risk clients are likely to take out insurance. Systemic risk refers to multiple clients being subjected to the same risk. Risk aversion reduces the spread of the risk to fewer clients and systemic risk means that there is a higher number of insurance claims (Keogh et al. 2011)

Single peril insurance

Single peril insurance covers yield loss due to a specific peril, typically hail, frost or fire. The percentage of damage to the crop caused by the peril is assessed and claims are made based on this percentage (World Bank 2014). Named peril products are the most common types of crop insurance in Australia (Hatt et al. 2012), are unpopular in the U.S. and Canada (Bielza et al. 2008), probably because of the alternative highly subsidized multi-peril insurance and in Europe are available in Sweden, Germany, France, the UK, Spain, the Netherlands and Austria (Smith and Glauber 2012) and in Africa,

Advantages

Named peril insurance premiums are lower than multi-peril premiums. The more perils the insurance covers the more expensive the premiums are (Roth and McCord 2008). Premiums can be as low as 0.1 to 0.55 % of the agreed crop value (Mahul and Stutley 2010; NRAC 2012)

Disadvantages

The disadvantage of named peril insurance is the scope of coverage, limiting claims to crop damage or loss due to sudden impact events such as hail, fire or frost. Named peril insurance does not cover the weather events related more to climate change such as drought and floods (World Bank 2014).

Index Insurance

Index insurance (also referred to as weather insurance, weather-index insurance, area yield insurance or weather derivatives) provides insurance for an item based on a related index and compensates for the uncertainty of weather conditions regardless of the actual damage to yield. Index insurance uses a standardized index - the basis for the contracts' payoff. For example, crops are insured using an index of rain, where too much or too little rain may result in lower than expected yield. A pre-defined index threshold is determined based on the correlation between index and yield, and once the threshold is exceeded (either higher in the case of floods or lower for droughts), clients are automatically paid.

Index insurance products are newer than traditional indemnity based insurance (named and multi-peril products) and are less common in developed countries but are becoming more popular in developing nations. In the large agricultural insurance developed countries such as the US and Canada, index insurance is much less popular because the multi-peril schemes are highly subsidised (Hatt et al. 2012). In developing countries, however, index insurance is becoming more popular due to the lower premiums .

Also, the removal of moral hazards further reduces administrative costs, as insurers are not required to investigate. Without the link to participants' individual behaviour, the fact that the index only depends on whether factors can eliminate problems of adverse selection and moral hazard (Ender and Zhang 2015). The main advantage of the index-based financial tools is their power to reduce the information asymmetry. The derivative payoff is estimated by objective, measurable, and transparent weather variable which cannot be intentionally modified by farmers or any other subject. Alternatively, the most important disadvantage of the weather derivatives and the index insurance they most frequently advert to is the basis risk. The cause of the production basis risk is that individual yield fluctuations in general are not perfectly correlated with the relevant weather variable. The spatial basis risk arises from the difference in weather patterns at the reference point of the derivative and the location of agricultural production (Spicka and Hnilica 2013).

Existing weather derivatives are commonly indexed using one weather variable, such as rainfall (R), temperature (T), wind speed (u), growing degree-days

(GDD) or CDD/HDD (cooling degree days/heating degree days, i.e., the number of degrees that a day's average temperature is above/below a certain level). Indices can also be constructed as a joint distribution of multiple weather variables (drought index). Mixture of practical single-variable and multiple-variable indices that provide the best predictive power for crop yields (Wang et al. 2013). Insured growers can achieve a higher utility from multivariate weather indices. Although this is quite obvious in theory, no such combination weather index is found in practice or in literature. There is a trade-off between choosing an index with a large number of weather variables that can improve on the efficiency of the contract, and choosing a single-variable index that is easily understood by the growers.

A financial weather contract can take the form of a weather derivative (WD) or of a weather insurance (WI) contract. Both instruments share the common feature of being triggered by an underlying weather index.

Advantages

The greatest advantages of index insurance are: cheaper premiums, faster payments, simple to manage and not vulnerable to moral hazards and risk aversion.

Index insurance has lower premiums than the traditional multi or named peril insurance due to lower administrative requirements. The simplicity of index insurance reduces participants cost for transaction and administration. Only the index needs to be monitored by the insurer, rather than individual client situations or behaviour (Greatrex et al. 2015).

Index insurance also provides faster payments to clients, as claims are not held up waiting on insurers to assess individual clients, enabling fast recovery from yield and income loss. A study in east Africa found that if insurance payments were delayed by 4 months or more after harvesting, the cost to farmers rapidly increased; a delay of 4 months increased cost to the farmer from $0 to $50, and a delay of 6 months increased the cost up to $13,000 (due to households being forced to sell assets or property due to reduced income) (Touffut 2015).

Index insurance is unaffected by moral hazards. The indemnity payments from index insurance occur only after a weather event has triggered the index, in contrast to multi or named peril insurance where payments are made based on the damage or loss of crops, therefore farmers are less likely to participate in moral hazard behaviour (Greatrex et al. 2015; NIBA 2016).

Disadvantages

Basis risk is the main disadvantage of index insurance and is the main reason farmers are unwilling to purchase index insurance premiums (Carter et al. 2016). Basis risk refers to poor correlation between the index and the product insured (i.e. crop) (Asia Insurance Review 2016). Because the insurance is based on an index (or derivative) rather than an actual loss, poor correlation can disadvantage farmers in the event of yield loss but no threshold exceedance. Although the reverse is also true, when threshold exceedance occurs but there is no damage or loss of yield – and therefore payments are still made – the risk of yield loss without payment is the greatest concern to insurance clients (Carter et al. 2016; IBLI ; Matul et al. 2013; NRAC 2012; Zaki 2016).

To minimize the basis risk, the chosen meteorological index has to be a good predictor of yields, and especially of bad yields. While products insure against low temperatures or frost (South Africa), others against excess water during harvest (India, Nicaragua, Rwanda and Tanzania) or against floods (Indonesia and pilots in Vietnam and Thailand), most of them insure against a lack of rain (Leblois and Quirion 2013).

Case studies:

There are limited studies on successful crop insurance schemes, particularly for multi-peril crop insurance products, either due to lack of data or the low popularity of crop insurance (Swain 2015). Therefore, in addition to some successful case studies, we have included studies which provide recommendations to highlight benefits of insurance products and opportunities to improve current insurance schemes (Lefebvre et al. 2014).

Table 4 Crop insurance case studies for the three main types of crop insurance (Single peril, multi-peril and index insurance) for different regions arounds the world, including successes and/or recommendations from each case study. Further details of each study can be found below.

Insurance product	**Region**	**Details**	**Successes (S) / Recommendations (R)**	**Reference**
Single peril	Iran	• Silkworm farming • Insurance began in 2003, insuring 8.5 % of silkworm eggs in Guilan Province, which increased to 57 % eggs insured in 2014 – 15 season (equivalent to 38 % of silkworm farmers in Guilan Province) • Increased to include more provinces • Not scaled in rural areas	(R) • Informing clients in a timely manner about: o the damage assessment schedule o expected wait on indemnity payments o policy purchase • Education about insurance products • Option to pay premiums in installments • Allowing clients to pay premiums upon receipt of indemnity payment • Close proximity to clients	Farzaneh et al. (2017)
Multi-peril	Bulgaria	• 1980 – 1991 compulsory, 1992 voluntary • Began as single peril, expanded to MPCI in 1992 • 80 % g'ment subsidised • 26.5 % of farmers purchased insurance in 2011 (60 % multi-peril, 20 % single peril) • Premiums = €6.6 million, indemnities = €4.7 million in 2011	(S) Increased participation likely due to: • Larger farms (i.e. larger incomes) • Being in a largely agricultural region (farmers in the north-west more likely to purchase insurance) • Increased risk profile (i.e. greater exposure to and perception of risk increased purchase of insurance products) (R) • Tailor insurance premiums to farmer needs • Increase education about insurance products, particularly more populated (lower rural) regions	Lefebvre et al. (2014)
	Spain	• Expanded since 1978 from basic cover (e.g. single peril) to include more perils • 1996 – 2008, premiums increased > than 3 fold (€200 million to €700 million) • In 2006 total liability insured was €10 billion (25 – 30 % of Spains total agricultural output) • Studied area yield for 41,600 farmers over 12 years (1993 – 2004) within 7 Spanish comarcas	(S) • Low premiums / premium subsidies • Expectation of high indemnity payout • Satisfactory economic return • Direct indemnity payout	Barnett (2014); Garrido and Zilberman (2008)
	China	• New scheme trialled in 2007 • Covered several perils • Grew from 6 provinces to 25 provinces in 2010	(S) • Premium subsidies were significant in scaling insurance from 2007 • Neighbouring farmers experience and recommendations improved	Boyd et al. (2011); Lyu and Barré (2017); Wang et al. (2011)

		• Low premiums • Moderate amount insured • ~50 - 80 % of premiums subsidised • Customers required to insure all crops (therefore not only lower risk crops) • Surcharges applied to higher risk clients and discounts to lower risk clients to improve participation • Successful case study in Changde municipality	participation (R) • Increase farmers trust of insurance companies by honouring indemnity payments • Improve promotion of insurance products • Increase insured amount to provide necessary compensation for farmers to continue yield production (S) • Insurance assistants and experienced officials assigned to each village which: o reduced administrative costs and the need for premium subsidies o improved communication o increased trust	
	Italy	• Multi-peril insurance increased from 2003 – 2009 while single peril decreased by ~ 50 % • Premium subsidies of up to 80 % against losses > 30 % of historical production average (but low participation)	(S) • Participation more common for: o northern Italy due to higher loss ratios (indemnity payouts / premium payments). Northern Italy has loss ratios approximately double southern Italy o higher altitudes due to greater risk profiles o larger farms due to larger revenues	Santeramo et al. (2016); Enjolras et al. (2012)
Index insurance	India	• National Agricultural Insurance Scheme (NAIS, yield insurance (MPCI)) and Weather Based Crop Insurance Scheme (WBCIS, index insurance) for ~ 15 years • 2007 - pilot scheme of WBCIS over 19 states o Penetration < 20 % of farmers • NAIS compulsory with credit and premiums subsidised • WBCIS outperformed NAIS	(S) Strength of scheme attributed to: • Flexibility responding to new technology • WBCIS more successful due to: o lower premiums o faster claim payments (45 days compared to > 6 months) (R) • Decrease unit size from area to village or individual farms for both schemes (NAIS for more accurate yield loss assessments and WBCIS for more accurate rainfall data) • Increase awareness about insurance product benefits • Simplify application process by appointing agents to visit customers • Increase farmer input into insurance products	Greatrex et al. (2015); Swain (2015)
	Africa	Agriculture and Climate Risk Enterprise (ACRE) • Largest in sub-Saharan Africa	(S) • Multiple data sources • Mobile technology to reach remote customers and provide	Greatrex et al. (2015)

		• First worldwide to use mobile technology to reach farmers • 2012, ~178 000 farmers received US$8.4 million partly due to insurance (or credit) • Predicted to reach 3 million farmers in 10 countries by 2018	faster indemnity payments • Wide range of partners with varying expertise (e.g. banks, government agencies, researchers) • Focus on education (both agricultural practices and of insurance products • Wide range of products • Insurance linked to credit	
	Syria	• Mostly small farms • Insurance schemes failed ~ 20 years ago as too expensive • High level government support; through premium subsidies, by purchasing crops from farmers at higher prices, and interest free loans • During extreme drought years, index insurance was successful at recovering yield losses	(S) • Government established microfinance companies to improve the distribution of insurance products • Farmers had positive attitudes to these microfinance schemes (R) • Trust of insurance companies • The use of mobile phone providers to promote insurance products (based on success from other studies)	(Bobojonov et al. 2014)

Single Peril Insurance

Iran

Iranian silkworm farming insurance is a single peril insurance product which has experienced increased participation since its inception in 2003, starting at 8.5 % of silkworm farm eggs insured compared to 57 % in the 2014 – 2015 season in the study region of Guilan Province (Farzaneh et al. 2017). Researchers conducted questionnaires of all silkworm farmers (~8000 in 2015) in Guilan Province, northern Iran.

The researchers found that the most important factors for insurance participation were informing farmers about the assessment timeline, expected indemnity payments and informing about policy purchasing. They also found that larger farm incomes, being in close proximity to the insurance company, and the ability to pay premiums in instalments or upon receipt of indemnity payouts would positively influence participation. In contrast, issues such as low indemnity amounts and longer indemnity payment wait times are likely to discourage farmer participation (Farzaneh et al. 2017).

Multi-peril Crop Insurance (MPCI)

Bulgaria

Agricultural insurance in Bulgaria has existed since the 19th century. Products were originally in the form of single peril products, and from 1980 – 1991 participation was compulsory. From 1992 coverage expanded to include multiple perils and participation changed to voluntary (Lefebvre et al. 2014).

Lefebvre et al. (2014) studied 224 farms in 2011. Most of the farms in Bulgaria are small, family owned and farmers don’t have access to credit. Of the 26.5 % of farmers who purchased crop insurance, 60 % purchased multi-peril products and 20 % purchased single peril insurance (it was not specified what type of insurance the other 20 % of farmers purchased) with 80 % of premiums subsidised by the government.

Farm size and farm location were the most significant contributors to insurance participation according to Lefebvre et al. (2014). Larger farms were more likely to purchase insurance, presumably due to larger farms having higher incomes being more able to afford it. Alternatively, smaller farms adopted risk management strategies such as crop diversification. Farm location was also important in determining whether farmers purchased insurance, with farmers in the north-west more likely to participate than other regions (61 % in the north-west compared to 37 % in the north and only 3 % in the south), probably because there is a higher focus from insurance companies on this major agricultural region.

The researchers also provided recommendations, including tailoring insurance products to small and medium farmers, adapting products to meet local needs and extending education about insurance products to all regions (Lefebvre et al. 2014)

Spain

The Spanish agricultural insurance market has grown since 1978 to cover more perils and now includes yield insurance and, in the last ten years, premium subsidies and indemnity payments have also increased. Garrido and Zilberman (2008) studied 41 600 farmers and 12 years of insurance records.

Garrido and Zilberman (2008) found that premium subsidies and an expectation by farmers of fair indemnity payouts were the most significant contributors to insurance participation. As in other studies, the researches found that having no or low premium subsidies from governments would lead to low participation from farmers, particularly for broader coverage products such as multi-peril insurance. Furthermore, farmers are reluctant to insure their crops against the less severe but more frequent peril events for which single peril products are generally purchased, therefore broader peril cover (i.e. MPCI) and greater premium subsidies are needed. Also, if farmers expect that they will receive low indemnity payments they are unlikely to purchase insurance, particularly if premiums are high (as they often are with MPCI products).

China

Agricultural insurance expanded significantly in the past five years from ~ 2012. Since government support began as pilot programs in 2004, subsidies for agricultural insurance has increased from 16 provinces in 2008 to 31 in 2011 with 80 % of premiums subsidised by the central and local governments (Boyd et al. 2011; Lyu and Barré 2017). Despite this, and the fact that China is the 2nd largest agricultural insurance market in the world for total premiums (2nd to the U.S., Lyu and Barré 2017), insurance coverage rate is low (with coverage of ~ 40 % of total area for main crops), particularly at the province level. This is probably because of the large number of small farms, which attract higher administrative costs (Boyd et al. 2011).

Wang et al. (2011), who have been conducting field surveys since 2007, found that government premium subsidies were responsible for the significant scale of agricultural insurance. Also, when no government support was provided, as in Changde Municipality, premiums could be reduced by employing insurance assistants and officers in each village. These assistants were responsible for collecting premiums and investigating claims for the village. The use of assistants not only reduced premiums but increased client trust in the insurance company.

Further issues affecting insurance participation include knowledge of insurance products (with only ~ 14 % of clients familiar with product details), trust in insurance companies, the experience of neighbouring farmers and insured amounts being too low (Wang et al. 2011). Insurance companies are encouraged to expand their businesses to reach more villages.

Italy

Multi-peril crop insurance is the most popular type of crop insurance in Italy, increasing in popularity since 2003, while the purchase of single peril insurance decreased by 50 % in the period 2003 – 2009 (Santeramo et al. 2016). The rise in multi-peril insurance products was a result of the large premium subsidies provided by the Italian Government (up to 80 %, one of the highest in the world), however, despite this, the expensive premiums and fixed premium price have kept participation relatively low and farmers generally do not purchase insurance for > 2 consecutive years.

For farmers who did purchase insurance, most were located in northern Italy and had larger farms. The northern Italian farmers face greater risk to crops due to the lower temperatures and higher winds in the region, and the loss ratios (indemnity payouts / premium payments) were found to be higher in the north (~ 1 in the north and ~ 0.5 in the south). Larger farms were also more likely to purchase insurance due to the higher incomes (Santeramo et al. 2016). In addition to these findings, Santeramo et al. (2016) cited other influences to insurance participation as corporate farm structures, education level, farm experience, debt level and receipt of disaster payments (presumably this would deter farmers from purchasing insurance if they were to receive this level of support).

India

The two main insurance schemes in India are the National Agricultural Insurance Scheme (NAIS, an area yield scheme) and the more successful Weather Based Crop Insurance Scheme (WBCIS). These schemes have been operating for around 15 years, purchased by ~ 20 million farmers.

The weather index insurance scheme (WBCIS) was more successful than the area yield scheme (NAIS) due to the lower premiums and faster, more frequent claim payments. Under the WBCIS payments took only 45 days compared to up to 6 months under NAIS. However, while WBCIS provides higher indemnity payments, it has narrower coverage of only weather related risks (Swain 2015). Farmers from larger farms tended to purchase NAIS insurance while smaller farm holders purchased WBCIS, presumably due to lower premium payments required for WBCIS.

The purchase of either NAIS or WBCIS products is compulsory under loan agreements (depending on the source of the loan, i.e. commercial bank, cooperative etc.), and the popularity of each product was assessed by the proportion of non-loan farmers who voluntarily purchased insurance (Swain 2015). Non-loan farmers purchasing NAIS declined from ~ 12 % in 2000 to 1 % in 2010, while non-loan farmers purchasing WBCIS products declined from ~ 9 % in 2009 to ~ 3 % in 2010. The reason for the decline in NAIS product participation from non-loan farmers was attributed both to the reluctance of insurance companies in providing NAIS products (due to limited manpower in adminstering the loans) and the lack of NAIS insurance benefit awareness among farmers (Swain 2015).

In addition to the compulsory purchase of insurance with loan schemes, participation in was attributed to high government subsidies, farmer input into product design, and a "flexibility in responding to new technology" (Greatrex et al. 2015) by insurance companies (Greatrex et al. 2015; Swain 2015). Approximately 24 % of farm households have crop insurance, and high premium subsidies of 60 – 75 % are provided by the government (Greatrex et al. 2015; Swain 2015). Furthermore, a pilot study in Tamil Nadu found that farmers were satisfied with insurance policies which allowed farmer involvement into the product design and the use of representatives for product improvement (Greatrex et al. 2015).

Despite this increased participation and the general satisfaction with premium costs under both NAIS and WBCIS, most farmers were dissatisfied with the choice of insurance due mainly to the large area size used to assess indemnity payments and the lack of individual assessments (Swain 2015). Large area size could result in reduced indemnity payments either because of poor correlation between average area yield and individual farm yield (in the case of NAIS assessments), or because of area rainfall levels and individual farm rain levels (for WBCIS assessments). Farmers would be more satisfied with individual assessments rather than large area assessments, providing more accurate indemnity payments related to farm yield loss.

Africa

The most successful index insurance case study in sub-Saharan Africa is the Agriculture and Climate Risk Enterprise (ACRE), covering Kenya, Rwanda and Tanzania (Greatrex et al. 2015). In the period 2009 – 2015 ACRE reached 200 000 farmers and is expected to grow to 3 million across 10 countries by 2018. In 2012, 177 782 farmers received $US 8.4 million (partly due to insurance and partly due to disaster aide), and in 2013 the total sum insured was $US 12.3 million.

The large premium purchase of ACRE can be attributed to a few key components. One of the most important is farmer education, both in terms of agronomic training and information about insurance products. In 2011, 40 % of ACRE's budget was used for agronomic training, phone help lines and radio programs to inform farmers about crop insurance (Greatrex et al. 2015). ACRE uses a wide range of index data sources, including satellite rainfall data, in-situ weather stations, and government yield data, which would improve the correlation between rain and crop yield, thereby reducing the basis risk (Greatrex et al. 2015). Also, ACRE index insurance is linked to farm credit, therefore farmers wishing to take out loans are required to purchase insurance proportionate to the loan amount. This compulsory insurance acts as collateral and can help repay loans which may otherwise be defaulted (Mishra and Mishra 1994).

Syria

Crop insurance participation in Syria has also been linked to high level of government support and positive experiences of farmers in microfinance companies (Bobojonov et al. 2014). The potential for index insurance to minimize drought associated yield loss in Syria in the main wheat zone was studied from 1985 – 2007, with data provided by the International Centre for Agricultural Research in the Dry Areas (ICARDA). ICARDA, located just south of Aleppo, is a well-known organization established 40 years ago and has been researching the use of index insurance to mitigate the risks associated with crop damage due to climate change (Bobojonov et al. 2014; ICARDA 2016).

The researchers found two types of index insurance in particular could be useful to minimize risks to crops (Bobojonov et al. 2014). Apart from the lower cost of index insurance, "agro-meteorological" index insurance (such as rainfall index or a crop model based index) was found to have a strong correlation to yield loss, and a remote sensing index (Normalized Difference Vegetation Index (NDVI), a measure of the proportion of green vegetation) would be useful in the event of limited weather or yield data (Bobojonov et al. 2014) (note, however, that other studies have found basis risk (no payout due to poor correlation between index and yield loss, see Index Insurance Disadvantages) to be the greatest deterrent to index insurance participation (Carter et al. 2016; IBLI ; Matul et al. 2013; NRAC 2012; Zaki 2016)).

Despite the present lack of insurance companies available to sell index insurance in Syria, the researchers made a number of recommendations for future participation. The current level of government support could be used to provide premium subsidies. Also, the use of microfinance companies and other trusted organizations such as ICARDA could improve farmer trust and positive experiences in insurance purchase and also improve farmer knowledge of the benefits of crop insurance. Furthermore, mobile phone providers could be used to increase insurance product publicity and purchase (Bobojonov et al. 2014).

Recommendations for insurance participation

The case studies outlined above have provided strategies for improving participation by farmers in crop insurance, either by observations from successful cases or through recommendations based on deterrents to insurance purchasing. The major recommendations are:

- **Increase education and promotion of insurance products**. Both the level of information provided to farmers and the regions receiving attention from insurance companies can improve participation as more farmers understand the benefits to purchasing crop insurance, particularly during future climate change uncertainty, how this may affect yields and how insurance can mitigate these issues.

- **Simplify insurance product administration, purchase and indemnity payments** by providing a single point of contact for customers and/or linking insurance contracts to mobile phone providers (if appropriate mobile phone coverage exists) so that farmers can more easily manage their insurance contracts and do not have to travel far.

- **Allow farmer input into insurance product design and tailor insurance products to different conditions and regions**, including flexible premiums and payment options such as fortnightly or monthly payments, and enabling premium payments upon receipt of indemnities.

- **Improve/increase data sources** for index insurance to improve correlations between index and yield, and for multi-peril and single peril insurance to improve predictions of the amount to insure and expected yields. Climate and crop yield forecasting is an important component of crop insurance to predict future yields and increase farmer awareness of climate related risks, which can increase farmer participation in insurance products. Using multiple climate forecasting data such as global climate models (GCMs) are beneficial for seasonal and longer term forecasting (6^+ months in advance) and can also provide daily time series weather data.

TOR 4: Compile assessments of future risks and opportunities to agricultural production under climate variability and change for key agricultural industries including wheat, coffee, rangelands, grapes, cotton, sugar, especially including aspects related to climate extremes.

Climate Variability

Wheat

The impacts of 1997-1998 strong El Nino followed by La Nina in 1998-1999 have prompted researchers to look for correlations between the crop yield loss and patterns of climate variability, particularly ENSO (Adams et al. 1995). In addition to ENSO, variabilities of climate decadal also affect the climate of US, namely the West Pacific Warm Pool (WPWP, Wang and Mehta 2008) the Tropical Atlantic Sea Surface Temperature Gradient (TAG, Mehta 1998; Rajagopalan et al. 1998), the Pacific Decadal Oscillation (PDO, Mantua et al. 1997), Atlantic Multi-Decadal Oscillation (AMO, Enfield et al. 2001), and the North Atlantic Oscillation (NAO, Enfield et al. 2001; McCabe et al. 2004; Seager et al. 2010).

In the last two decades, rapid progress in crop simulation models has also happened such as the Environmental Policy Integrated Climate (EPIC, Mehta et al. 2011), APSIM (Tian et al. 2015), and DSSAT 4.5 (Sarkar et al. 2015). The models were applied in many studies of responses of plant growth and yield components to various climatic conditions and cultivation practices. Simulation results of the plant are used to identify adaptation strategies to reduce the impact of climate variability.

Wheat in the USA

The widest food centre in the US is Missouri River Basin (MRB), which includes 10 states (Montana, Wyoming, Colorado, North Dakota, South Dakota, Minnesota, Iowa, Nebraska, Kansas, and Missouri), covers an area of 1.2 million km^2, and produces around 46% of US wheat (Mehta et al. 2011). In addition to ENSO, the area is also affected by the PDO (Ting and Wang 1997), the NAO (Hurrell et al. 2001), and WPWP (Wang and Mehta 2008). ENSO influence on the rainfall diversity is about 20%, while decadal scale of climate affects rainfall diversity by 40-50% (Cayan et al. 1998).

The increase winter rainfall caused by ENSO results in increased wheat production in Southern High Plains (SHP, Mauget and Upchurch 1999; Mjelde and Keplinger 1998), Texas (Mauget and Upchurch 1999), Georgia (Alexandrov and Hoogenboom 2001), and Alabama (Sarkar et al. 2015). Nevertheless, according to Rosenzweig et al. (2001), the impact of ENSO on the US national wheat production is not much, because the production centres are located in the area with no significant ENSO influence.

Correlation between the simulation results using the EPIC crop in Missouri River Basin and indicators of decadal climate variability (PDO, TAG, and WPWP) with wheat yields was analysed using linear regression equation (Mehta et al. 2011). The study concluded that the production of spring wheat decreased (increased) by 5-20% during phases of PDO^- (PDO +) and TAG- (TAG +). Below normal rainfall and above normal air temperatures in the phases of PDO- and TAG + have lowered the yield of winter wheat by 10-30% and 5-30%, respectively. Instead there were yield increases by the same amount in the PDO- and TAG + phases. Tian et al. (2015) used DSSAT 4.5 with input Flares 1.0 reanalysis data with a resolution of 10 km to see the diversity of winter wheat yield in the US southeast and correlation between winter grain yields and the average yearly data of AMO, PDO, NAO winter index for cross-wavelet analysis of the power spectrum. The results showed that the three indicators were correlated only with the results of winter wheat. The highest correlation was with PDO, followed by NAO and AMO.

Wheat in India

Wheat crops are cultivated in the northern region of India (as Punjab, Uttar Pradesh, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, and Haryana) in the dry winter or Rabi season of November to March with rainfall only 15% of the total. ENSO negatively correlated with rainfall in the northern part of India in the peak (or boreal) winter months from December to March

(Yadav et al. 2010). ENSO negatively impacts on wheat production. Eleven out of the 13 events of ENSO positive phase (El Nino) relate to a negative anomaly on wheat production. Nine out of 13 positive phase of ENSO (La Nina) relate to increased production of wheat .

DSSAT crop simulation model has been used by researchers to simulate wheat in India (Aggarwal et al. 2000; Pathak et al. 2003). Pathak and Wassmann (2009) applied DSSAT-CERES-Wheat to simulate wheat yield in Ludhia and New Delhi. In negative anomaly conditions of low rainfall, a decline in wheat yield by 33-55% occurred. The plant simulation model is an operational decision-making tool at field level, especially in the areas with high rainfall diversity and in which irrigation application is very expensive and scarce.

The impacts of ENSO are mostly rainfall deficits causing drought that so many studies link drought index and wheat yield. Several indices are used, among others, Standardized Precipitation Index (SPI, based on meteorology), Normalized Difference Vegetation Index (NDVI, based on satellite and plant), Crop Growth Simulation Model based on Drought Index (GCSM-DI). Subash and Mohan (2011) integrates SPI, NDVI, and GCSM-DI into Rational Integrated Drought Assessment Index (RIDAI) to get a complete picture of plant growth until harvest. RIDAI can describe up to 94% variability of wheat yield in Indo Ganga Plains (IGP).

Risks/Opportunities/Recommendations

By integrating the prediction of inter-annual and decadal climate variabilities with wheat production could potentially be used to improve seasonal prediction to better management of wheat cultivation. The integration is needed to improve the accuracy of less accurate seasonal predictions. Despite there has been no decadal climate variability predictions yet, however, the study on it is still in progress and needs to be accelerated.

Rice

Rice in Indonesia

Rice is a staple food crop of more than 250 million people in Indonesia and planted in most areas. Its production centres are located in the southern hemisphere such as South Sumatra, Lampung, Java, and South Sulawesi. However, the crops are most vulnerable to extreme weather occurrences associated with El Niño, and the rainfalls in central rice production areas of Indonesia are affected by ENSO, especially during summer and transitional sessions.

Impacts of climate variability, particularly ENSO, on rainfall and rice production in Indonesia have been studied by several researchers since 1978. El Niño was generally associated with rainfall reduction causing droughts in most parts of Indonesia (Allan 2000; Quinn et al. 1978) and the effects were only significant in the dry (MK) and transitional seasons (Ropelewski and Halpert 1987; Hendon 2003; Aldrian and Dwi Susanto 2003). According to Boer *et al.* (2014), a 1°C increase in sea surface temperature (SST) in the Niño regions coincides with a decrease of monthly rainfall by 0-50 mm in Indonesian area. The impacts are stronger in most parts of Kalimantan and Sulawesi, and partly in Java and Papua islands with a rainfall decrease by 20-40 mm, whereas the reduction is less than 20 mm in other islands.

In strong El Niño of 1982/83 and 1997/98, the declines in rice production are mostly caused by changes in harvested area rather than reduction in productivity per ha (Falcon et al. 2004). According to Naylor et al. (2002), the difference of rice planting area in 1982/83 El Niño and 1975/76 La Niña was approximately 800,000 ha, which is equivalent to 3.5 million tons or 7% of total annual rice production. In addition, it is stated that in strong El Niño of 1997/1998 during May to September 1997, there was a reduction in planted areas by 925,000 ha so the rice production decline in September 1997-April 1998 reached 4.8 million tons. Low rainfall in September-December during El Niño years causes planting delay in wet season until cumulative rainfall is sufficient (Naylor et al. 2001; Heytens 1991; Naylor et al. 2002). Therefore, the rainfall during this period can explain 84% of planted area in September-December and 81% of harvested area variability in January-April.

There have been some studies using ENSO indices in relation to rice production in Indonesia. Kirono and Tapper (1999) used correlation lag between SOI and rice production for each planting season in Indonesia and concluded that ENSO affects Indonesia's rice production in May to August and September to December. Falcon et al. (2004) employed ENSO indices to predict national rice production in Indonesia and concluded that every 1°C increase of Niño 3.4 index in August leads to decrease plated area by 261,000 ha and also reduce the next year's rice production by 1.32 million tons. There was significant correlation between planted area and production in trimesters of September to December and January to April but not significant in May-August trimester, in which the most extensive drought occurred.

Rainfall decline in a long period due to El Niño has caused damages and parches on rice plants. Data from the Indonesian Ministry of Agriculture show that strong 1997 El Niño affected droughts on 513,000 ha of rice crop areas. While weak to moderate El Niño intensities caused more extensive drought areas: 870,000; 539,000; and 538,000 ha in 1991, 1994, and 2003, respectively. Drought occurs largely in May to October being the dry period.

Surmaini et al. (2015) stated that the Niño 3.4 index in March is potential to cause rice dryness in May-July (dry season-1) varying from 0-0.5°C followed by a consistent increase by about 0.5-1.0°C (weak El Niño) over the next 5 months. Rice drought in August-October (second dry season) is also potentially to occur if Niño 3.4 index in June ranges from 0.5-1.0°C (weak El Niño) and consistently increases during the next five months by 1.0 to 1.5° C (moderate El Niño). There is low probability of rice drought to happen in the first dry season because ENSO condition at that time is still neutral, however, it has high degree of uncertainty in the next ENSO development.

Rice in Vietnam

Vietnam is the second largest rice exporting country in the world, after Thailand (FAO, 2010). Therefore, variability in Vietnam rice production contributes significantly to global food security. Climate in Vietnam region is influenced by tropical monsoon causing frequent floods and droughts. High rainfall generally occurs in September-October, while long dry season is from December to July. Rice is generally planted three times yearly. However, in the area of Cam My located in the coastal province of Ha Tinh (Central Vietnam), rice is grown 2 times a year from November-April and May to August, and it is fallow during August to October in order to avoid flooding. Yield losses due to extreme droughts and floods are more than 40% (Nguyen *et al.*, 2013). Some challenges (such as low soil fertility, sea water intrusion, pests and diseases) are the limiting factors in increasing rice productivity. These challenges are compounded by the impacts of climate change to cause increasing uncertainty of rice production in the country. According to Dasgupta et al. (2009) and Wassmann et al. (2004), Vietnam is one of the five countries most affected by sea level rise because its rice production centres are located in coastal zone.

Central area of rice production in Vietnam is Mekong Delta located in southern part of Vietnam. The Delta consists of 13 provinces and is inhibited by 80% of the population. This area is rice bowl of Vietnam supplying about 50% of national rice production. According to Yusuf and Francisco (2009), the Mekong Delta area is extremely vulnerable to be affected by rising sea level due to climate change. Sea level rise is projected as high as 1 mm in 2100 and about 12,000 km^2 area of the Mekong Delta will experience inundation (submerged). According to Dang *et al.* (2014), the farmers' perceptions to climate variability and extreme climate include increasing rainfall frequencies during dry season, higher frequency and intensity of rainfalls, more frequent typhoon occurrences, and seawater intrusion leading to increasing paddy fields salinity.

Nhan et al. (2011) studied the impacts of climate variability on rice production in Mekong Delta of Vietnam using 1990-2008 statistical data. Probability of weather anomalies to appear is calculated using double regression analysis to identify the influences of climate variables on rice production. The results showed that air temperature and precipitation are the main climate indicators most affecting rice production. Crop vulnerability level differs for each stage of its growth, growing season, and region. Rice production is more sensitive if the impact of climate variability occurs in early stages of vegetative, flowering, and ripening phases. Furthermore, it is stated that rice crop planted in rainy season on the coastal areas is more vulnerable to climate anomalies than that in dry season on irrigated land.

Rice in India

Rice is the main agricultural crop in India with an area of about 24% and contributes 45% on cereal production. Average rice productivity in India is 2.2 tons/ha and is still below average global productivity of 2.7 tons/ha. The main rice-growing areas are in West Bangal, Uttar Pradesh, Orissa, Andhra Pradesh, Punjab, and Assam provinces. West Bangal has the widest and the largest rice area and production in India, while other province with the highest productivity is Punjab (CRRI 2011). Rice is grown 2 times a year in Kharif (June-October) and Rabi (November to May), and annually. In the growing season of Kharif, most areas grow rice, little shorgum and cotton, and in Raba season, most areas grow wheat, followed by rice and shorgum (Moorthy *et al.*, 2012).

Nearly 65% cropping area in India is strongly influenced by the summer monsoon season (approximately 70% of total rainfall occurs in June-September). Approximately 35% of total rice area is located at foodgrain zone and 15-20% of the area is planted in Kharif (June to October) season. This suggests that rice cultivation in India is strongly influenced by monsoonal rainfall or summer monsoon rainfall (Singh *et al.*, 2016; Kumar and Barbosa, 2012).

India is a big country with diverse topographies from mountainous in Himalaya in the north to tropical coastland in the south parts, so that the climatic conditions are also various. Indian climate is dominantly affected by great Asiatic Monsoon wind system. Driest condition in almost all regions of India occurs in December-February. The dry condition is still ongoing up to March-May, however, summer heat causes the wind direction to turn around so that in June-October India region is affected by moist bearing monsoon coming from the south-west. The west and northeast coasts are the wettest regions, meanwhile the northwest part located Rajasthan desert has very low rainfall. ENSO also affects Indian precipitations by decreasing rainfall in most parts of India, either during or outside the monsoon (The Met Office, 2011).

Relationship between climate and rice cultivation has been widely studied and researched, either using time series data or the SST indices (Parthasarathy *et al.*, 1988; Parthasarathy *et al.*, 1992; Selvaraju, 2003; Krishna Kumar *et al.*, 2004; Moorthy *et al* ., 2012; Kumar and Barbosa, 2012; Auffhammer *et al.*,). Rice production in India significantly correlates with summer monsoon rainfall (Parthasarathy *et al.*, 1988; Parthasarathy *et al.*, 1992; Selvaraju, 2003; Krishna Kumar *et al.*, 2004). Parthasarathy *et al.* (1988) found that correlation value between rice production and summer monsoon reaches 0.82, and furthermore Parthasarathy *et al.* (1999) reported that rice production in India can be estimated using indexes of summer monsoon rainfall. Kumar *et al.* (2004) found that the Nino-3 SST indices in June to August significantly correlate with total rice production. Detailed spatial analysis shows that strongest influences of Nino-3 SST in Kharif growing season are in the west and central parts of the Peninsula including the provinces of Gujarat, Rajasthan, Uttar Pradesh, Punjab, and Andhra Pradesh, and its influence is getting weaker in Karnataka and Tamil Nadu provinces. Selvaraju (2003) employed Nino-3.4 indexes to estimate total rice production in India for the next few months.

Moorthy *et al.* (2012) analyzed the influence of climatic variables on rice production using time series data of 1961-2010 and found that precipitation and air temperature increases can threaten some areas, however, they also have positive impacts in other regions. Kumar and Barbosa (2012) analyzed the influence of Indian summer monsoon rainfall anomalies (ISMR) on the production of rice and wheat using Global SST ENSO Index (GSEI). His research results state that ISMR significantly correlates with GSEI and ENSO to affect rice production. Selvaraju (2003) examined the impacts of ENSO on foodgrain production in India and found that correlation values between NINO-3 SST and rice production are higher in Kharif season (June to September) than those in Rabi season (October to February). In Kharif season, warm phase of ENSO decreases rice production by 3.4 million tons (7 %) while the cold phase increases it by 1.3 million tons (3 %).

Risks/Opportunities/Recommendations

There have been some studies on the impacts of climate variability on rice production in Indonesia using ENSO indices, however, further research is still needed to study influences of other climate variability indexes such as the MJO and monsoon indices which may also affect rice production. Besides, studies on the impacts of climate variability using crop modeling are still limited. While in Vietnam, studies on the impacts of global climate indexes need to be done in order to determine their effects on rice production variability inter seasons and years.

In general, rice production in India is influenced by monsoonal rainfall. ENSO (in this case NINO-3 SST) is one of the indices that can be used to infer characteristics of Indian monsoonal rainfall. Further studies by applying the index as rice production predictor by using more detailed resolution data need to be carried out. In addition, study on the impacts of climate variability on rice production can also be conducted using crop modelling. Information on yield gap production in various climatic conditions and agro-climatic zones is very important in order to get production components information which can probably be improved in order to obtain maximum results. India is a very spacious country with varying climatic conditions, so that the impacts of climate variability (especially rainfall) on rice production need to be mapped well. Agricultural areas without climate variability impacts could be focused as production centre regions.

Millet

Millet is a summer crop relatively tolerant to drought, so it is considered as an important component of dryland farming. Millet can be grown on various soils and it requires low rainfall and short daylength for ripening (Pokharia et al. 2014. Millet requires minimal water (only about 25%) from rainfall for production, adaptive to climate change, and able to grow on marginal land {Padulosi, 2015 #43).

As one of the major food crops in Africa, millet is relatively resistant to climate variability and grows well in areas with rainfall range from 200 – 1.500 mm is this annual rainfall?, evenly distributed throughout during the growing season. Optimal planting time is in early October to November, because at that time the soil temperature is around 18°C being suitable for the development of millet roots (Board on Science and Technology for Development Interval, 1996). Some studies indicate that either current or future projected conditions, that precipitation and temperature trends could affect the millet production (Sultan et al. 2013). For example, research by Ben Mohamed et al. (2002) projects millet production to decline by 13% in 2025, while (2012) estimates the yield decrease up to 26% by 2080.

Millet in India

India is one of the major millet producing countries in the world. More than 90 % millet crop is grown in rainfed and marginal uplands covering around 23-24 million hectares with a production of about 20-22 million tonnes (ICAR 2006). Pearl millet (*Pennisetum glaucum* L. (R.) Br.) is the primary millet type grown in

India so that it becomes the world's largest millet producer by 9.5 million tonnes from an area of 9.3 million hectares which has rapidly increased in the last few decades (Mal and Padulosi 2013; Padulosi et al. 2015; Yadav et al. 2012).

Pearl millet is grown on marginal rain-fed land of Alfisols for 80 to 90 days. During the El Niño years, there has been a decline in planted areas of more than 7 % with output decrease of more than 20 %. This is caused by a decrease in rainfall during the Southwest monsoon season (Rao et al. 2011).

Millet in Nigeria

Analysis results by(Olaniran 1981) show that the higher number of rainfall in June was significantly correlated with increasing millet yield. It was predicted that the period coincided with the vegetative growth phase of millet. Tim (2000) observed that during the period of 1961 to 1990, in the north east of the dry zone of Nigeria experienced with a decrease of annual rainfall leading to a decline of millet production in the region.

In Nigeria, there has been still a lack in knowledge about the impact of ENSO or general climatic characteristics and precipitation in particular. Some authors try to connect ENSO climate anomalies in the Sudano-Sahel zone of Nigeria. Rainfall variability observed in the zone resulted in differences in the types of cultivated crops and the products of the region (Adejuwon 2004). Spatially and temporally high variabilities of rainfall are reflected by repeated droughts and floods, which can be considered as the most important factor to affect agricultural productivity in sub-Saharan Africa (Sivakumar 1988; Sultan et al. 2005) so that the impacts of climate variability on growth and yield of millet in the region still require deeper study.

Several strategies for adaptation to climate variability for the sustainability of millet production in developing countries (Kadyampakeni 2014), including India and Nigeria:

1. Fertilization management to boost crop yields and maintain the environmental quality with appropriate application of mineral fertilizers with specific location recommendations, as well as increasing nutrient retention through efficient use of both organic and inorganic sources of nutrients.
2. Increase Efficiency and Improve Irrigation Management along with agronomic practices including planting time. Efficient water use management practices using site-specific irrigation, for example drip, surface, and sprinkler irrigation systems.
3. Use of Dynamic Model for crop simulation. Several models have been developed to predict climate variability using planting scenarios combined with irrigation. The model was able to predict the biomass, grain yield, and leaf area index (LAI). APSIM be the best model to simulate millet response in relation to climate and soil fertility management (Akponikpè et al. 2010).

Risks / Opportunities / Recommendations

The challenge to anticipate the impact of climate variability and change requires a review on the current agricultural policies both in Asia and Africa, particularly in India and Nigeria. Improving crop resiliences against climate is very important to carry out in these regions, where rainfall variability and uncertainty are predicted to increase and impact on livelihoods susceptibility, especially on small millet farmers. Climatic projections show several scenarios that would affect or restrict agricultural production due to erratic rainfall, persistent drought, desertification, and high temperatures.

Considering the rates of population growth and marginal land degradation due to continuous cultivation, especially in India and Nigeria, the option to fix the problem - related to climate change will require an intensification of agricultural production through the use of improved varieties tolerant to drought - water efficient; application of of integrated nutrient management strategy; implementation of highly efficient irrigation systems, intensive training on extension workers; and scientists training in analyzing application of crop modeling both in research institutes and universities regarding to climate scenarios and management.

Maize

Maize productivity is significantly influenced by climate variability, including the phases of ENSO (El- Nino and La - Nina) (Phillips et al. 1999) (Hansen *et al.*, 1998; ~~Phillips *et al.*, 1999)~~. The simulation models used for maize are CERES-MAIZE (Southworth et al. 2000), EPIC (Anderson et al. 2015; Southworth et al. 2000), APSIM (Chen et al. 2004), the Hybrid-Maize model (Meng et al. 2013), and MCWLA-Maize (Shuai et al. 2016). MCWLA (the Model to Capture the Crop-Weather relationship over a Large Area) is a simulation model applied to assess the mechanism of maize production variability in association with ENSO and also to suggest possible adaptation ways to address climate variability during ENSO years.

Maize in USA

The states of Iowa, Illinois, Minnesota, and Wisconsin are the four major corn centers in the United States (Anderson et al. 2015). There are two maize planting time in the US : Summer (mid-summer / June to August) and Winter (November-February) in northern Missouri (Phillips et al. 1999).

Climatic factors limiting growth and production of maize are maximum temperature (Lobell and Field 2007; Southworth et al. 2000). According to Rosenzweig (1993 *in* Southworth *et al.*, 2000), there was a negative correlation between daily maximum temperature of > 33.3^{o}C in July and August with corn production in the US Maize Belt, while the daily maximum temperature of > 37.7^{o}C can cause damage to crops. Significant reduction of corn production can occur in silking and tasseling phases (Southworth et al. 2000).

Anderson et al. (2015) used EPIC model to carry out a study in the states of Iowa, Illinois, Minnesota, and Wisconsin, and stated that high temperatures causing a decrease in corn production could be prevented by irrigating sufficiently. An increase in temperature by 1^{o}C on high enough and low water availability conditions may cause a decline in production by 10 and 32.5%, respectively.

In the USA, the impact of ENSO on maize is not uniform. Hansen *et al.* (1998) and Martinez and Jones (2011) stated that production of corn is affected by ENSO events. Maize production during La-Nina years is higher than normal and then decreases after La Nina events. Different results obtained by Phillips et al. (1999) who stated that in Missouri there is high production during El-Nino years and low during La-Nina years. Along the La-Nina years, the air tends to be warmer and drier in the summer within CornBelt areas. Based on wavelet analysis by Tian et al. (2015) to determine closeness among the NAO, PDO, and AMO against production of winter wheat and summer corn, it is known that the influence of decadal oscilasi is only strong on crops production during winter, however it is not visible on summer crops.

Martinez and Jones (2011) examined the closeness correlation between SST and corn production in Alabama, Florida, and Georgia by using singular value decomposition (SVD) and PCA analyses. In association with ENSO, the results showed linkages between SST in the Pacific and Atlantic oceans and corn production at the site. Based on the lag on relationship between seasonal SST with corn production, it was found that the index obtained can be used to predict corn production in the southeast USA. The model can provide yield prediction for the next 2 to 7 months and enables to carry out planning activities more accurately.

Maize in China

In North China (The North China Plain), maize is planted in the summer, i.e. June-July-August (*et al.*, 2010), and in the Northeast region, it is cultivated in the spring (Zhao et al. 2015). In addition, it is stated that the climate parameters considered as limiting factors to production are temperature, rainfall, and radiation. However, the temperature is variative depending on locations. According to Zhao et al. (2015), specific to areas in the East China Sea during spring time, climate parameters becoming the key to production are average temperature in August and September; maximum average temperature in May, July, and September; minimum average temperature in May, July, and August; total rainfall from early May to mid-September; and average solar radiation in May, July, and August.

Tao et al. (2015) stated that the production gap of corn yield in China is big enough. Potential production of maize is affected by increasing air temperature and mainly by a decrease in the intensity of solar radiation in Southwestern China. However, in contrast to the conditions in the Northeast and Southeast China, where potential production increases along with increasing temperature and radiation.

Shuai et al. (2016) conducted a simulation using Model to capture the Crop-Weather relationship over a Large Area (MCWLA) in 18 locations scattered in China. The results of both simulation model and observation showed increases in maize productivity in many areas, especially in the northern part, during the years with El-Nino events, while the areas in southern part showed decreases. Some differences occurring in the La-Nina events that there were increases in maize productivity in the southern part China, however, some decreases happened in the North and North East China.

Based on statistical information greatest yield loss of maize production in China was caused by drought compared with other disasters (Zhang et al. 2014). In Northwestern Liaoning Province of Songliao plain being one of the major corn centers in China, drought occurences have become dominant disaster that can reach up to 60% of the total disasters in the area.

Some research on corn yield losses due to drought has been carried out in China (Zhang, Zhang, et al. 2016; Zhang et al. 2014). Zhang et al. (2014) constructed a model of early warning drought for corn to reduce potential yield loss. The research location was in Northwestern Liaoning Province by using logistic regression to predict probability relationship between droughts and endogenous crisis signals. Rainfall, wind speed, and temperature are also considered to assess the drought. Similar studies were also carried out Zhang, Xu, et al. (2016), using monthly standardized precipitation index evapotranspiration (SPEI). The smaller the values of SPEI are the more serious drought possibility to occur.

Maize in Indonesia

Risks/Opportunities/Recommendations

Coffee

Brazil, Vietnam, and Indonesia are the three major coffee producing countries in the world. dos Santos et al. (2015) mentioned that robusta (*Coffea canephora*) and arabica (*Arabica coffee*) types dominate almost 99% of world coffee. In general, arabica coffee is more vulnerable to changes in the biotic environment while robusta type is more tolerant of heat and is more susceptible to low temperatures.

Climate variability, increasing air temperatures, longer droughts, and increasing rainfall threaten the sustainability of arabica coffee production(van der Vossen et al. 2015). The impacts of climate variability on coffee production are : a) a decline in suitable lands for coffee plantation caused by increasing the minimum elevation required for cultivating coffee (Laderach et al. 2011). b) an increase in pests (e.g. CLR) and diseases (coffee berry and stem borrers), c) a decrease in productivity and quality of coffee beans, and d) a serious threat to the lives of millions coffee farmers.

Sachs et al. (2015) analyzed the effect of climate cycles on coffee production globally. As for the climate cycles analyzed were El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NOA), Southern Oscillation Index (SOI), Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). ENSO is found as multiyear climate cycle most important to affect the dynamics of producing coffee.

Coffee in Indonesia

Most of coffee beans produced in Indonesia are arabica type, cultivated in mountainous areas at elevation of 1,000-1,200 m above sea level. The main areas producing arabica coffee in Indonesia are Aceh, North Sumatra, Sulawesi, Flores, Bali, and East Java, whereas robusta coffee centres are South Sumatra, Lampung, and Bengkulu. Overall the island of Sumatra accounted for 70% of national coffee production. Main harvesting time is usually around April-July. Schrot *et al.* (2015) identified land suitability for arabica coffee plantation in Indonesia for today and future uses. The results found that there are many areas which are climatically suitable for cultivating arabica coffee outside of today's central areas.

There have not many studies and research on the impacts of climate variability on coffee production in Indonesia. Supriadi (2014) found that ENSO affects strongly on coffee production in Indonesia. During dry months, El-Nino causes decreased in coffee production by 34-79%, while the incidence of La-Nina also lowers coffee production by 98.5%. Prolonged dry months (the months with rainfall below 60 mm) being more than 3 months cause a decline the quality of coffee. Temperature rise by 10 ^{o} C causes a decrease in producing coffee beans as much as 30.04 %.

Coffee in Brazil

The three main coffee growing areas of Brazil are Mogiana and Cerrado in Sao Paul, as well as Minas Sul in Minas Gerais. The areas have a stable 21^{o}C air temperature with moderate rainfall and radiation so they are suitable for the cultivation of arabica and robusta coffee (Haggar and Schepp 2012). Almost 70% of the coffee grown in Brazil is Arabica coffee, while another 30% is Robusta. The country is listed as a producer of Arabica coffee in the world. Climate variability (photoperiodic variations, the distribution of rainfall and air temperature) the climate is a major factor affecting production fluctuations and failures coffee production in Brazile (Camargo 2010).

To understand the impacts of climate variability on coffee production in Brazil, Camargo (2010) analyzed time series data of 119 years (1890-2008) where the agro meteorological adversities occurred in 15-20 year cycle. One of the examples was the frost that had caused damages to the coffee cultivation in southeastern part Brazil (1892, 1902, 1918, 1942, 1953, 1975, 1981, 1994) (Camargo *et al.*, 2002). Some of the events declining coffee production significantly were droughts in 1961 and 1963 which led to a decrease in production in 1962 and 1964. Brando (2014) also reported that the drought in 2014 also led to a decline in coffee production in Brazil.

Sachs et al. (2015) analyzed the influence of ENSO on production using SST NINO 3.4 and SOI indices. The results of this study showed that ENSO affects coffee production in Brazil. In the 1997/1998 El-Nino, coffee production in Brazil fell down by 32%. This study also tried to look at the combined effect of ENSO and other climate signals. When the values of Nino 3.4 (El-Nino events) and PDO are high, coffee production in Brazil declines. And in contrary, when La-Nina occurs with low PDO values, coffee production generally increases in Br in Brazil. In combination of ENSO and AMO during El-Nino occurrences and high AMO values, dynamic production of coffee is unduly influenced.

Adaptation strategies that can be done (Camargo 2010) are (a) agronomic approaches: coffee crop management, genetic breeding, and new molecular tools, (b) strategies to mitigate the reduction in air temperature: shading management, high planting density, vegetated soil, and improving irrigation system, (c) the use of molecular tools for studying responses of coffee to both drought and temperature has not been implemented in most studies (DaMatta and Ramalho 2006), (d) due to the long lead-time of perennial cropping systems and the complexity of global supply chains for coffee, it is urgent to identify the strategy Appropriate adaptation strategies must-operate locally but be connected with the global supply chain (Laderach et al. 2011).

Coffee in Vietnam

Coffee is major agricultural production accounting for 40% of Vietnam's GDP. Vietnam recorded as the world's largest producer of Robusta coffee, about 40% of global production (Amarasinghe et al. 2015). Main coffee areas in Vietnam are located in 5 provinces known by the nickname of central highland, where moderate tropical climate is dominant. The main factor affecting rainfall in Vietnam is monsoon circulation. High rainfall occurs in May to October in the south and the north parts, while in the middle part, high rainfall occurs in September to January. Interannual variations of ENSO (El Niño Southern Oscillation) affect the monsoonal characters (McSweeney et al. 2010).

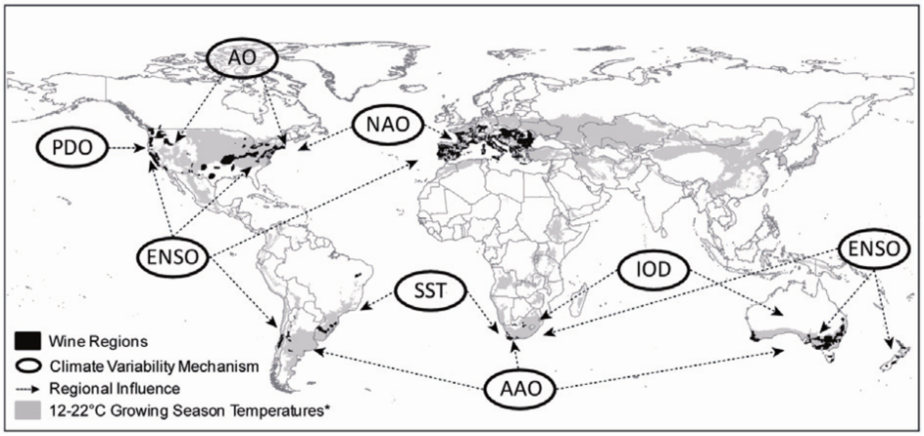
Study on the impacts of climate variability on coffee production in Vietnam greatly associated with irrigation (Amarasinghe et al. 2015; Duong et al. 2014) (D'haez *et al.*, 2003). Duong et al. (2014) analyzed the impacts of ENSO on coffee production by using GIS. ENSO affects agricultural production in most part of the country, especially Vietnam's coffee production in central high land. El Nino causes longer dry periods than normal years. This situation leads to a decline in production. In 1997/1998 and 2003 El-Nino, coffee production in Vietnam fell down by 30 and 25%, respectively.

Risks / Opportunities / Recommendations

Grape

Grape is cultivated in many countries in the world with diverse climatic and environmental conditions. Air temperature is the main factor to affect the growth and production of grape. While other climatic factors limiting grape cultivation are minimum temperature in winter (minimum winter temperature), spring and fall frost, short growing season, and water availability (Jones, 2010).

Jones (2010) already mapped the centres of grape producing regions of the world and also illustrated mechanisms of climate variability to affect grape cultivation in such areas. Generally the indicators used to study climate variability are: El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO), Indian Ocean Dipole (IOD), Arctic Oscillation (AO), Antarctic Oscillation (AAO), and Sea Surface Temperatures (SST).



Wine producing regions of the world and indicators of climate variability

Grape in France

France is the main grape producing country in Europe. The grape centres in France are Bordeaux, Burgundy, and Champagne. In general, inter-annual climate variabilities affecting grape cultivation in Europe are ENSO and NAO (Jones, 2010). NAO is the main atmosphere circulation to affect decadal climatic variations in North Atlantic, Western Europe, and Middle East (Hurrell et al. 2001).

Positive NAO during growing season leads to decrease grape quality in Mediterranean and Iberian Peninsulas (Grifoni et al. 2006). NAO correlates significantly with time of harvesting (or harvest dates) grapes in France (Souriau and Yiou 2001). Further Krieger *et al.* (2011) also saw the influence of climate on harvesting time in Burgundy, France. Grape harvest time is strongly influenced by local temperature in the months of April to August (April to August temperature, AAT) how does climate influence harvest time?. Meanwhile, by using time series data of the past two decades for Bordeaux region of France, Jones and Davis (2000) saw the influence of climate variability. The analysis results indicate that the dynamics of grape production have not been clearly defined from the relationship between crop phenology and climatic parameters, but regression modelling suggests that rainfalls over a period of important physiology (flowering and ripening) tend to cause a decrease in production.

Grape in South Africa

The main grape producing areas in South Africa are Western Cape, Northern Cape, and Limpopo (Department of Agriculture, Forestry, and Fisheries of South Africa, 2012). Rainfall in summer (summer rainfall) in the country is strongly influenced by ENSO where El Nino causes drier conditions and La Nina leads to wetter conditions (Reason, 2002; Misra, 2003). Meanwhile rainfall in winter season (winter rainfall) is influenced by Antarctic Annular Oscillation (Reason and Rouault, 2005), Antarctic sea ice extend (Reason *et al.*, 2002), and the South Atlantic Sea Surface Temperature (Reason *et al.*, 2002; Reason and Jagadheesha, 2005).

Some of the inter-annual climate variabilities affecting grape cultivation in South Africa are ENSO, IOD, AAO, and SST (Jones, 2010; Araujo *et al.*, 2016). Araujo *et al.* (2016) analyzed the impact of ENSO on grape plant dryness at district and farm levels in Western Cape, South Africa. Method used to analyze the drought was Standardized Evapotranspdration Precipitation Index (SPEI), and APSIM crop simulation model was used to observe the drought effect on production. In general, dry period is in association with El-Nino and wet event correlates with La-Nina. Correlation between drought and ENSO at district level is weak (r = 0.5), while at farm scale is highly significant (r = 0.9). APSIM simulation shows that grape production would be more sensitive to drought in spring and summer seasons if there is no irrigation.

Risks/Opportunities/Recommendations

Cotton

Cotton plants are grown in more than 70 countries extending from 37^{o}N to 32^{o}S latitudes, particularly in semi-arid to arid environments, and planted on rainfed and irrigated lands. Cotton plants need a clear dry season in order to get optimum harvests. The five world cotton producing countries are China, India, USA, Pakistan, and Brazil, respectively. Climate variability affecting cotton production was observed by ENSO, air temperature, and precipitation. The method applied statistical analysis and crop simulation models of CROPGRO-Cotton and CWRF-GOSSYM. The simulation model of GOSSYM uses weather and soil conditions as well as the actual practical management in the field (Liang et al. 2012).

Cotton in USA

Cotton plants in the United States are seasonal crop grown well in south of the USA, from California in the west part, Texas until Virginia in the east. Cotton production varies depending on air temperature, solar radiation, water (rainfall/irrigation), and fertilization (Liang et al. 2012). The climatic conditions in the west (California and Arizona) : air temperature 34 ° C, rainfall 1 mm/day, radiation 298 W/m^2, ETP 6 mm/day, and intensive irrigation (500-900 mm/yr) that this region is the primary producer in the American cotton belt (> 1,200 kg ha^{-1}); in Texas : air temperature 31 ° C, rainfall 2 mm/day, radiation 292 W/m^2, ETP 3 mm/day, and limited irrigation, so that the area is lowest cotton producer (<600 kg ha^{-1}); in Mississippi : air temperature 29 ° C, rainfall 3 mm/day, radiation 256W / m^2, ETP 3.6 mm/day, and a potential irrigation so it is a potential area of cotton plants with a production potential of> 800 kg ha^{-1}; in the South East : air temperature 29 °C, rainfall 3.5 mm/day, radiation 250 W/m^2, ETP 3 mm/day, and sandy soils which quickly disappears water, so that the area is less suitable for growing cotton.

Schlenker and Roberts (2008) through three models (the most flexible dummy-variable, Chebyshev polynomials, and piecewise linear) showed the rise in temperatures would increase cotton production to a critical limit of air temperature of 32^{o}C. By using CROPGRO-cotton model (Garcia y Garcia et al. 2010) (Joel *et al.*, 2012), that there was an influence of ENSO in Georgia where El Nino (La Nina) led to higher (lower) rainfall in the months of October to April and it was closely related to water use efficiency what was the impact on cotton?. Results/cotton productivity due to the influence of El-Nino/La-Nina can be solved by setting the planting schedule. At the state level, appropriate planting time in case of La Nina is middle of May and the results may be higher than normal/El Nino. In case of El-Nino, best planting time is after May 16 to get higher results than normal or La-Nina. However, for the area of Calhoun (the junction of Alabama, Florida, and Georgia) on El Nino, planting anytime in April-June will increase results significantly.

Liang et al. (2012) simulated production of cotton by using climate stresses (rainfall, daily Tmax, radiation, evapotranspiration, and wind speed at a height of 10 m) in the period 1979-2005 and applied CWRF-GOSSYM model in American cotton belt, but the relationship between climate stress and increase/decrease in cotton yields has not been quantitatively described yet. The results of simulation and field observation of cotton production are almost the same (87%). GOSSYM is a very promising simulation model for modelling spatial climate and cotton growth. Analysis results revealed that Tmax in July-August and soil temperature anomalies from August to September could be used to predict annual yields/production of rainfed lands. The simulation results also show a positive correlation between yield/production and LAI in July-August.

Cotton in Brazil

Climate in Latin America is affected by ENSO climate variability, so it is closely associated with the rise and fall of precipitation (Sivakumar et al. 2005). Extreme temperatures, floods, and droughts brought disasters on farming systems in the region. El-Nino causes a decrease in rainfall in North part of Brazil and increases rainfall in Southern Brazil (Alves and Repelli, 1992; Cunha, 1999 and 2001). In strong 1997/98 El Nino, there were droughts, frosts, and floods in several different areas causing yield losses up to 50 % (Cotrina, 2000).

Risks/Opportunities/Recommendations

Simulation results of GOSSYM model are generally higher than observation ones. This may be due not to consider dead plants caused by weather disasters, pests and diseases, storms, and differences in technology and management. Improved GOSSYM CWRF Model can be used to project cotton production with climate interactions. According to Joel *et al.* (2012) and Garcia y Garcia et al. (2010), yield losses in cotton plantation due to climate variabilities could be prevented with determining appropriate planting schedule, and Liang et al. (2012) recommended to set an optimal irrigation.

Sugarcane

Climate variability is a major source to influence on fluctuation of food production globally (Sivakumar et al. 2005). Hot and extremely cold air temperatures, droughts, floods, and other extreme climatic phenomena effect on agricultural systems in areas vulnerable to climate variability. Most assessments indicate that climate variability affects negatively on agriculture and forestry in the humid and sub-humid tropics, and for commercial crops, extreme events such as storms, droughts, and floods cause greater damages (Zhao et al. 2005).

One of the agricultural commodities vulnerable to climate variability is sugarcane (*Saccharum officinarum* L.). As a tropical plant, sugarcane does not have adaptability to survive in freezing condition and it depends very much on abundant sunlight for healthy growth. Cane growth is resulted from the conversion of solar radiation energy into plant fibre and sugar. The influence of climate variability in sugarcane is generally observed through the parameters of precipitation, air temperature, albedo, evapotranspiration, and visible impact with indicators of cane yields/production, water use efficiency, stalk fresh mass, soil moisture, water availability, ecosystems, Tonnes of Sugarcane per ha (TSH), and Total Recoverable Sugar (TRS) (de Souza Rolim et al. 2015; Loarie et al. 2011; Marin et al. 2013b; Monteiro and Sentelhas 2014). The methods used are among others: observation, field trials, and plant simulation. Major sugarcane producing countries are Brazil, USA, Australia, and Indonesia.

Sugarcane in Australia

Australia's sugarcane industry contributes up to $2 billion to the Australian economy (Everingham et al. 2009). Sugarcane is grown in a variety of climatic conditions, along 2100 km of coastline from the wet tropics in North Queensland, through dry tropic and sub-tropical areas, to northern NSW (see Figure 1, CANEGROWERS 2012), with 95 % grown in Queensland and 5 % in northern NSW (Australia).

The ideal growing conditions for sugarcane are long periods of warm weather with high solar radiation and "adequate" moisture content (i.e. not too much or too little water and rain falling consistently during the growing season), while during ripening and harvesting periods, sugarcane is better adapted to cooler, drier conditions, and any excess moisture can result in poor quality yields (NETAFIM ; Skocaj et al. 2013). The proportion of annual rainfall occurring during the summer growing season (November to April) declines from 80 % in the northern tropics to 60 – 70% further south, and regions with low or variable rainfall need irrigation management to adapt to conditions. In contrast, excess rain during either the growing season or ripening and harvesting could cause widespread damage and low yields, such as the damage due to excess rainfall during the strong La Nina of 2010 – 2011, which caused severe flooding and crop damage across most regions, rendering 18 % of sugarcane crops unable to be harvested (CANEGROWERS 2012; Skocaj et al. 2013).

Australia's climate is strongly influenced by the El Nino / Southern Oscillation (ENSO) inter-annual patterns and to a lesser extent the sub-tropical ridge and the Madden Julian Oscillation. The strong ENSO phases of El Nino and La Nina result in either higher than average or lower than average rainfall over Australia, and intense ENSO conditions can lead to droughts or severe flooding (CANEGROWERS 2012; Skocaj et al. 2013). Tropical cyclones in the north associated with ENSO can also have devastating consequences for agriculture. Category 5 Cyclone Yasi, a severe system which struck the north Queensland coast in early 2011, caused up to $500 million in damage to the sugarcane industry (CANEGROWERS 2012). The sub-tropical ridge is a band of high pressure resulting in reduced rainfall located in the lower half of the country. Although this band typically occurs further south of the canegrowing regions, its position can shift further north, particularly if influenced by the ENSO, further increasing the variability of northern rainfall. Another climate pattern influencing northern Australia is the Madden-Julian Oscillation (MJO) which is a shorter period (intra-seasonal, 30 – 50 days) eastward moving system potentially resulting in inconsistent rainfall patterns which can influence the ENSO rainfall pattern; if the MJO is strong, it can cause periods of increased rainfall followed by a spell of dry conditions, each lasting 30 – 50 days (CANEGROWERS 2012; Madden and Julian 1994).

Sugarcane in Brazil

To determine the impact and the relationship between climate variability and sugar cane crops in Brazil, a research used several analysis methods, such as linear Pearson (de Souza Rolim et al. 2015), DSSAT/CANEGRO plant simulation models and field trials (Marin et al. 2013b), observations and field measurement (Loarie et al. 2011; Monteiro and Sentelhas 2014). The data used are generally detailed yearly sugarcane production data for a long time during strong El-Nino and La-Nina.

The impact of climate variability on sugarcane crop in Brazil was studied by de Souza Rolim et al. (2015) by looking at the relationship between Tonnes of Sugarcane per Hectare (TSH) and Total Recoverable Sugar (TRS) in the years of El Nino, La Nina, and Normal of 1999-2011. Pearson linear regression method showed that production of sugarcane varies widely, but TSH values tend to be higher in normal, followed by El-Nino and La-Nina years. TRS values are higher in La-Nina years followed by Normal and El-Nino. The highest TSH value of 114.76 t/ha was recorded in April 2010 (La-Nina) and the lowest was 61.21 t/ha occurred in October 2000 (La-Nina). The highest TRS value of 163.79 kg/ha occurred in September 1999 (La-Nina) and the lowest was 103.72 kg/ha in December 2009 (Normal). The highest TSH was resulted in normal year followed by the El-Nino and La-Nina years. TSH variability occurred more frequently in La Nina years, while the TRS values varied very much in normal years and less variable in El-Nino. Correlation between TRS and air temperature during harvest years and the year before showed that air temperatures in November and December before harvest correlated most strongly (r = 0.4 and 0.56) with TRS of May to October in the El-Nino years. Temperature had little effect on TSR in La-Nina year. Temperatures in most harvest months and the previous years were positively correlated (r = 0.40) with TRS in Normal year, except for January to April in which the temperature was negatively correlated with TRS of October and November (r = -0.40 and - 0.69),

A research by applying crop simulation of DSSAT/CANEGRO model was conducted by Marin et al. (2013b) in Sao Paulo to determine the effect of changes in temperature and CO_2 on cane results and Water Use efficiency (WUE) this is more climate change impacts and not climate variability impacts. All the scenarios showed an increase in Stalk Fresh Mass (SFM) and WUE. Average SFM and WUE increases for rainfed sugar cane were 24 and 34%, respectively. An increase in WUE was due to providing water supply in the southern region of Brazil. Prediction results of 2015 were 96-129 tons/ha, about 15-59% higher than current conditions.

Loarie et al. (2011) used the parameters of albedo and evapotranspiration to determine the effect of land use change into sugar cane plantation as a result of biofuel expansion. Conversion of natural vegetation warmed savanna with an average of 1.55 (1.45 to 1.65) °C, however, the subsequent conversion from the sugarcane mosaic cooled the area with an average of 0.93 (0.78 to 1.07) °C, resulting in a net average increase of 0.6 °C. Sugarcane expansion to exist cane crops and pastures provides direct local cooling effect which reinforces indirectly the climate benefit from these land use options.

Sugarcane in Indonesia

As a tropical country, Indonesia has a unique climate because of monsoon influence. This monsoon becomes a cycle regulating the movement of water vapour (source of rainfall) to the areas under its effect. Upland area in Indonesia is about 148 million hectares (Mulyani and Las 2008). The area allows for cultivating variety of agricultural commodities, including sugar cane. In Indonesia sugar cane crops are mostly planted on uplands where water needs are fulfilled from rainwater. The amount and distribution of rainfall has strong influence on the distribution and productivity of sugarcane. Farmers generally grow sugar cane in May-July and harvest in April-June (Jayanti 2016). By applying good cultivation techniques, sugarcane in Indonesia is capable of producing an average dry weight of 1,000-1,200 quintals per hectare (Pratama et al. 2010).

The main constraint of sugar cane plantation in Indonesia is pest as indirectly impact of climate variability. Primary pest on sugarcane are striped stem borer (*Chilo saccharipaghus*), shiny stem borer (*Chilo auricilius*), and shoot borers (*Scirpophaga nivella*). A decline in sugar production due to pest attacks may reach 20% per year (Sutejo 2008). Losses in sugar plantation due to stems and shoots borer attacks in West Java range between 30-45%. Both pests can cause losses ranging between 10-35% (Kumar *et al.*, 2010). Sugar yield is strongly influenced by water content. Based on observation data on sugarcane productivity in 2008 (normal year) and in 2010 (La-Nina year), it is found a indication that rainfall increased in dry season will also increase sugarcane productivity around 9%, however, its yield tends to decrease that sugar production decreases significantly by about 14 % (Margono 2011).

The climatic conditions in 2013 were likely wet (La-Nina) bringing impacts of a decrease in average yield by 0.5-1 points lower than in 2012. The yield was 7.5% in 2012and 6.5 % in 2013 (P_3GI 2013). Increase rainfall within harvest time brings consequences of increases in felling and transport fees, cost of processing sugar, and the amount of dirt (soil, leaves, shoots, sogolan) carried in sugarcane to exceed the maximum limit of 5%. Some sugarcane crops get early maturing due to impaired drainage. Many others grow flowers with low sugar content. In addition to precipitation, temperature difference (between day and night) generally >8°C becomes 7-8°C on climate anomaly condition. This affects the process of sugar formation being not optimal so that yield tends to be low. Climate anomaly in 2013 had an impact on decreasing sugar production by 10-20% compared to 2012 (P_3GI 2013).

Sugarcane in USA

A study of climate variability and its impacts on sugarcane crops in the USA was carried out through field observation and interviews as well as simulation using Climatic Variables Critical (CCV) model (Greenland 2005), observation and long-term data analysis (Fraisse et al. 2006; Vaughan 2003).

ENSO impacts on climatic condition in the south-eastern United States were quite diverse in terms of both locations and periods. There were four focus areas to be assessed their local climate impacts caused by El Nino, Florida Peninsula, Tri-State Region, Western Panhandle, Central and North Alabama and Georgia. During El-Nino, the impacts were wet, cool climate (October-December), very wet, damp, and cold (January-March), somewhat dry and rather wet (April-June), a bit dry (July-September), and no impact. At La-Nina, the impacts were dry and rather warm, slightly dry, and dry (October-December), very dry and warm, dry, and partly dry and partly wet (January-March), slightly damp, dry (April-June), and rather cold and cold (July-September). For the neutral condition, these four areas were not impacted at all (Fraisse et al. 2006).

Effects of summer and winter seasons are quite evident on sugarcane plantation in Louisiana. During summer, sugarcane grows ideally, however, the influence of very low temperatures (0 to -16°F) in winter could damage the plantation (Vaughan 2003). Based on simulation results in Louisiana that provided and maintained drainage, then the sugarcane results will keep increasing (Fraisse et al. 2006).

Risks/Opportunities/Recommendations

The influences of climate variability in sugarcane plantation are quite varied depending on its territory. In general, the impacts of climate variability on sugarcane are indicated by the yields. In Brazil, variation in sugar cane results expressed in TSH is more significant in La-Nina, while TRS is more varied in normal year. For the US condition, influences of climate variability are clear in the form of variability in wet, dry, and cold climates. Sugarcane production increases in summer time, while low temperatures influence in winter may damage the plants. For Indonesia, the sugar cane plant can grow well on the El-Nino under adequate support of drainage, however, sugarcane production tends to decline in La-Nina.

Some anticipations and adaptation actions to respond climate variability include : Creating new varieties of sugarcane plants tolerant to lack of water stress; optimizing the remaining milling time; improving management in cutting-loading-transporting sugarcane; early maturing cane, pengeprasan soon after felling to avoid decaying stumps; controlling weeds as soon as possible before the rain; fertilizing accurately in time, dose, and application; providing composts at sufficient doses; improving drainage system; arranging crop varieties; stop milling when rainy season begins to come; selection of healthy, original, and productive seeds; being accurate in selection of varieties and planting period; and soil tillage, plant protection, and transport to the factory.

Climate Change

Wheat

According to FAO (www.fao.org), wheat (triticum aestivum) is cultivated on 200 million hectares worldwide, and represent a significant part of the world´s food (around 21%). Therefore, wheat is an international commodity and developing countries are major importers. However, 81% of wheat consumed is produced within the same country and often within the same community (CIMMYT, 2005).

Projections up to 2020, indicate that demand for wheat in developing countries is expected to grow at 1.6% annually for human consumption and 2.6% annually for feed, in order to maintain the wheat chain production. These required yield increase leads to improved germplasm and appropriate agricultural management in order to enhance productivity. Another aspect and related to global warming resulted from climate change, is that wheat yield shall be affected negatively (Tubiello et al. 2007).

Food security aspects such as food production, access and price stability are potentially affected by climate change. For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to have negative impact on production at local temperature increases of 2°C or more (above late 20th century levels), although individual locations may benefit. Projected impacts vary across crops and regions, with about 10% of projections for the 2030 to 2049 period showing yield gains (more than 10%), and about 10% of projections showing yield losses (more than 25%), compared with the late 20th century. Global temperature increases, combined with increasing food demand, would pose large risks to food security, both globally and regionally (IPCC 2014b).

Results from a study including 66 yield impact studies are shown in Figure 8 (Porter et al., 2014). The graphs demonstrate that yields of wheat begin to decline with 1°C to 2°C of local warming in the tropics. These confirm that even slight warming will decrease yields in low-latitude regions (tropics). At higher temperature changes, decreases in yield are continuous up to 5ºC. For temperate regions, moderate warming will raise wheat yields.

In the referred Figure differences in yield value do not measure the CO_2 fertilization effect, as changes in other factors such as precipitation may be different between studies. Bootstrap samples are indicated by shaded bands at the 95% confidence interval. Regressions are separated according to the presence - in blue - or absence - in red - of simple agronomic adaptation.

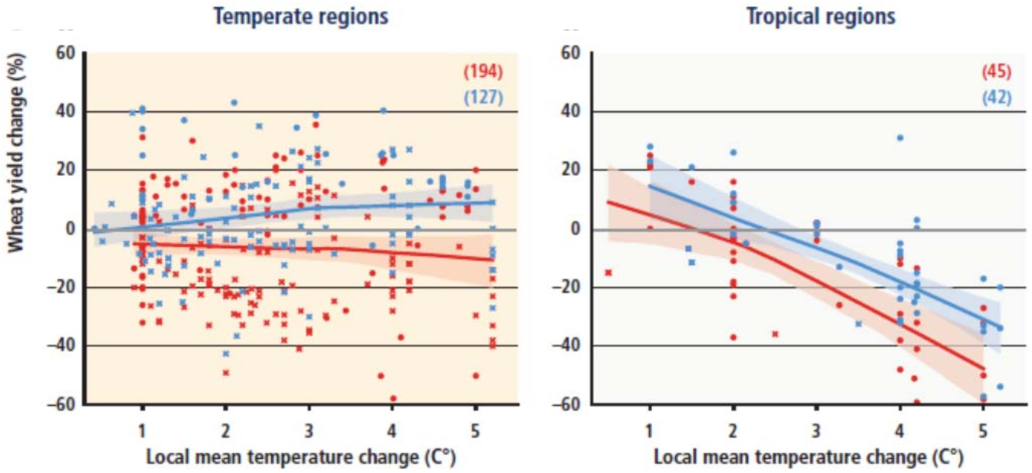


Figure 8 percentage simulated yield change as a function of local temperature change for wheat for temperate and tropical regions. Dots indicate where a known change in atmospheric CO2 was used in the study and remaining data are indicated by x (Source: Porter et al., 2014)

Wheat in India

India is home to over 1.2 billion people (world's second most populous country), and has shown progress on food production and availability. Despite that, large numbers of food insecure and undernourished people remain. Climatic regions include the tropical south, which can be wet, dry or humid, the Himalayan north which is temperate alpine mountain ranges. Year-round, there are four different seasons and two are driven by the effects of the monsoon. Out of this 15 different agro-ecological zones are established, each differing in climate, soil type, fertility condition, cropping patterns and hydrology.

India has 180 million hectare of land and around 60% used for agriculture. The sector contributes with 14% of total GDP and employs 50% of the workforce. Therefore, farming is an important industry and plays a key role in the socio-economic development of the country.

The Indian cropping season is classified into two main seasons: (i) Kharif (July-October) and (ii) Rabi (October-March) based on the monsoon. The kharif crops include rice, maize, sorghum, millets, pulses, soybean, and cotton. The rabi crops include wheat, barley, oats, chickpea/gram (pulses), linseed and mustard. In terms of economic value of total production, rice, wheat, sugarcane, cotton, soybean and pulses are the major crops in India.

Using InfoCrop-WHEAT model (Kumar, et al., 2014), regional vulnerability of wheat production to climate change in India was assessed. The study indicates that climate change will reduce wheat yield in India in the range of 6 to 23% by 2050 and 15 to 25% by 2080. Negative impacts of climate change are projected to be less severe in low-emission scenarios than in high-emission scenarios. The magnitude of uncertainty varies spatially and increases with time. Differences in sowing time is one of the major reasons for variable impacts on yield. Late-sown areas are projected to suffer more than the timely-sown ones. Warmer central and south-central regions of India may be more affected. Despite CO_2 fertilization benefits in future climate, wheat yield is projected to be reduced in areas with mean seasonal maximum and minimum temperatures in excess of 27 and 13°C, respectively. However, simple adaptation options, such as change in sowing times, and increased and efficient use of inputs, could not only offset yield reduction, but could also improve yields until the middle of the century. Converting late-sown areas into timely-sown regions could further significantly improve yield even with the existing varieties in the near future. Therefore, the study emphasises the need for intensive, innovative and location-specific adaptations to improve wheat productivity in the future climate.

Wheat in USA

The United States is a major wheat-producing country, and wheat ranks third among U.S. field crops in both planted acreage and gross farm receipts. Planted wheat area is down by about 30% and covers up to 50 million acres of farmland and total wheat production amounted to 55 million tons (www.nass.usda.gov). Nearly half of the wheat production is exported.

While wheat can be grown throughout the continental United States, production is concentrated in the Great Plains and the Columbia River Basin. Wheat varieties are classified as having a winter or spring habit, depending on whether the plants require a cold period to flower (Walthall, et al., 2012).

Warming will cause negative effects on wheat across the Fall, Winter, and Spring months. Figure 9 depicts that the negative effects are larger than the beneficial effects of reduced exposure to freezing. The one exception is Spring under the 1 °C warming scenario, which shows a net positive effect. The biggest drivers of yield reductions are associated with the Fall and Winter months until the 5 °C warming scenario, at which point the Spring effects are largest.

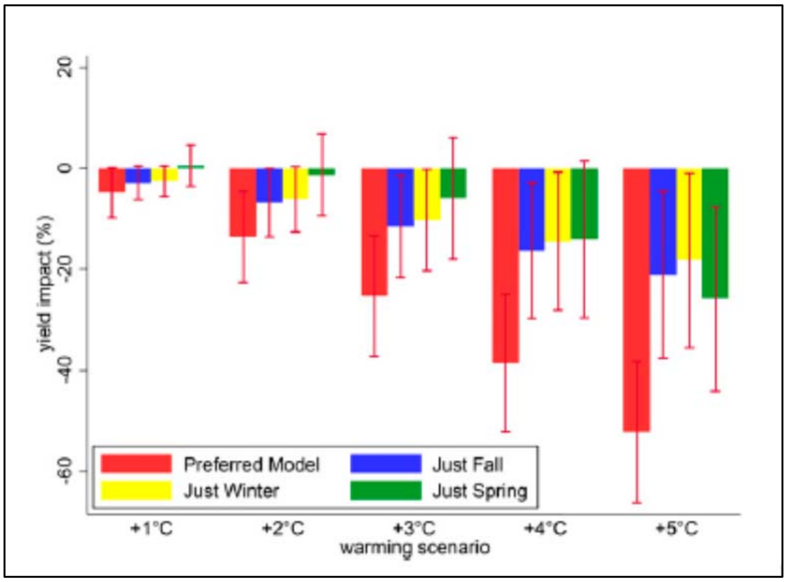


Figure 9 Predicted warming impacts on wheat yields under alternative uniform temperature changes across subsets of the growing season. Each four-bar cluster shows estimates from the preferred model (using Interpolated Degree Days) accompanied by alternatives that restrict subsets of these effects to be zero. Bars show 95% confidence intervals using clustered by year and variety (Source: Tack et al., 2015)

An extreme adaptation to changing climate for a specific location is to change crops. Ortiz et al. (2008) suggested that by 2050 the spring wheat belt in North

America might shift more than 10º latitude northward, into Canada. Presumably, winter wheat would move north into former spring wheat regions and portions of the southern-most winter wheat lands would become unsuitable for wheat. Hubbard and Flores-Mendoza (1995) predicted that warming would substantially increase land used for growing wheat. One option would be that Southern United States might become more suitable for winter-sown spring wheat.

The high latitude wheat-cropping systems are included in mega environment (ME) 6 (defined climatically as areas with coolest quarter minimum temperature above -13ºC and the warmest quarter minimum temperature below 9ºC). This ME comprises the cool temperate regions of North America, where wheat is spring sown because winters are too severe for the survival of winter wheat. Today North American farmers grow wheat up to 55ºN, but under the 2050 (doubling of CO_2) scenario the North American mega-environment 6 may shift northwards up to 65ºN due to a positive warming benefit ensuing from climate change (Figure 10). Major expansion of potential wheat growing areas are based solely on climatic factors, with no consideration of other factors such as suitable soils, land use (e.g. forestry or protected areas) or infrastructure (Ortiz et al. 2008).

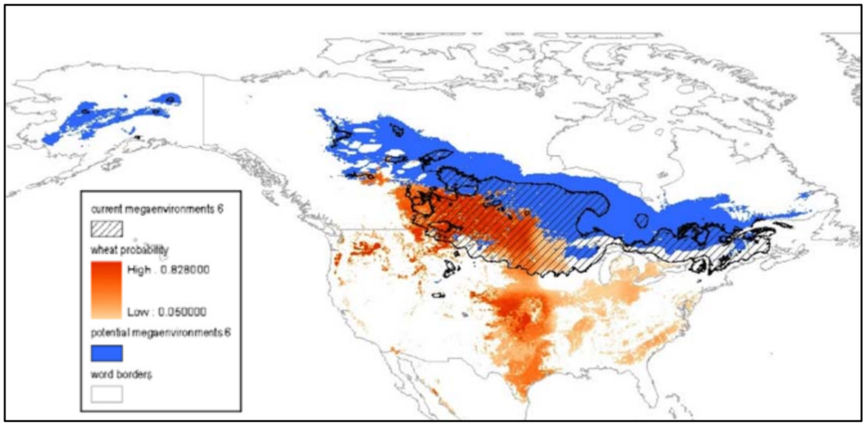


Figure 10 Global warming and potential northward expansion of wheat mega-environment 6 in North America (2050) (Source: Adapted from Ortiz et al., 2008)

Wheat in Russia

Russia wheat production for 2015/16 crop season should be at 60.0 million tons. Current prospects are favorable for spring wheat in the Siberian, Volga, and Ural Districts. Based on data from Rosstat (the State Statistical Committee of Russia), the final sown area for 2015/16 winter wheat in Russia is up to 14 million hectares. Spring wheat area increased to 13.54 million, partly in response to high winter-wheat losses in the Central and southern Volga Districts and subsequent replanting with spring wheat (USDA, 2016).

Global warming impact on Russian agriculture is currently assessed as favourable. It has already considerably reduced the number of winters with low air temperatures threatening winter crops. In many regions, the vegetation period for field crops has been lasting longer. For instance, in Stavropol territory due to climate change the rated grain crop capacity has increased by 30% (WWF Russia and OXFAM, 2008).

As growing seasons become longer and precipitation patterns change, using lands for agricultural purposes that previously would have been too far north — too cold for too much of the year — will become possible (US Nation Intelligent Council, 2009).

Regarding food supply, the longstanding popular presumption in Russia has been that a warmer global climate would translate into a significantly more hospitable Russian environment for agricultural production. There are several respects in which climate change by 2030 will reduce longstanding challenges for Russian agriculture. Growing seasons have already become longer and are predicted to become longer still. Accompanying this change will be a reduction in the frequency of winter temperatures that can damage winter plantings. More sensitive varieties of winter plantings will be possible in much of Russia by 2030, and it will be possible to plant existing varieties farther north (US Nation Intelligent Council, 2009).

There are other factors that negatively impact yields. Limited land availability and lower soil fertility outside of Chernozem (Black Earth) belt, located in Russian steppes, make it unlikely that the shift of agriculture to the boreal forest zone will bring significant production increase. The benefits of declining frost damage are already being reduced by increasing crop damage from ice and longer wet periods in spring. But the principal limiting factor for crop yield in the major agricultural areas in South European Russia is summer precipitation. For the twenty-first century, studies indicate increasing risk of severe droughts in the zone with the most fertile soil under current climate, only a relatively small area in Lower Volga River basin (presently one of the driest parts of the Russian grain belt) has a high frequency of severe droughts. In the future, the area of frequent severe droughts will likely extend to a considerable part of South European Russia. In consuming regions of the north, land reserve is also not very significant, as large areas are unsuitable for agriculture due to inferior soils, existing land use or prohibitive terrain. The territories newly becoming available for grain production due to increasing temperatures are subject to rural depopulation and widespread abandonment of agricultural lands (Dronin and Kirilenko, 2011).

Table 5 shows future climate related potencial crop production given as percentage of current mean potential crop production (average annual production from 1961 to 1990 = 100%), based on climate scenarios from HADCM3 and ECHAM climate models. The warmer and drier climate in the South will threaten the potential production of wheat. The average potential production of grain in the densely populated and highly productive economic regions (Povozhskey, Central Chernozem, North Caucasus) will drop by between 7% and 29%in the 2020s, and by 23–41% in the 2070s (relative to current averages). However in Russia as a whole, the gains largely balance out the losses. Depending on the scenario, either a 9% loss or a 12% gain in total potential grain production by the 2020s (relative to averages during the climate normal period). By the 2070s, only losses are estimated, ranging from 5–12% for net country-wide grain production (Alcamo et al., 2016).

Table 5 Future climate-related potential crop production for various economic regions for wheat and rye (Source: Alcamo et al., 2016)

Economic Region	***IPCC A2 Scenario***				***IPCC B2 Scenario***			
	2020		***2070***		***2020***		***2070***	
	HADCM3	ECHAM	HADCM3	ECHAM	HADCM3	ECHAM	HADCM3	ECHAM
Central	92	93	93	86	104	95	90	89
Central Chernozem	73	85	75	59	93	84	67	71
Far East	108	125	101	143	119	124	100	128
Kaliningradskaya	106	85	92	77	96	94	91	74
North	127	112	148	147	140	122	159	135
North Caucasus	82	88	60	62	73	80	65	67
North West	120	105	111	97	122	109	107	100
Ural	92	129	89	95	70	92	83	89
Volga-Vjatka	97	99	94	93	94	97	102	96
East Siberia	218	271	340	493	210	332	306	442
West Siberia	110	154	86	109	97	121	83	107
Povozhskey	76	92	77	64	71	80	76	68
Russia	94	112	90	95	91	101	88	95

Risks, Opportunities and Recommendations for Wheat

Table 6 Risk, opportunities and recommendation under climate change for wheat

Crop	***Risk***	***Opportunities***	***Recommendation***
Wheat	Yield decrease; Reduction on actual (today used) farmland; Most productive semi-arid zone could suffer a dramatic increase in drought frequency;	Production/yield gains through the CO2 fertilization effect, winter temperature increase, extension of the growing season; Expansion of cultivated land to higher altitudes and northern latitudes;	Promotion of climate-smart practices and technologies across the country; Improve germplasm to provide higher tolerance to stress associated with heat; Zero tillage in rice-wheat-cropping systems;

Rice

Rice is the most important world food source and is consumed by more than half of the population. About 90 % of rice production take place in the tropical/sub-tropical Asia where more than 60 % of the world population lives, and represent approximately 30 % of the total dietary intake, globally and in South Asia (FAO, 2013; Lobell et al., 2008). Due to the positive population growth rate, demand for rice is estimated in 2.000 million metric tons by 2030 (FAO, 2002). This increase will require improvements in rice productivity (yield per hectare). Achieving this demand will be a challenge with climate change imposing temperature increase and water availability decrease (Boumann et al., 2006).

Rice is grown in almost every country in the world and Figure 11 and Figure 12 show rice production and rice area harvested in the top ten countries.

Global warming has significant effect on rice production. High temperatures of more than 35ºC during the reproductive stages (mainly flowering) reduces rice production. Higher night temperatures during the ripening stage also decrease rice yield and grain quality. At vegetative growth stage, high temperatures cause leaf yellowing and accelerated development, leading to low yield potential in sensitive rice varieties (IRRI, 2002).

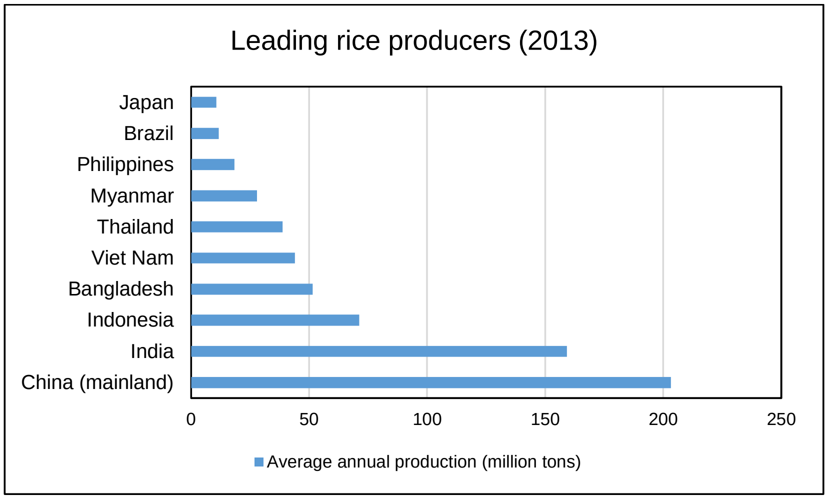


Figure 11 Leading countries rice producers (2013) (Source: FAO (www.faostats.org))

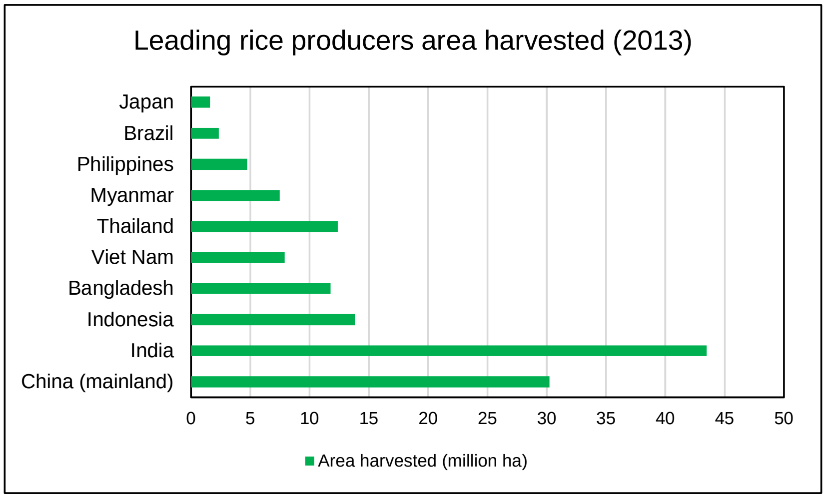


Figure 12 Area harvested by leading rice country producers (2013) (Source: FAO (www.faostats.org))

Rice in India

India is located in South Asia and has 3,287,590 km2. It is the world's second largest rice producer and second most populous nation, with a population in 2010 of more than 1.2 billion, which grew at 1.4% per year from 2005 to 2010 (GRiSP, 2013).

Climate change impacts in India are more severe due to the population depending on agriculture and excessive pressure on natural resources. Warming in India over the past 100 years (1901 to 2007) was observed to be 0.51ºC with accelerated warming of 0.21ºC per every10 years since 1970 (Kumar 2009). The projected impacts are likely to aggravate yield oscillations with impact on food security and prices.

There are evidences of negative climate change impacts on rice yield in parts of India due to increased temperature, increasing water stress and reduction in number of rainy days. In Western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Southern Bihar are likely to be more vulnerable in terms of extreme events (Mall et al. 2006).

Water requirement of crops is also likely to go up with projected warming and extreme events are likely to increase. There is a need to address the whole issue of climate change and its impacts on Indian agriculture in totality to cope with it through adaptation and mitigation (Venkateswarlu, et al., 2013).

However, there is a rice production opportunity in India since yields are below potential. Improvements can be reach through the expansion of irrigation facilities and government subsidies, as well as a broad adoption of appropriate technologies for increasing productivity in irrigated and rain fed rice (GRiSP, 2013).

Figure 13 shows the production states in North, Central and South India.

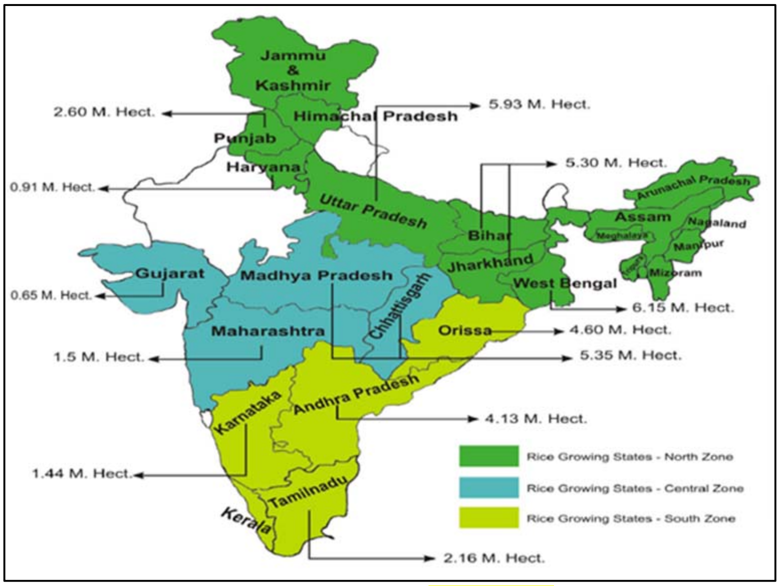


Figure 13 Rice growing distribution in India (Source: Jena, 2015)

Rice in Indonesia

Indonesia is the world's third largest rice producer and rice planting area expanded to 13.2 million ha in 2010, which represented 24% of the total agricultural area. Rice yield increased slightly from 4.3 t/ha in 1995 to 5 t/ha in 2010 (GRiSP, 2013).

Indonesia will require 38% more rice in 25 years, and therefore yield must increase to more than 6 t/ha (IRRI, 2012). To avoid huge imports, most rice policies in Indonesia have been aimed at achieving rice self-sufficiency. For this government set a production target of 10 million tonnes of annual rice surplus and it is providing fertilizer subsidies to small rice farmers.

Climate change will have a devastating impact in Indonesia. Delayed wet season (monsoon) and a temperature increase beyond 2.5°C is projected to substantially drop rice yields and reduce farm-level net revenue of 9 to 25% (Lal, 2007). For example, a recent study that looked at assessing the risks of climate change on Indonesia rice production suggests that under future climate projections, there is a significant 30-day delay in the onset of monsoon season and a substantial decrease in precipitation later in the dry season (Naylor et al., 2007).

Approaching adaptation issues, Förster et al. (2011), presented a study of impact analysis regarding inundation impacts on agricultural areas, using 2 meter sea level rise scenario. Figure 14 shows the risk of rice area loss.

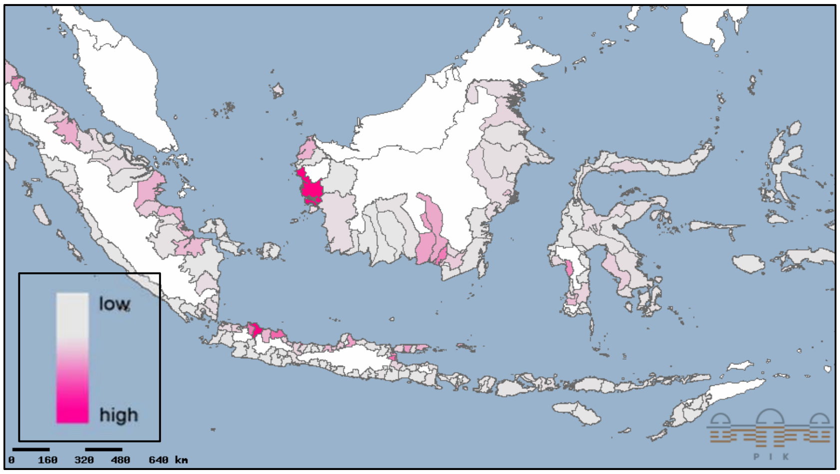


Figure 14 Relative rice production risk of area loss due to sea level rise (Source: Förster et al., 2011)

Rice in Vietnam

Vietnam has 332.698 km^2 with 3.300 km coastline and estimate of 92 million inhabitants (2015). National agriculture economy is based on rice crop systems. Rice is cultivated on 82% of the arable land and it provides 80% carbohydrate and 40% protein intake of the average Vietnamese. Most of the rice areas in Vietnam are in two deltas of the north and south, which are Red River and Mekong, respectively. About 52% of Vietnam's rice is produced in the Mekong River Delta and another 18% in the Red River Delta (IRRI, 2012).

Vietnam is expected to have a big impact by climate change due to its tropical location, a very long coastal line and large river deltas. Rice cultivation is currently grown at current average temperatures and precipitations are already over to optimum, except for precipitations in dry season. Based on the median emission scenarios it is shown that average temperature have increase about 3ºC and precipitations have increase to 5% in rainy season but have fall about 5% in dry season by the end of 21 century (MONRE, 2009). Therefore, rice farmer in Vietnam would be impacted by climate change and its losses would be up to 15% compared to average net rice revenue in 2008.

Figure 15 shows the prediction of climate change impacts distributed in 7 climatic regions in Viet Nam, based on scenario B2 (medium emission). South Central and South regions should have higher losses in terms of farmer net income. On the contrary, losses should be reduced in higher latitude regions and even may benefit in specific sites of the north, where almost ethnic-minority groups are living under the deficit conditions such as difficulty of transport, unstable production and lower productivity.

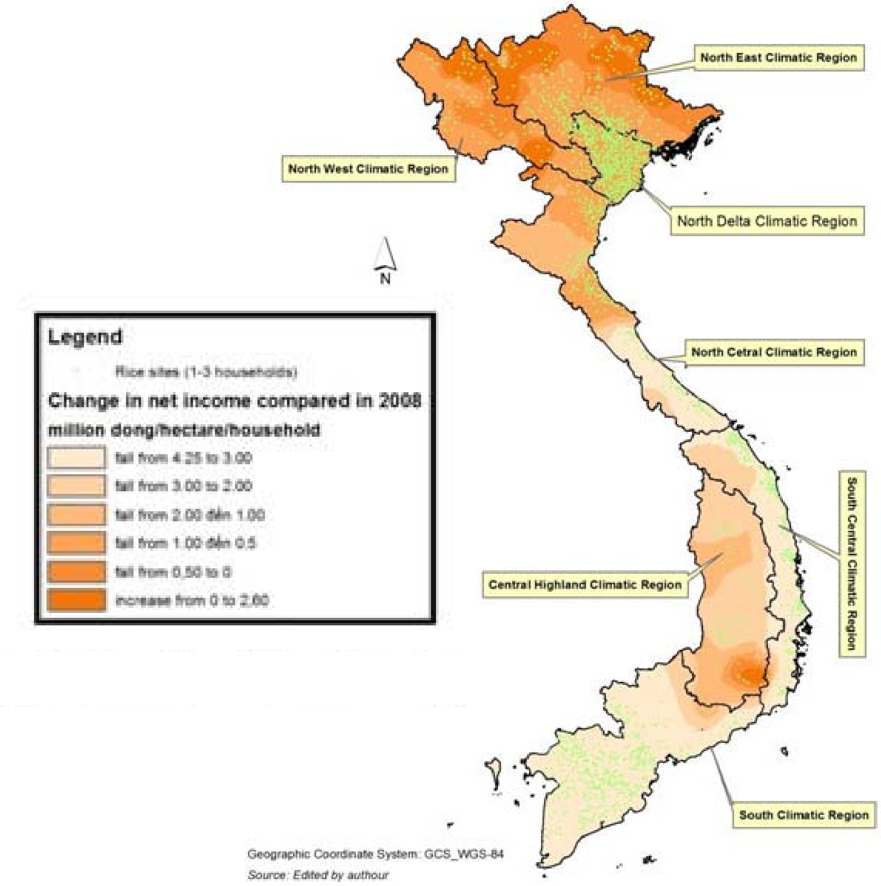


Figure 15 Prediction of climate change impacts in terms of net income in Viet Nam in 2100 (Source: Phung, 2012)

Risks, Opportunities and Recommendations for Rice

Table 7 Risk, opportunities and recommendation under climate change for rice

Crop	***Risk***	***Opportunities***	***Recommendation***
Rice	Yield decrease with higher temperatures; Threaten crop yields, endangering country food security; Reduction on actual (today used) farmland; Most productive semi-arid zone could suffer a dramatic increase	Yield gains through the CO2 fertilization effect, winter temperature increase, extension of the growing season; Expansion of cultivated land to higher altitudes and northern latitudes;	Promotion of climate-smart practices and technologies across the country; Improve germplasm to provide higher tolerance to stress associated with heat; Use of early-morning flowering species (e.g., *Oryza. glaberrima*); Zero tillage in rice-wheat-cropping systems; Reduce the water and environmental footprint of rice production ("Greener

	in drought frequency;		rice”); Extracting more value from rice harvests through improved quality, processing, market systems, and new products; Development and deployment of suitable salt tolerant rice varieties (due to higher sea level); Improved soil management practices; development of drought-resistant crop

Coffee

The two main coffee species are *Coffee Arabica* and *Coffee canephora* var. *Robusta*, which are grown in tropical countries along the equator between 22°N and 26°S. Worldwide distribution is shown in Figure 16. *Arabica* coffee is grown mainly in tropical highlands and it is used in gourmet coffees. *Robusta* is grown at lower altitudes producing lower quality coffee. *Arabica* and *Robusta* together dominate production summing up to 8.2 Mtonnes in 2011 (Ovalle-Rivera et al. 2015).

Coffee crops can be influenced by climate change because their lifespan is about thirty years, therefore the likely effects of future climates are already a concern. Research on adaptation is in high demand across the entire supply chain.

In terms of climatic conditions, coffee productivity is influenced by temperature, water availability, sunshine intensity, wind, type of soil and topography. The optimal mean temperature for *Arabica* is 18°C during the night and 22°C during day time. Extremes should not be lower than 15°C during night and not exceed 25 to 30 °C at daytime. Low temperatures will favor diseases. Temperatures lower than minus 2°C for more than 6 hours are potentially lethal for the plant. *Robusta* is generally more tolerant towards high temperatures but may die at 4 to 5°C. *Arabica* requires about 1400 to 2000mm of annual rainfall, *Robusta* between 2000 and 2500mm. A dry season of about 3 months is considered to promote productivity. Atmospheric humidity has an influence on transpiration and is therefore linked with necessary rainfalls. Ideal humidity is 60% for *Arabica* and 70% for *Robusta* (Descroix and Snoeck 2009). However, recent publications demonstrate that general recommendations are overly generalized. A differentiation of coffee growing sites according to characteristics like slope, shade level, variety and others shows that management recommendations need to be site specific (Laderach et al. 2011).

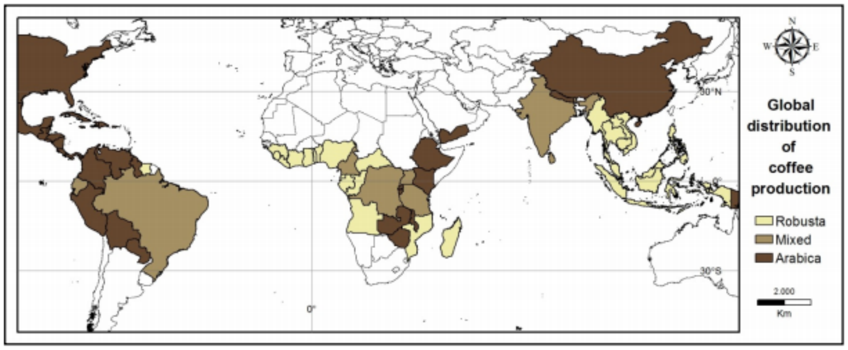


Figure 16 Average area shares for coffee (*Robusta*, *Arabica* and mixed) (Source: Bunn at al., 2015)

In terms of coffee sector adaptation, latitudinal migration, altitudinal migration of production, or replacement of Arabica with Robusta had been suggested to respond to climate change. However, considering bioclimatic effects, a machine learning approach (Bunn et al. 2014), showed that for *Arabica* heat stress determines the spatial distribution and *Robusta* is largely confined to locations with an even climate without seasonal and diurnal temperature variation. These variables were found to rule out a general latitudinal migration of coffee production, but a global trend that production will migrate in elevation was confirmed.

Suitable areas can be reduced by about 50% for *Arabica* and *Robusta*. In terms of yield reductions can be up to 34% for *Arabica* and 17% for *Robusta* relative to historic climate data (Bunn et al. 2014).

Climate change will have a profound negative impact on global coffee production, independent of emission scenario, climate or model used to simulate crop development. Increase in temperature will reduce yields, make area unsuitable for production, and water management tougher.

Adaptation to climate change will be a major challenge for producer countries, especially given the considerable uncertainty in climate modeling on local scale. However, for the coffee industry higher prices will compensate. Thus, there will be coffee on the table in 2050, but it will be of lower quality, will cost more and it will still be in the focus of sustainable enterprises because its production will still be shaped by poverty risk and environmental problems.

In terms of global marks, with increasingly uncertain climatic conditions price fluctuations could be exacerbated. Climate change means the increasing likelihood of a (locally) very unusual event to occur, such as a heat spell once in 10 years rather than once in 100 years (Hansen et al., 2012). The resulting uncertainty will affect stakeholders along the entire supply chain. The high economic risk has been found to be a major reason which will drive producers towards more reliable income sources (Baca et al. 2014). Fluctuations on coffee markets will increase to an extent that even global trade houses will not be able to offset the risk by using regionally diversified portfolios due to climate change.

Table 8 shows changes in suitability and area (in km^2) of *Arabica* coffee growing areas by 2050. The predicted changes in coffee suitability are directly linked to latitude. Higher temperatures would cause areas growing *Arabica* coffee within 5°–10° of the equator at elevations less than 1,000 m to lose climatic suitability. Changes in annual precipitation and its seasonality would have little effect.

Mexico, India, Honduras, Brazil, Uganda and Viet Nam are the countries that should be impacted with an average decrease in area suitability for *Arabica* coffee between 25 and 29%,

Table 8 Changes in suitability and area (km2) of *Arabica* coffee growing areas by 2050 (Source: Ovalle-Rivera et al. 2015)

Country	**Potential area for Coffee (km2)**	**Potential area for Coffee excluding protected areas (km2)**	**Change in suitability by 2050 (excluding protected areas)**		
			Average	**Minimum**	**Maximum**
Mexico	30,605	27,430	-29	-85	11
India	2,705	2,110	-28	-69	4
Honduras	13,795	12,315	-27	-67	12
Brazil	129,335	118,770	-25	-70	13
Uganda	8,070	7,550	-25	-46	6
Vietnam	6,165	4,730	-25	-58	14
Tanzania	18,315	15,710	-22	-84	11
Costa Rica	3,130	2,165	-20	-55	18
Bolivia	9,435	4,915	-20	-57	6
Ecuador	8,245	7,345	-20	-72	14
Peru	10,480	7,390	-20	-73	16
Guatemala	7,385	6,635	-19	-82	18
Indonesia	36,510	22,740	-18	-62	16
Colombia	21,880	18,970	-16	-61	21
Kenya	10,380	9,550	-12	-40	17
Ethiopia	40,800	35,095	-11	-61	23
Papua New Guinea	14,690	14,310	-9	-54	13

Coffee in Brazil

Brazil is the world's largest producer of *Arabica* coffee and in charge of 25% of the total global coffee supply (FAO 2016). *Arabica* accounts for about 70% of total harvest and *Robusta* makes remaining 30%. Adverse climatic events in its major production regions have global repercussions through market and industry. Climate change impacts on the Brazilian coffee production are thus of high interest to understand long term trends on global coffee markets.

Results of models under different scenarios indicate a marginal migration of suitable areas for coffee growing towards the Southern states of Santa Catarina and Rio Grande do Sul. In Northern states such as Bahia, Rondonia and Goias, suitable coffee areas are projected to be reduced. This also applies for Minas Gerais state (Bunn et al. 2014).

Once full climate change effects are imposed, Brazil could have all the suitable coffee areas reduced by 2080. On the other hand the shifting to the south will impose a dispute with other agricultural areas. Therefore, Brazil will face huge challenges to remain a major *Arabica* coffee producing country.

Coffee in India

Coffee production in India is dominated in the hills of South Indian states. Karnataka state accounting for 71%, Kerala state for 21% and Tamil Nadu for 5% of total production. In the 2016-17 crop season, estimates indicate 320,000 Mts of coffee production in India. India is a minor world producer but coffee is a very important crop and there are approximately 250,000 coffee growers in India. 98% of them are small growers (CBI, 2014).

Suitable climates for Arabica coffee in India would shift upward from the current 400 to 1500 masl to 700 to 1800 masl. However, there will be a loss of suitability below 1200 masl (Ovalle-Rivera et al. 2015).

Coffee in Vietnam

Vietnam's coffee production is concentrated in the provinces known as Central Highlands: Dak Lak, Dong Noi, Gia Lai, Kun Tom and Lam Dong (Marsch, 2007). Vietnam is the world's largest Robusta producer, coffee with *Robusta* covering 95% of total production. It is grown on more than 500,000 ha, mainly in the Central Highlands. To the Vietnamese farmers belong the higher coffee yields around the globe. Productivity around 3.5 t/ha is due to intensive monoculture combined with deforestation, land degradation, water over-exploitation and intensive use of fertilizer (Haggar and Schepp 2012).

Temperature increase and changing precipitation distribution should be highly considered because they will impact the irrigated Robusta production system. This system depends upon groundwater and river flows to maintain the high yields.

Risks, Opportunities and Recommendations for Coffee

Table 9 Risk, opportunities and recommendation under climate change for coffee (*Arabica* and *Robusta*)

Crop	Risk	Opportunities	Recommendation
Coffee	Decrease in coffee yield and production; Increase in incidence of pests and disease; Some areas currently used for coffee will be unsuitable; Suitable area for coffee will be cut by half by 2050;	Some areas will become suitable for coffee; Increase suitability of *Arabica* coffee in higher areas;	Need for high quality varieties adapted to higher temperatures and disease resistant; Shade management (arborisation), over planting at high densities, vegetated soil, irrigation, genetic breeding to pest management;

Rangeland

Rangelands are very important environment and occupy approximately 50% of the Earth terrestrial surface corresponding up to 68 million km2. In these are included grasslands, shrublands, savannas and hot and cold deserts (Lean et al., 1990). The main use of rangelands is for grazing domestic livestock and wildlife. Overgrazing and land degradation consequences are very common worldwide (WRI, 1992).

Rangelands represent an environment with a strong influence of climate and presenting interactions between plant growth, livestock and human management with additional factors such as soils, above sea level altitude and topography.

Increase CO_2 by itself can have positive impacts on rangeland forage production and sustainability. This occurs largely because increased CO_2 concentrations make plants more water-efficient resulting in potentially more growth in water limited regions. The added growth would be particularly pronounced in dry years and in dry regions. The likely increase in plant growth will improve ground cover and therefore reducing runoff and soil erosion. Also, deep drainage component will increase which may increase the risks and rates of salinisation in areas where there is a potential hazard for that. The increase in drainage is particularly likely in sites with poor soil nutrient status and in areas with strongly seasonal rainfall patterns (Weindl et al., 2015). In the other hand, increase in CO_2 can result in the reduction of forage quality and palatability due to the increase carbon to nitrogen ratios. These will take place in lower latitude rangelands where low nutritional value is already a problem (Allen-Diaz, 2000).

If rainfall and CO_2 increases, there should be some increase in pasture production but this will be limited by nutrient availability. This will be more of an issue in the higher rainfall regions than in the more arid areas. The increase of CO_2 in combination with increase in temperature are likely to lengthen the growing season in many regions (subject to the change in rainfall), resulting in increased liveweight gain potential by livestock. However, this is likely to be offset by: (i) Forage quality is likely to decrease due to both decreased nutrient contents of leaves with high CO_2 and decreased digestibility of C4 grasses with increases in temperature; (ii) Increased frequency of heat stress days (Weindl et. al., 2015).

Rangelands in Brazil

Climate change with mean precipitation decreases are expected for several South American rangelands. In these case, assuming that linear relationship between mean annual precipitation and livestock biomass, rangelands will be affected. Increases in the frequency and intensity of extreme events, where dry years might be more common and even more pronounced, are expected to cause higher production variability between years, with negative consequences in forage production and for the stability of livestock production (Yahdjian & Sala, 2008).

Temperature can impact directly animal production leading cattle and dairy productivity to decline. In addition, temperate grasslands and the animal production depending on them are vulnerable to drought. Therefore, livestock production could be negatively affected by higher temperatures or increased evapotranspiration rates. However, the experience has shown that extreme events, such as large-scale floods or drought-erosion cycles, may also pose high risks (Allen-Diaz, 2000).

With the objective to evaluate climate change impacts in Brazil in terms of agricultural land use change and economic aspects, the PRECIS model was used considering three major land use: agriculture, rangeland and forest. Simulations indicate that climate change impacts should vary spatially in Brazil and the impacts will be different. There is an indication of reduction in forestry areas and land conversion into pasture (rangeland), and therefore increasing the pressure for deforestation in the Amazon Forest. Due to the Brazilian territorial extent, climate change and impacts shall be different through the regions. In the South region, there should be a change in land from rangelands to croplands, because climate change will favor the conditions for crop systems and the increase in yields. In the Center East region, the changes are towards the increase in rangelands due to the decrease in crop yields (Feres et al., 2009).

Table 10 shows estimated changes and shifts in areas (ha) of agriculture (crop), pasture (rangeland) and forest, considering scenario B2. For the period 2070 to 2100 there is an overall increase in pasture in all the regions with exception of South. The land shifts are in detriment of forest.

Table 10 Changes in areas (ha) of crop, pasture and forest (2010 to 2100) (Source: adapted from Feres et al., 2009)

Region	**2010 to 2040**			**2040 to 2070**			**2070 to 2100**		
	Crop	***Pasture***	***Forest***	***Crop***	***Pasture***	***Forest***	***Crop***	***Pasture***	***Forest***
Brazil	0.5	9.9	-16.2	2.7	10.6	-18.2	-3	10.1	-15
North	4	13	-11.3	10.3	15.5	-14	24.9	12.8	-13.3
North East	-26.6	25.5	-15.3	-23.5	25.1	-16.4	12.6	14.1	-22.3
South East	13.6	3.5	-25.2	16.3	3.7	-28.4	-20.3	13.6	-24
South	22.6	-2.7	-31.8	27.1	-1.7	-42.1	15.9	-8.6	-4.7
Center West	-5.1	8	-13.8	9.6	9.6	-15.9	-15.2	10	-15.3

Risks, Opportunities and Recommendations for Rangelands

Crop	**Risk**	**Opportunities**	**Recommendation**
Rangeland	Decrease in the extent of natural rangelands areas due to agricultural pressure; Cattle and dairy productivity is expected to decline (due to	Land restoration for rangeland and livestock;	In terms of management: Reduce animal numbers, chance mix of animals, alter animal distribution, use of adapted species (either natural or exotic), implement agroforestry systems, use of irrigation systems;

	increasing temperature);		

Grapes

All crops and agricultural industry dependent upon and are interconnected to climate and weather. Grape yards are specially no different because very narrow temperature ranges are needed. "Individual winegrape varieties have even narrower climate ranges, which further limit the areas suitable for their cultivation. These narrow niches for optimum quality and production putting the cultivation of winegrapes at greater risk from both short term climate variability and long term climate changes than other crops (Jones and Webb, 2010)." Winegrapes and wine – as an economic commodity - are both at risk due to climate change.

Climate change impose a huge influence on vineyards and grape composition, affecting vinification, wine microbiology and chemistry, flavor and tasty wine aspects. The most important climate change impact is related to advanced harvest times leading to increased grape sugar concentrations and high wine alcohol levels, lower acidities and modification of varietal aroma. Under extremely hot temperatures, vine metabolism may be inhibited leading to reduced metabolite accumulations, which may affect wine aroma and color. Musts with high sugar concentrations leads to increased formation of fermentation co-products, such as acetic acid. If not controlled by acid addition, the higher pH can lead to significant changes in the microbial ecology of musts and wines and increase the risk of spoilage and organoleptic degradation (Orduna, 2010).

In general, the range of grape growing climate zones is about 10ºC globally and for some grapes, the range is limited to 2ºC (Santisi, 2011). The general shift of warmer temperatures poleward will lead to a shift in the geographic distribution of vineyards. Some areas would cease production all together. A mitigation action include to move planting regions one Celsius isotherm further poleward for each degree of average temperature increase (Tate, 2001; Kenny and Shao, 1992).

Figure 17 shows global change in viticulture suitability shifts using 17 GCM (Global Change Model) ensemble (Hannah et al., 2013). North Hemisphere shall hold newly suitable areas.

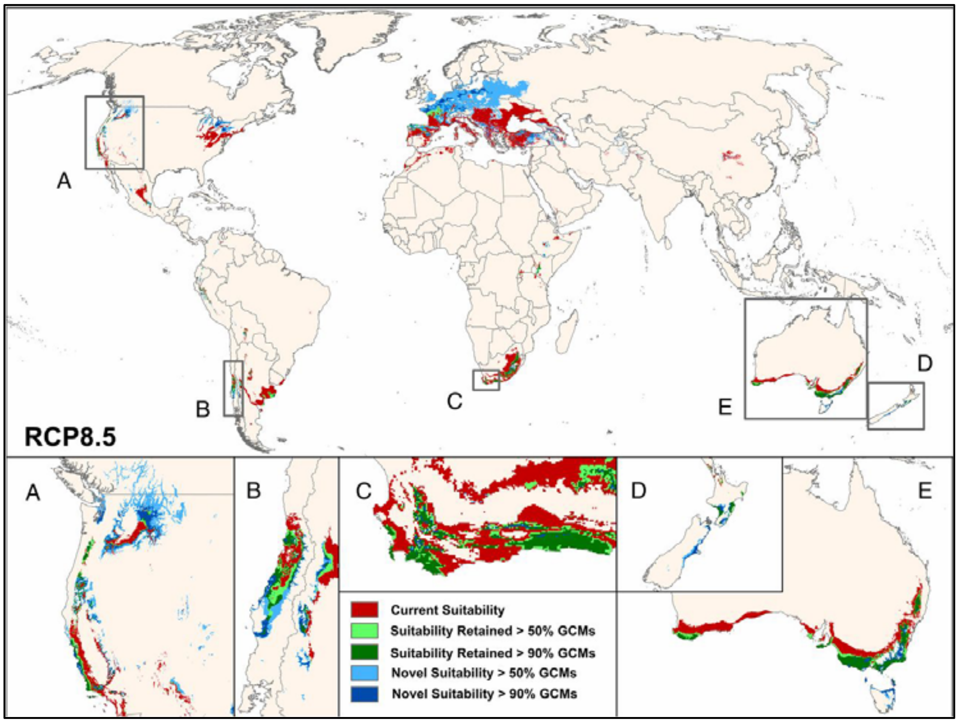


Figure 17 Global change in viticulture suitability is shown between current (1961–2000) and 2050 (2041–2060) time periods. Areas with current suitability that decreases by midcentury are in red. Areas with current suitability that is retained are in light green and dark green. Areas not suitable in the current time period but suitable in the future are shown in blue (Source: Hannah et al., 2013)

Grapes in France

South of France (Languedoc Region) over the last 30 years is facing spatial and economic impacts due to the shift in the production of table wine to quality wine. This lead to the relocation of vineyards from the plains to the hillsides, where grapewines tend to have higher alcohol content. However, climate change will inflict some constraints to these area shifts. Hillside vineyards areas are already facing lower yields and quality variability, as areas in the plains with deeper soils can offer the advantage of a greater water holding capacity. Considering only temperature, in the future higher altitude areas will represent the suited areas for high quality vineyards due to a cooler climate.

In France and most other European countries, the production, exchange, and consumption of wine is regulated by standards and rules. One example is the *Appellation d'origine controlee* (AOC) label, which guarantees the origin, control practices, as well as the spatial location of the vineyards. Climate change impose a risk to maintain and keep the labels if there will be a need to shift vineyards to better and suitable areas, if grape quality and characteristics will change. The contribution of wine to trade balance, positive externalities on tourism activities and gastronomy, and retention of employment in isolated regions could be affected (Ollat et al., 2016, Ollat and Touzard, 2014).

To continue to produce high-quality wines in an environmentally and economically sustainable way, adaptation, defined as "the set of organization, localization and technical changes that societies will have to implement to limit the negative effects of climate change and to maximize the beneficial ones" is a necessity (Hallegatte et al., 2011). The main challenge in France to face climate change is to set up adaptation measures to maintain yields, grape composition to avoid perturbations on vinification and keep typical wine quality and AOC labels.

Figure 18 shows possibly shifts in area of wine cultivation in France and other countries.

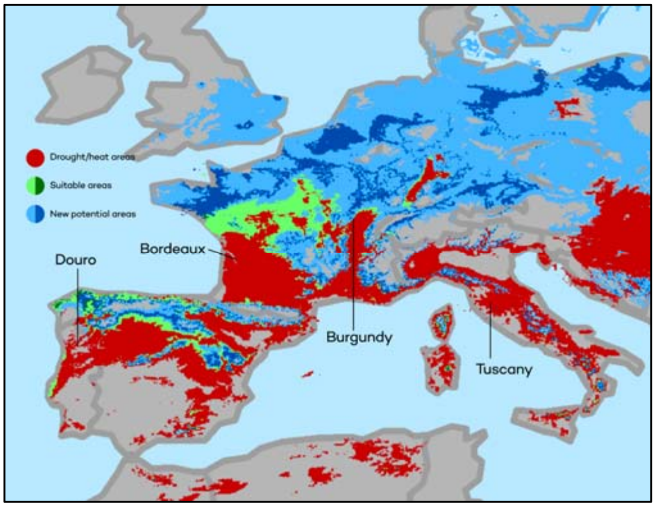


Figure 18 Wine producing regions in France, Spain and Italy (in red) and new areas up in northern lands (in blue) (Source: Conservation International, 2015)

Grapes in South Africa

Climate change will directly impact South Africa´s mean annual temperature and rainfall rates, which will affect grapeyards in terms of pest and disease distribution, flowering and fruiting periods, water availability, choice of cultivars and therefore, impacts on wine quality and taste. By 2050, temperature increases will range from ~1.5ºC at the coast and up to 3ºC inland of the coastal mountains (Midgley et al, 2005). Using 30 year control climate precipitation data (1961 to 1990), rainfall projections for 2046 to 2065 over wine regions show decrease in early winter rainfall (Carter, 2006). Also, it is expected severity of drought which can be one of the major impacts to the agricultural industry in South Africa, particularly within the Western Cape, the major fruit and wine region. Generally speaking, one can expect warmer and drier conditions for South Africa grapeyards (Vink, 2009).

Potential impact on South Africa wine industry (VinIntel, 2010):

Summer temperature increase during the growing season:

- Warmer September = better and more even budding;
- Warmer spring/early summer = better fertility;
- Warmer flowering period = depending on regions can be better or worse;
- Warmer harvesting period = sunburn grapes, sugar accumulation, lower acid;

Winter temperature increase during dormant season:

- Sooner uplift of dormancy;

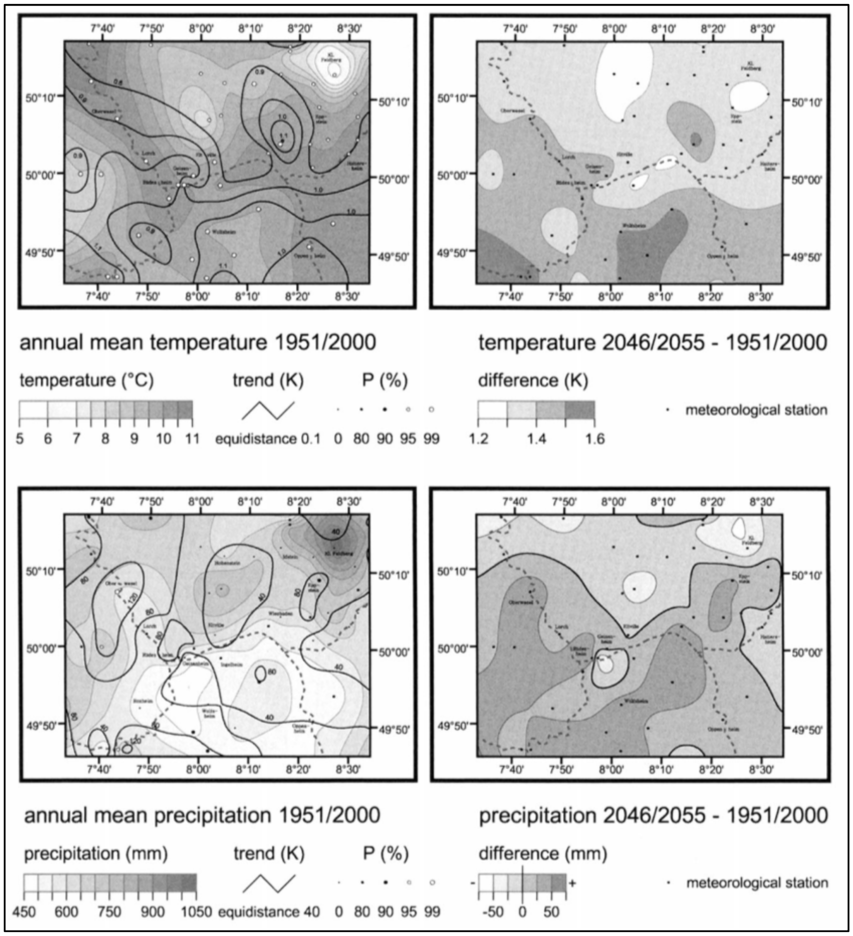
- Higher temperature during May/June = delayed budding;

Rainfall:

- Dry spring = control growth of vigorous growing cultivars, control berry size;
- Dry summer = less disease problems;
- Dry winter = lack of irrigation water;

Grapes in Germany

Average temperatures in Germany central wine growing regions in the last 50 years has already increased around 1ºC. A further increase is expected, mainly in the South and less in the North. On the contrary, precipitation will be less in the North and more in the South (see Figure 19). Impacts on phenological development will take place by anticipating harvest up to 30 days earlier when compared to 1950 (Figure 20). In this case there is a high risk of the incidence of pests and diseases. Rising temperature may not necessary have only positive impact on Riesling quality ripening the fruit. Can be harm during maturation through the reduction of acid affecting wine quality (Stock et al., 2005).



annual mean temperature 1951/2000

temperature 2046/2055 - 1951/2000

annual mean precipitation 1951/2000

precipitation 2046/2055 - 1951/2000

Figure 19 Rhine Valley and Rheingau region distribution of annual mean temperature and precipitation for 1951 to 2000 (in the left) and projections for theyears2046 to 2055 (in the right) expressed as differences (Source: Stock et al, 2005)

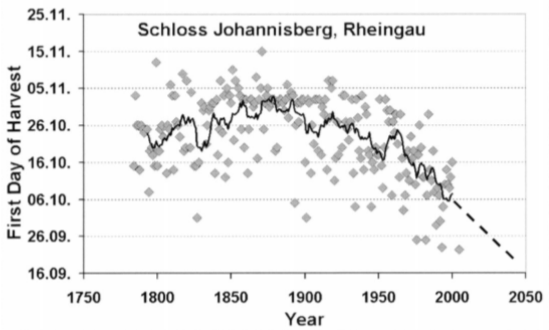


Figure 20 First date of harvest of "Riesling" from 1784 to 2003, and estimated first date harvest up to 2015 (Source: Stock at al, 2015)

Risks, Opportunities and Recommendations for Grapes

Crop	Risk	Opportunities	Recommendation
Grapes	Yield reduction; Shortening in the growing season; Impacts and changes on the appellation system and appellation maps;	Yield increase in good vintages; Establishment of new grapeyards in higher altitudes and latitudes (polewards); Increase in sugar accumulation and alcohol levels;	Improving soil water balance through a change in canopy management to provide additional shade; Improving water irrigation techniques; Adoption of night harvesting and quicker deliver of the berries; Adoption of different row orientation to offset increased sunlight; Development and adoption of new cultivars adapted to higher temperatures, droughts, pests and diseases; Breeding programs should develop heat-resistant vine stocks;

Cotton

Cotton is a perennial crop with an indeterminate growth habit. Vegetative and reproductive growth occur simultaneously making interpretation of the crop's response to climate and management sometimes difficult (Bange et al., 2010).

As other crops, cotton will have climate change impacts. As a contributor, cotton agricultural production, processing, trade and consumption contribute up to 40% of the world's emissions - when forest clearance is included. Cotton has a resilience to high temperatures and even drought due to its vertical tap root. However, water availability is crucial at flowering and boll formation. The increase in temperature together will increase in CO_2 will promote plant development by stimulating photosynthesis. In the other hand, pests, water stress and weather extremes will impose new challenges for cotton production.

Accordingly to ITC (2011), negative impacts of climate change on cotton production relate to the reduced availability of water for irrigation will take place in China, Pakistan, Australia and the western United States. Heat stress creating depressed yields in Pakistan. Positive impacts due to rainfall will take place in the Yellow River area (China), in India, in southeastern United States and South Eastern Anatolia (Turkey). The impacts on rainfall in Brazil and West and Central Africa are unclear.

Figure 21 illustrates the ranking of cotton production countries.

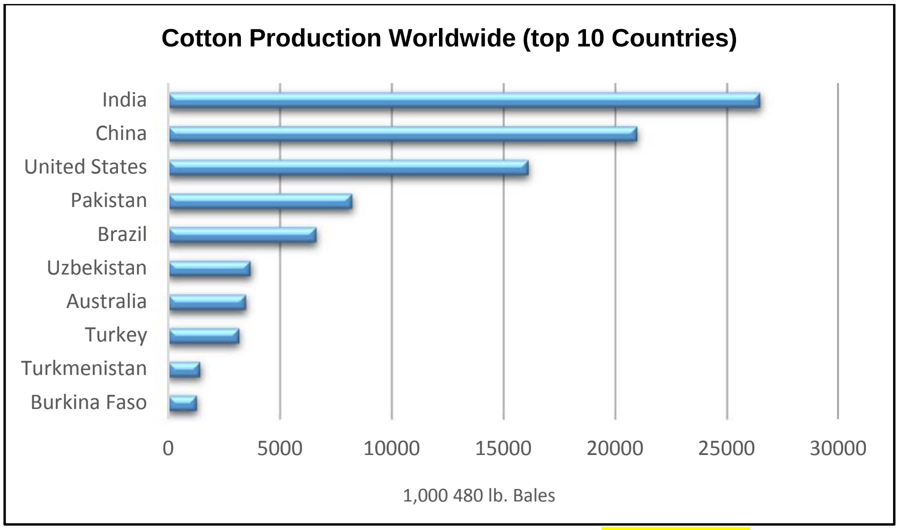


Figure 21 Cotton production worldwide (Source: adapted from USDA, 2016)

Cotton in USA

The USA is the third largest producer country and the largest cotton exporter. Cotton is grown in southeast (22%), mid-South (34%), southwest (35%) and the West (9%), all together the so called Cotton Belt. In general, cotton yields are expected to rise with limited increases in temperature and atmospheric CO_2. However, the number of very hot days is expected to increase and cause a negative impact in yields. The mostly rain-fed cotton areas in the south-east and mid-south may see an increase in rainfall, but also an increase in extreme weather events. Production in the Southwest and the West relies mostly on irrigation (ITC, 2011).

In order to simulate climate change impacts over cotton in Southeastern USA, the National Center for Atmospheric Research (NCAR), use a global scale and regional scale crop models. The regional scale model predicts a cotton yield increase of 5% and the large scale model, 15% increase. A second run considered additionally to elevated CO_2 levels, farming adaptations like planting crops earlier to take advantage of a longer growing season. In this case, regional scale model predicts a 26% increase, and the global scale model a 36% increase in cotton yields (NCAR, 2001). Figure 22 shows the distribution of cotton yields change percentages. In the center part of the referred region, including Missouri, Arkansas, Mississippi and Louisiana States, decreases in yield can be up to 20%, when no adaptations are considered. Reddy et al. (2002) using a cotton simulation model, also found a decrease in cotton yields in a study in the Mississippi Delta area.

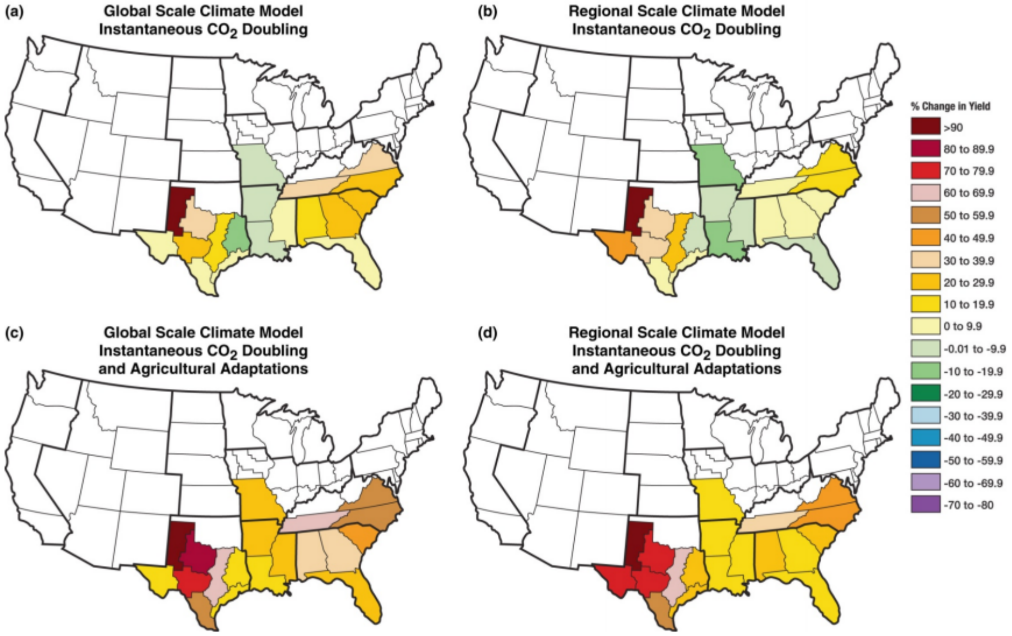


Figure 22 Distribution of possible future cotton yields in Southeastern USA (Source: adapted from ITC, 2011)

Cotton in Brazil

Brazil is the fifth largest cotton producer and advances in crop management technology and new crop varieties help yields to double world average. Cotton production is expected to grow at an annual average rate of 4.6% to reach 2.3 Mt in 2024, which is 52% more than the base period (Figure 23).

Cotton is grown in the Centre-West region, mainly in Mato Grosso, Mato Grosso do Sul and Goias States. The production in Brazil is highly efficient and farmers are technically advanced (Graham, 2009).

Cotton in Brazil is mainly rain fed and there are few irrigation plants. Studies indicate that change on rainfall still present uncertainties over the effects and impacts in Latin America. Nevertheless, arid and semi-arid areas will receive even less rain causing degradation of agricultural land and impact food security. Cotton yields are expected to decrease by the end of the century, except for mid-latitude areas, where CO2 fertilization effects may balance out the negative effects of climate change (UNFCCC, 2008).

If mitigation measures are not implemented, there will be an impact on cotton due to increased temperature and water deficiency. In terms of agricultural zoning the estimated reduction will be about 11% in areas with low risk for cotton cultivation. This should take place 2020 and reach around 16% in 2070, with high negative economic impacts due to the cotton importance in the agricultural chain (Zullo Junior et al, 2006).

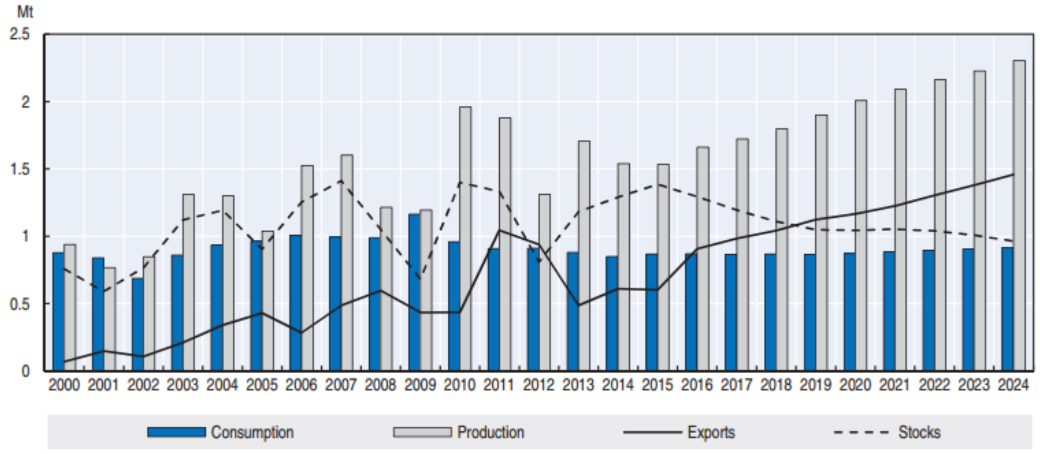


Figure 23 Cotton market in Brazil (Source: OECD/FAO, 2015)

Cotton in India

India is the largest producer of cotton worldwide (USDA, 2016) and cotton is grown in 3 regions: (i) Central region which includes Gujarat, Madhya Pradesh and Maharashtra, with 65% of total area of cotton, (ii) South region including Karnataka, Andra Pradesh and Tamil Nadu, with 20% of total area, (iii) North region including Punjab, with 14% of total area of cotton.

Temperatures are expected to increase in all the regions where cotton is growth and rainfall intensity (during monsoons) may become a problem. Rain-fed cotton may suffer an impact due to climate variability through droughts and also floods. Cotton irrigated systems occurring mainly in the North of India, may suffer from lower water availability due to the reduction of snow and ice from Himalayan and Tibetan Plateau (ITC, 2011).

Considering the case of CO_2, conventional cotton varieties/hybrids are well adapted to its increase. This is due to better morpho-physiological and biochemical attributes. The Central Institute for Cotton Research (CICR), found that the productivity of cotton in terms of total number of bolls and weight increased significantly (73%). Elevated CO2 levels in the atmosphere of up to 650 ppm and temperature of 40º C was found to be optimum for cotton plant growth. However, pest problem will be aggravated. In overall terms, research indicates that the impact of climate change on India cotton production and productivity can be favourable (Kranthi et al, 2009).

Cotton in China

China is the second largest cotton producer and consumer. Cotton production is concentrated in three regions: (i) Yellow River valley (42% of total), (ii) Yangtze River valley (26%), (iii) Northwest region (32%). Figure 24 illustrates China cotton producing regions.

Production along the Yellow River region, which includes the Northern provinces of Shandong, Hebei, Henan, Shanxi and Shaanxi, is very important and may come to benefit from a longer growing season as temperatures rise. Production along the Yangtze River region, which includes Jiangsu, Anhui, Hubei, Hunan and Jiangxi provinces, will likely decrease and there could be competition from food crops. Production in the western Xinjiang region includes the Xinjiang Uyghur region and Gansu province and depends entirely on irrigation. Water availability will be a limiting factor for cotton in the future due to higher crop water requirements and increasing demand for water. Rising competition from cereal production will further limit land and water available for cotton (ITC, 2011).

In general terms, rainfall in China is expected to increase, which is favorable for cotton production, particularly in combination with limited rises in temperature and atmospheric CO_2 (Ton, 2011).

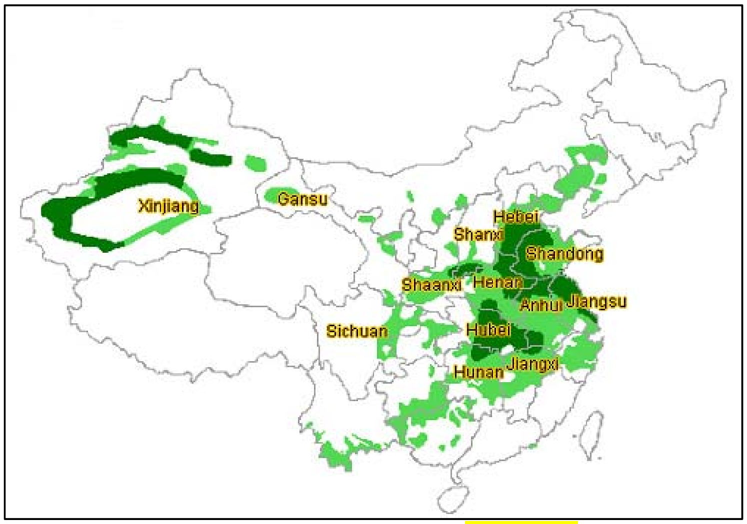


Figure 24 China major cotton producing regions (Source: ITC, 2011)

Risks, Opportunities and Recommendations for Cotton

Crop	Risk	Opportunities	Recommendation
Cotton	Increases in atmospheric evaporative demand may increase water use in well watered crops and increase the impact of stress when water is limited. An increase in the frequency of days	Increased CO2 levels may increase photosynthesis and water use efficiency leading to higher yields in the absence of water stress. Temperature increases at the start and end of seasons may have a positive effect on yield by	Earlier planting to avoid the flowering of cotton in the high temperatures (occurring during mid to late summer). Adjust sowing dates to offset moisture stress during the warm period, to prevent pest outbreaks, and to make best use of the length of the growing season.

	with very high temperatures will negatively impact on both growth and development. Decrease in yields due to reduced water availability (drought spells). Reduction of suitable areas for cotton growth.	extending time for cotton growth.	Development of breed cotton varieties that are more resistant to heat stress, drought spells, weeds, pests and diseases. Use of irrigation systems to meet higher water demand. Integrate research process to assess the exact effect of climate change on cotton production.

Sugarcane

Sugarcane in Australia

The greatest challenge ahead for management of sugarcane production in relation to climate change in Australia is the uncertainty of future rainfall patterns (IPCC 2014b; Sexton et al. 2014; CANEGROWERS 2012). Predicted increased CO_2 levels are also expected to impact sugarcane production by increasing canopy growth (Singels et al. 2014). Sugarcane grown in the wet tropics, a region characterized by high rainfall and low solar radiation, is particularly vulnerable to future climate change conditions and will likely be adversely impacted by changes in rainfall patterns (i.e. intensity, duration and frequency), temperatures and the amount of solar radiation (Skocaj and Everingham 2014; Park et al. 2010). Over a 20 year period (1969 – 1988), rainfall was found to be responsible for up to 47 % variation in cane yield in the Tully Mill area (located in the wet-tropic region) and in 2011, heavy rains associated with an intense La Nina event in this region were responsible for up to 50 % lower yield than the previous year (Skocaj and Everingham 2014).

The Intergovernmental Panel on Climate Change 2014 report predicts an increase in the intensity of extreme rainfall events (i.e. storms), expected increase in the number of hot days and decrease in the number of cool days in northern Australia – potentially altering the length and timing of the growing (ideal in hot conditions) and ripening (ideal in cool conditions) seasons (IPCC 2014b). Previous studies into the impacts of climate change on sugarcane yields predict either increased or decreased yields depending on changes in temperature, rainfall and increased CO_2 levels; increases of 4 – 7 % were predicted for 2030 and 2070 based on elevated CO_2 levels of 437, 610 and 734 ppm, decreases of up to 10 % were predicted based on "significantly warmer and drier" (Everingham et al. 2015) conditions, and decreases of up to 47 % in 2070 based on the driest predictions (Biggs et al. 2013; Everingham et al. 2015; Marin et al. 2013a; Park et al. 2007).

Managing sugarcane production through future climate change uncertainty is both challenging (due to the dynamics of climate science and sugarcane production) and important to mitigate negative impacts on cane yields (CANEGROWERS 2012; Singels et al. 2014). Adapting farming practices to suit changing conditions and accurately predicting crop yields (which are usually made 12 months in advance of harvest) are necessary to minimize climate change impacts, both of which require accurate climate forecasting (CANEGROWERS 2012; Everingham et al. 2009). The “Climate Variability Tools for Primary Producers” project, carried out by CANEGROWERS and the Queensland Government, has made recommendations for adaptive farming practices in each Australian canegrowing region, including ideal times for planting, harvesting, spraying, fertilising and irrigating (see CANEGROWERS 2012 for further details). Furthermore, a number of approaches for climate prediction were also provided, including the use of SOI phase to predict rainfall variation one or more seasons in advance (see Stone et al. 1996 for further details) as well as the use of coupled global climate models (GCMs), which combine interactions between ocean and atmosphere and are beneficial for seasonal and longer term forecasting (6^+ months in advance) as well as providing daily time series of weather data (CANEGROWERS 2012).

Millet

According to MINI (Millet Network of India), millets are cereal that present the main following characteristics:

- Crops that need very little water for their growth;
- Require just around 25% of the rainfall regime demanded by crops such as sugarcane and banana;
- Are often growing on skeletal soils that are less than 15 cm deep;
- Do not demand rich soils for their survival and growth;
- Production is not dependent on the use of synthetic fertilizers and most millet farmers use farmyard manures (reducing fertilizer subsidy by the government);
- If grown under traditional methods do not attract any pest;
- A majority are not affected by storage pests;
- Are three to five times nutritionally superior to rice and wheat in terms of proteins, minerals and vitamins.

Millet is cultivated on more than 30 million hectares in the semi and tropical regions of Asia and Africa. India is the largest producer of this crop both in terms of area with 17 million hectares and production of 11.500 million tons, with an average productivity around 800kg/ha (FAO, 1995).

Among millets (Table 11), pearl millet is the most widely grown type of millet. Because of their tolerance to difficult growing conditions such as drought, low soil fertility and high temperature, they can be grown in areas where other cereal crops, such as maize or wheat would not survive (Basavaraj et al., 2010).

Table 11 Millets worldwide (Source: adapted from FAO, 1995)

Crop	Common names	Suggested origin
Pennisetum glaucum	Pearl millet, cumbu, spiked millet, bajra, bulrush millet, candle millet, dark millet	Tropical West Africa
Eleusine coracana	Finger millet, African millet, koracan,	Uganda or

	ragi, wimbi, bulo, telebun	neighbouring region
Setaria italica	Foxtail millet, Italian millet, German millet, Hungarian millet, Siberian millet	Eastern Asia (China)
Panicum miliaceum	Proso millet, common millet, hog millet, broom-corn millet, Russian millet, brown corn	Central and eastern Asia
Panicum sumatrense	Little millet	Southeast Asia
Echinochloa crus-galli	Barnyard millet, sawa millet, Japanese barnyard millet	Japan
Paspalum scrobiculatum	Kodo millet	India

Millet in India

Millets is traditional 'coarse cereals' whose importance is more in terms of their role as a staple food consumed by the poor. In terms of food grain production millets ranked fourth in India behind rice, wheat and maize (FAO, 2013).

Pearl millet in India is grown mainly in a single season crop and cultivation predominantly takes place on marginal and not irrigated areas. It is also grown in small areas as summer crop under irrigation particularly in the Northwestern states of India, and in this case mainly as a fodder crop. Millet production is concentrated in Gujarat, Maharashtra, and Rajasthan which account for 70% of production in India. In these states there is the highest concentration of millet consumers. However, a concern is that the area of pearl millet in India is declining. Between 1972 and 2005, up to 3 million hectares were shifted to other crops (Gupta et al., 2014).

Using PRECIS model, Patel et al. (2015) (was Patel et al. (2014)) evaluate climate change impacts on Millet in Gujarat state in west India. Results pointed that average yield reduction in kharif pearl millet was 12, 15, 10 and 15 % in Junagadh, Bhavnagr, Bhuj and Rajkot areas, respectively. In summer season the projected yield reduction was 4, 8, 6 and 9 %, respectively. The adaptation strategies such as adopting fifteen days early transplanting, change in variety, better water management with additional fertilizer and early transplanting, the crop yield raised between 4 and 9.5 %.

Millet in Nigeria

Pearl millet is the most important dry land food crop of West Africa and it is the most important cereal in the dry sub-humid and semi-arid zones of Nigeria. The three main millet producing countries in West Africa were Nigeria with (54%), Niger (20%) and Mali (9%). In Borno state, pearl millet is the main stable food and dominant in the agricultural production systems (Rowland, 1993, Ojedran et al., 2010).

Using the Erosion Productivity Impact Calculator (EPIC) crop model, Adejuwon (2004) demonstrated how crop yield in Nigeria respond to changes in rainfall, relative humidity, temperature, solar radiation and CO_2 concentration. For millet there was a general increase in yield for the 3 periods baseline: 2010 to 2039, 2040 to 2069 and 2070 to 2099. This increase was due to increases in rainfall, decreases in water stress, increases in CO2 concentration, increase relative humidity, increase in rainfall and solar radiation. This trend is expected for all West Africa. However, if global warming will continue at the second half of the century, and as consequence minimum and maximum temperatures reaching the limits of tolerance, crop yields will decrease.

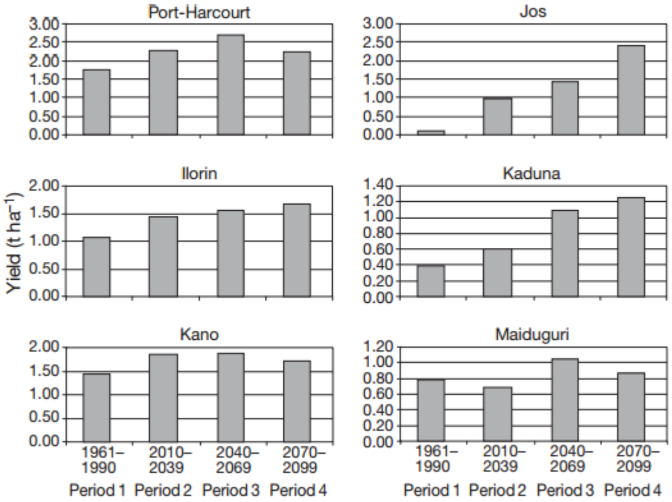


Figure 25 Millet yield projection in Nigeria (Source: adapted from Adejuwon 2004)

Risks, Opportunities and Recommendations for Millet

Crop	Risk	Opportunities	Recommendation
Millet	Area of millets are shrinking due to overtake of commodities crops; In some areas yield decrease; Any impact on millets will have consequences in food security and smallholder subsistence poorest farmers in Africa and South Asia;	Millets are already capable of growing under severe conditions like droughts, they can resist to higher heat; Millets can persist under water stress; In some areas yield increase;	Developing variety types with genetic heterogeneity for climate adaptation;

Maize

Maize (Zea mays L.) is a critical crop in sustaining human life in terms of its role as a major grain commodity, a feed commodity, and a significant bioethanol energy source. Its production in the United States and China accounts for over 50% of total world maize production (USDA, 2016).

Maize is one of the most important crop for food source for human consumption and as global population increases, maize production must increase.

The three most import climate variables that impacts maize yield variability are temperature, precipitation and solar radiation. Future climate change will modify these variables in different ways across the planet and affect maize production.

Maize in US

USA maize acreage 2016/17 projection is 35.14 million hectares representing the second largest maize area planting. In China maize is cultivated in 36.76 million hectares. However, the USA is ranked first in the world maize production and yield is 11 mtonnnes/hectares and in China is 5.97 mtonnes/hectares (USDA, 2016).

Maize production plays a major role in USA economy and it is growth is dominated by west/north central Iowa and east central Illinois.

Figure 26 shows the spatial distribution of maize cultivation in USA indicating a concentration in central north part of the country.

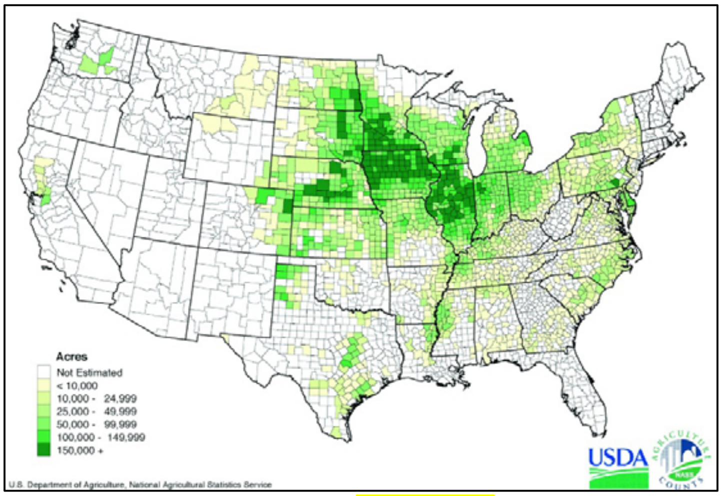


Figure 26 Maize cultivation area in USA (Source: USDA, 2016)

A work done by Southworth et al. (2000), include the investigation of the consequences of climate change across the midwestern Great Lakes region in USA. A five state area including Indiana, Illinois, Ohio, Michigan, and Wisconsin were considered. In this area, 61% of the land is used for cropping and it is considered the most productive of the world. Different crop simulation models were used to combine environmental effects on crop physiological processes and evaluate the consequences of such influences. Results show that agricultural areas in the northern states will have increase in maize yields. However, in the southern and central regions (western Illinois, eastern Illinois, southern Illinois, southwest Indiana, and east-central Indiana), will have a yield decreasing trend. The increase in temperatures will result in a reduction in productivity due to earlier flowering and a shortening of the grain-fill period. The shorter the crop duration, the lower yield per unit area. This is the case for central and southern regions. In the northern regions - where low temperatures currently limit the grain fill period – the increase in temperatures will result in the grain filling period lengthening and consequently increase in yields.

Figure 27 shows the spatial distribution of the decrease in maize yields, which is stronger in the southern region.

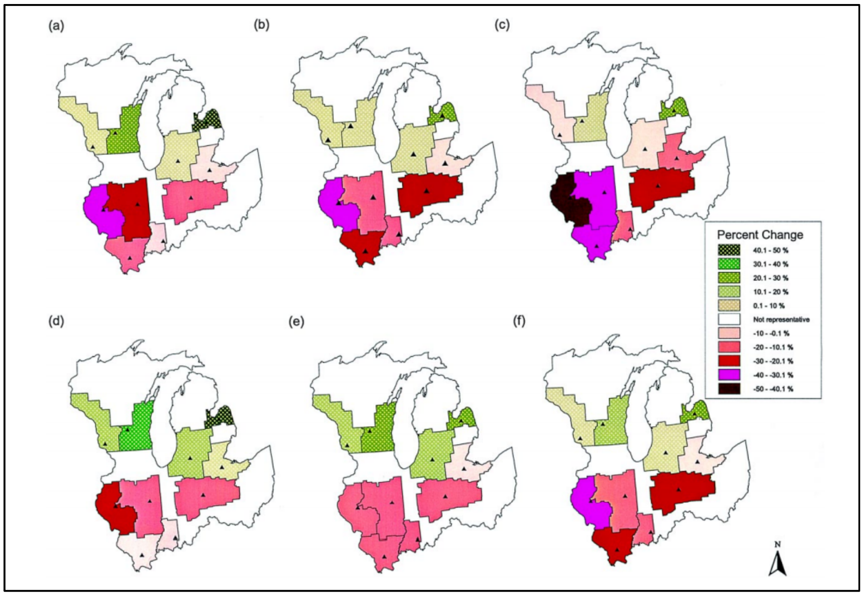


Figure 27 Change in mean maximum decadal yield for long season maize in 10 agricultural regions in Indiana, Illinois, Ohio, Michigan, and Wisconsin states using six crop simulation models (Source: Southworth et al., 2000)

Maize in China

Figure 28 shows the spatial distribution of maize cultivation in China where the North and Central West concentrate the major maize production. The forecast for 2016/17 is 218 Million mtonnes (USDA GAIN 2016).

A regional climate change model (PRECIS) was used to develop climate change scenarios for China (country level). Output of maize crop model predict changes in yields and indicate that climate change without carbon dioxide (CO_2) fertilization could reduce yields up to 37% by 2080. Interactions of CO_2 with limiting factors, especially water and nitrogen, are capable of strongly modulating observed growth responses in crops. The extent of the CO_2 fertilization effect will depend upon optimum breeding, irrigation and nutrient applications. If the direct effect of CO_2 is included, average yields are projected to increase for rainfed maize and decrease for irrigated maize (Table 12). The increase is highest for rainfed maize under the A2 emissions scenario, possibly because the higher CO_2 concentration would boost the yield of rainfed maize under the current water limited conditions prevalent in North China (which is the biggest maize cultivation area). Without the CO_2 fertilization effect, the average yield of both rainfed and irrigated maize is likely to fall for both A2 and B2 emission scenarios. This is because higher temperature may shorten the growth period by between 4 and 8 days. Yield decreases would be greatest if higher temperatures occur during the period when the maize ears are swelling (Erda et al. 2005, (Southworth et al. 2000). These results show a large relative benefit to maize yields from elevated CO_2. This is in contrast to most C4 crop experiments which show minor absolute changes in yield due to CO_2 enrichment.

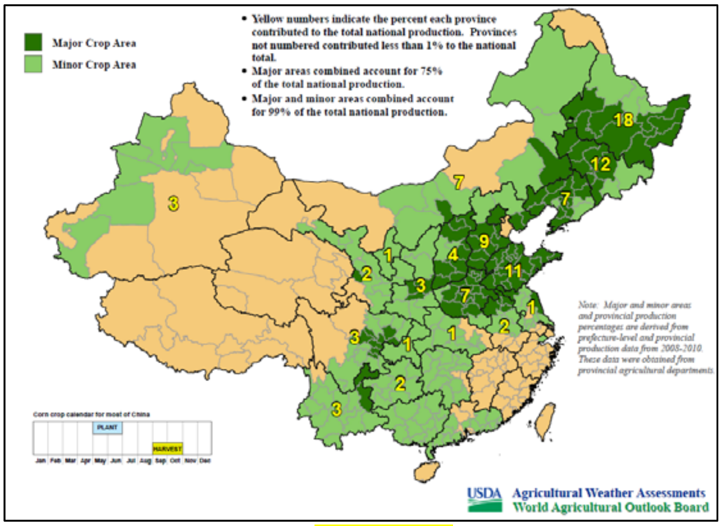


Figure 28 Maize cultivation in China (Source: USDA, 2016)

Table 12 Projected changes in maize yield (average) in China under base line 1961 to 1990 (Source: adapted from Erda et al., 2005)

Year	2020s		2050s		2080s	
Scenario	**With CO2 fertilization**	**Without CO2 fertilization**	**With CO2 fertilization**	**Without CO2 fertilization**	**With CO2 fertilization**	**Without CO2 fertilization**
A2 Scenario: Rainfed	9.8	-10.3	18.4	-22.8	20.3	-36.4
A2 Scenario: Irrigated	-0.6	-5.3	-2.2	-11.9	-2.8	-14.4
B2 Scenario: Rainfed	1.1	-11.3	8.5	-14.5	10.4	-26.4
B2 Scenario: Irrigated	-0.1	0.2	-1.3	-0.4	-2.2	-3.8

Risks, Opportunities and Recommendations for Maize

Crop	Risk	Opportunities	Recommendation
Maize	Climate change is a significant factor influencing maize causing decrease in future yields;	Use of long season maize;	Improvement on crop irrigation; Improvement on soil infiltration and water holding capacity; Adjustment of crop planting time;

			Development of a more heat tolerant hybrid; Cultivar shifting from maize (C4 crop) to soybeans (C3 crop) for taking advantage of CO2 increase;

Référence (from Climate and weather events, consequences and farmers adaptation strategies on agriculture in Chad)

Mlle L H Y Beultoingar (sept 2011) : Influence du changement climatique sur les modes de vie des populations ripuaires du Lac Tchad dans sa partie tchadienne

https://gc21.giz.de/ibt/var/app/wp342deP/1443/wp-content/uploads/filebase/ va/vulnerability-tools/Climate_change_impact_chain_for_millet.pdf

https://www.caritas.ch/.../Changements_climatiques_au_Tchad.pdf

http://unfccc.int/resource/docs/napa/tcd01.pdf

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