Could climate change influence the trade in staple crops in developing countries? Evidence from Thailand and Egypt

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Abstract

This paper analyses the observed and projected impacts of climate change on the trade in rice and wheat in Thailand and Egypt, respectively. Climate change has affected the size of Thailand's exports of rice through its impacts on the country's total rice production. An increased frequency and intensity of extreme weather events, including floods and droughts, have resulted in seasonal disruptions in the country's total rice production. The periods that followed the major floods or droughts have generally involved a decrease in the country's rice exports. The impacts of climate change on Egypt's demand for wheat imports seem to be insignificant as compared to other factors such as population

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growth, government policy, and the availability of foreign currency reserves. The supply of wheat exports to Egypt, however, has been strongly influenced by climate change during recent years. The incidence of extreme weather events in the major wheat exporting countries that are trade partners with Egypt has resulted in reductions in Egypt's wheat imports. Projected climate change is expected to further affect the production of and the trade in both crops in both countries.

Introduction

Global climate change is a topic of growing significance worldwide. It has resulted from natural causes, anthropogenic causes, or as a result of interactions between natural and anthropogenic causes (IPCC 2013). It represents a major risk to global physical and biological systems. In addition, it has resulted in adverse effects on the different aspects of human life directly and indirectly.

According to the Intergovernmental Panel on Climate Change (IPCC), climate change is defined as

> Change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean

> and/or the variability of its properties, and that persists for an extended period, typically decades or longer (2013, p. 5).

Agriculture is considered a vital sector in the economies of developing countries as it plays a significant role in food security, sustainable development, and poverty reduction. It is considered one of the most vulnerable sectors to climate change. Global climate change is expected to result in large-scale adverse impacts on agriculture and food production in developing countries (IPCC 2014). Crop production, for instance, relies on various climate factors, including temperature, carbon dioxide, and precipitation. Changes in these climate factors, which are induced by global climate change, could result in adverse impacts on crop production (IPCC 2014). In addition, climate is a major determinant of agro-ecological zones globally. Consequently, climate change is expected to modify the location of these zones around the world. This would, therefore, affect global and regional competitiveness.

Climate change is expected to contribute to shifts in global agricultural trade flow through its impacts on crop production. International trade is primarily induced by the differences in factor endowments and technological capacities between various economies. Countries tend to specialize in the production of goods that rely on the relatively abundant factor of production in their territory (Huang & Lampe 2011, p. 9). Climate change is expected to cause major shifts in the geographic specialization in agricultural production through its impacts on crop productivity, crop yields, and the availability of arable land and water (Huang & Lampe 2011, p. 9). These impacts would cause changes in factor endowments and technological capacities utilized by agriculture and will consequently change the returns of factors of production employed in agriculture (Huang & Lampe 2011, p. 9). It must be noted, in addition, that the potential damages that would be caused by climate change to the agricultural production would be critical in the low-latitude regions as compared to the mid- and high-latitude regions. Consequently, climate change would contribute to increased cereal imports of developing countries (Huang & Lampe 2011, p. 11).

Agriculture in Thailand is vulnerable to climate change. Crop production is substantially dependent on the various climate factors, including temperature and precipitation. Consequently, changes in these factors would influence the production of major crops, including rice. Rice production constitutes a significant part of agriculture in Thailand considering its role in the economy and food security. The country is regarded as a major exporter of rice. In the recent years, rice production in Thailand was subject to various abiotic stresses caused by climate change. Elevated temperatures, sea-level rise, and intense droughts, have caused heat, salinity, and water stresses on the rice crops. In addition, variations in precipitation patterns have affected rice production indirectly through promoting pest infestations and disease infections in addition to causing limited availability of water for both rain-fed and irrigated rice production systems (CIAT 2012). In this respect, climate change affects the sustainability of rice production systems in Thailand.

In Egypt, agriculture is among the sectors that are extremely vulnerable to climate change. The increased vulnerability of agriculture to climate change is attributed to its reliance on irrigation from the River Nile, which is the major conventional water resource in the country. Climate change could reduce the availability of irrigation water through its impacts on the discharge of the River Nile (EEAA 2010a; USAID 2013). In addition, being located on the coast of the Mediterranean Sea, the Nile Delta is particularly vulnerable to the risks of sea-level rise (El Raey 2010). Wheat is a staple crop in Egypt as it is an ingredient of the Egyptian flat bread that constitutes an essential part of the dietary intakes of the majority of Egyptians. The country is regarded as the largest importer of wheat worldwide due to the existence of a huge gap between the production and consumption of wheat. Climate change could jeopardize wheat production by causing combined abiotic stresses on the wheat crops.

This paper aims to analyse the observed and projected impacts of climate change on the trade in both staple crops in both countries. It is composed of two parts. The first part aims to analyse the observed and projected impacts of climate change on the trade in rice in Thailand. The second part of this paper, in contrast, aims to analyse the observed and projected impacts of climate change on the trade in wheat in Egypt. Each of these two parts provides some background on the production of and the trade in each crop in each country. In addition, each part analyses the impacts of climate change on the production of each crop in each country before analysing the impacts of climate change on the trade in each crop in each of the two countries.

Methodology

The research is based on mixed research methods. The qualitative design is visible in systematic comparative and content analysis. In contrast, the quantitative design is visible in analysing the projected impacts of climate change based on the results of relevant studies. Consequently, the research relies on both primary data and secondary data. The primary data was obtained through in-depth interviews with farmers, researchers, experts, and government officials during my fieldwork trip in Thailand. The main aim of this fieldtrip was to gather in-depth data from various stakeholders about the vulnerability of rice production in Thailand to the impacts of climate change. During the fieldwork, I further investigated whether or not these impacts have had an influence on the size of rice exports at the macro level. Stakeholders in this context included farmers, researchers, experts, and government officials. Two provinces in the Chao Phraya Delta were selected for the fieldwork trip: Chainat Province and Pathum Thani Province.

In Pathum Thani Province, interviews were conducted in Noppharat Sub-district in Nong Suea District (approximately 87 km north of Bangkok). In Chainat Province, random samples of farmers were selected in a village called Ban Wat Phra Kaew, Phraek Si Racha Sub-district, Sankhaburi district of Chainat (approximately 193 KM north of Bangkok).

Secondary data was obtained from official reports, government documents, and research papers based on their relevance to the research. For instance, part of the secondary data was obtained from datasets from government agencies in both countries, including the Office of Agricultural Economics of Thailand, the National Statistical Office of Thailand, the Thailand Greenhouse

Gas Management Organization, the Thai Meteorological Department, the Economic Affairs Sector of the Ministry of Agriculture and Land Reclamation in Egypt, the Egyptian Environmental Affairs Agency, and the Egyptian Meteorological Authority. Finally, the results of various studies relevant to this research were further utilized by this research. In Thailand, for instance, studies conducted by the Agricultural Technology and Sustainable Agriculture Policy Division, the Office of Agricultural Economics of Thailand, and the International Rice Research Institute were included in this research. In Egypt, studies conducted by the United Nations Development Programme, the United Nations Environment Programme, and the Agricultural Research and Development Council of the Ministry of Agriculture and Land Reclamation, were included in this research.

1. Climate change and the trade in rice in Thailand

Thailand is a major exporter of rice. Climate change could influence the country's exports of rice through its impacts on the total production of rice. This part provides some background of the country's agriculture, rice production, and the government agricultural policies. In addition, the observed impacts of climate change on rice production in Thailand will be analysed in order to determine whether or not the country's size of rice exports could be influenced by such impacts.

1.1 Background

Agriculture is a major sector in Thailand's economy. In 2014, the total agricultural area was approximately 21.28 million hectares; it occupied approximately 41% of the country's total land area (Singhapreecha 2014). The country's GDP was estimated to be $373.8 billion during 2014 in which agriculture's contribution was approximately 11.6% (World Bank 2015a, 2015b). Thailand is a major exporter of agricultural commodities, including rice and rubber; the exports of agricultural products generate approximately 13.3% of the country's GDP (Nara *et al.* 2013, p. 138). The country is considered a major producer and exporter of rice. In March 2015, the total harvested area of rice was estimated to be 11.228 million hectares as compared to 11.38 million hectares in March 2014 (USDA 2015). The total rice (rough) production was estimated to be 29.400 million tonnes during 2014/2015. Rice exports were estimated to be 11 million tonnes during 2014/2015 as compared to 10,969 million tonnes during 2013/2014 (USDA 2015).

Rice farmers in both Chainat and Pathum Thani provinces, when asked about the role of the government in the rice industry, they indicated that the government intervention in the rice industry was limited in the past. Nevertheless, the increasing significance of rice in the country's economy and trade induced the government to intervene in the rice market through subsidizing rice (2015, pers. comm., 7&10 March). Following the 2011 elections, the Pheu Thai Party introduced a different rice pledging scheme in order to improve the livelihoods of rice farmers and increase revenues from rice exports (2015, pers. comm., 7&10 March). According to this scheme, farmers pledged their rice crop under the government possession at the commencement of harvesting in exchange for a later purchase by the government at an increased price (15,000 Baht per tonne) as compared to the market price (2015, pers. comm., 7&10 March).

The Rice Pledging Scheme that was applied by the government in 2011 aimed to increase export revenues through stockpiling substantial quantities of the rice crops purchased from farmers and reducing the rice exports in order control the global market and sell rice at increased prices (Mahathanasetha & Pensuparb 2014). The government decision during that time turned out to be inaccurate due to the competitiveness of the Indian and the Vietnamese rice exports (Mahathanasetha & Pensuparb 2014). The Thai government was eventually forced to sell its rice inventory at the global market price after purchasing rice from farmers at an increased price as compared to the local market price (Mahathanasetha & Pensuparb 2014). Public expenditures on this scheme caused pressure on the country's budget as a result (Mahathanasetha & Pensuparb 2014). The revocation of the 2013/2014 second rice pledging program contributed to recovery of the country's rice exports by increasing the price competitiveness of the Thai rice exports with the Vietnamese and the Indian rice exports (USDA 2015). In early 2015, the rice exports decreased by 13% as compared to early 2014 (USDA 2015). This could be attributed to the competitive price of the Vietnamese rice exports adopted by the Vietnamese government to expand its exports in the African market (USDA 2015).

The climate of Thailand is tropical and monsoonal. It is influenced by the northeast and the southwest monsoons (Thai Meteorological Department 2012). Thailand's climate varies between two seasons, the dry season that commences in November and ends in April, and the rainy season that commences in May and ends in October (Thai Meteorological Department 2012). Average surface temperature in Thailand ranges between 12˚C and 40˚C (Thai Meteorological Department 2012). The country's average annual rainfall ranges between 1200 mm and 1600 mm (Thai Meteorological Department 2012). Thailand's climate is further characterized by the occurrence of tropical cyclones that originate from either the north-western

Pacific Ocean or the South China Sea. The annual mean frequency of tropical cyclones is three to four times (Thai Meteorological Department 2012).

1.2 Observed climate change in Thailand and its impacts on rice production

Climate change has been visible in Thailand in an increase in the annual mean, minimum, and maximum temperatures, sea-level rise, an increase in the frequency and intensity of extreme weather events, and reduced precipitation patterns (CIAT 2012; Emde 2012; Komori *et al.* 2012; Thai Meteorological Department 2012). According to CIAT (2012), the country experienced an increase in the annual mean, minimum, and maximum temperatures during the 20th century. The annual mean temperature increased from 22˚C to 29˚C during the 20th century (CIAT 2012). The central part of the country, which encompasses the Chao Phraya Delta, is additionally vulnerable sea-level rise of the Gulf of Thailand. According to Trisirisatayawong *et al.* (2011, p. 138), the Gulf of Thailand has been rising more rapidly than global average sea level since the 1940s. The coast of the Chao Phraya Delta was subject to 500 m erosion between the 1960s and the 1980s and to 200–300 m erosion between 1987 and 1992 (Dutta 2011, p. 811; Emde 2012). In addition, Thailand has experienced a series of frequent and intense extreme weather events, including floods and droughts, in the recent decade. The country-wide floods that occurred in 2011 caused large-scale economic damages. These floods commenced during late July and they continued for approximately six months until mid-January 2012 (Komori *et al.* 2012, p. 42). They were caused by extreme precipitation events that were estimated to be 143% relative to the seasonal average of 1982–2002 (Komori *et al.* 2012, p. 42). In March 2015, the country experienced an intense drought prior to the end of the dry season of 2014/2015. This drought, which resulted from reduced precipitation patterns, caused limited availability for irrigation water in the central part of the country (Duangporn Vitoonjit 2015, pers. comm., 10 March).

These observed changes in the various climate conditions could result in various abiotic stresses that could affect the country's rice production adversely. For instance, there is a maximum temperature threshold that the rice crops can tolerate. An increase in temperature over this threshold would result in heat stress on the crops and yield reductions would accordingly occur (Gerald *et al.* 2010; Hijioka *et al.* 2014, p. 1344). This could be attributed to the fact that elevated temperatures minimize the growing period of rice (Gerald *et al.* 2010; Hijioka *et al.* 2014, p. 1344).[2] In addition to its

[2] Several uncertainties are associated with the impacts of climate change on rice production. As previously explained, elevated levels of

impacts on yield, temperature is a primary determinant of the suitability of land for crop production. Elevated temperatures could reduce the suitability of land for rice production. Accordingly, an additional potential impact of elevated temperatures would be reducing areas allocated for rice production in the Delta (Gerald *et al.* 2010; Hijioka *et al.* 2014, p. 1344).

The impacts that could be caused by sea-level rise in the Gulf of Thailand would involve coastal erosion, coastal flooding, storm surges, saline intrusion, and inundation of agricultural areas (Emde 2012). Sea-level rise in the Gulf of Thailand constitutes a major risk to rice yields and cultivated areas in the Chao Phraya Delta. Sea-level rise could adversely affect rice production through causing salinity stress and/or submergence of rice areas in the lower part of the Chao Phraya Delta (Emde 2012).

The gravity of the impacts that are caused by extreme weather events on rice production emerges from the fact that they result in exceeding the maximum threshold of the climate conditions that the rice crops can tolerate. The impacts of extreme weather events on

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atmospheric CO_2 could result in positive impacts on yields through CO_2 fertilization. The outcome of interactions between these positive impacts and the negative impacts resulting from changes in temperature is uncertain (Hijioka *et al.* 2014, p. 1344).

rice production range between yield reductions and complete yield failures (Chitnucha Buddhaboon 2015, pers. comm., 6 March). Floods, which are induced by extreme precipitation events, could cause total or partial inundation of rice areas in addition to waterlogging (Mohanty *et al.* 2013). Total inundation would result in immediate crop failure, while partial inundation would cause crop failure over extended periods (Mohanty *et al.* 2013). Droughts could cause large-scale crop failure as they could reduce the availability of water essential for crop development (Chitnucha Buddhaboon 2015, pers. comm., 6 March).

Rice farmers in Chainat and Pathum Thani provinces indicated in group discussions that they have observed a continuous increase in temperature in the recent decades. This has resulted in heat stress that has adversely impacted rice yields (2015, pers. comm., 7&10 March). Mr. Boomsong Sutong is a rice farmer in Noppharat sub-district located in Pathum Thani Province; he possesses 35 rai of cultivated land where he produces rice solely. He stated that his average rice yield is normally 800 kg/rai and his total annual production is 56,000 kg/year (2015, pers. comm., 7 March). He further indicated that the observed increases in temperature in the recent years have been unprecedented; they have reduced the length of the growing season of his crop and yield has been gradually decreasing as a result (2015, pers. comm., 7 March). These statements were confirmed by the rice farmers in Chainat Province; they indicated that elevated temperatures and heat stress have caused yield reductions in the rice crops by 30% (2015, pers. comm., 10 March).

When asked about the impacts of elevated temperatures on rice production, Mr. Amnat Janchoung, who is project leader of research project conducted by the Thai Community Foundation in Noppharat sub-district, indicated that an increase in temperature has been observed in the sub-district in the recent years (2015, pers. comm., 7 March). He further pointed out that heat stress constitutes a major risk to rice yields in this sub-district (2015, pers. comm., 7 March). In addition, Dr. Chitnucha Buddhaboon denoted that the incidence of heat stress during certain growth stages of rice could result in yield reductions and this was evident in the Chao Phraya Delta (2015, pers. comm., 6 March). He further indicated that these impacts on yields have not, however, resulted in major reductions in the total production of rice in the Delta (2015, pers. comm., 6 March).

The 2011 floods resulted in adverse impacts on rice yields in Thailand. These floods resulted in the total submergence of rice cultivated areas in several locations and substantial crop failures occurred (Chitnucha Buddhaboon 2015, pers. comm., 6 March).

Farmers in Chainat and Pathum Thani provinces pointed out in group discussions that rice production has been subject to frequent and intense floods in the recent decade (2015, pers. comm., 7&10 March). The 2011 floods were among the major floods they have observed recently. The rice farmers in Noppharat sub-district indicated that the location of their village at a higher elevation as compared to the surrounding areas and using sandbag walls had mitigated the damages of the 2011 floods on their rice crops. Nevertheless, the inundation of the surrounding areas by flood waters prevented the farmers from transporting their crops after harvesting (2015, pers. comm., 7 March). The rice farmers in Ban Wat Phra Kaew village, located in Chainat Province, noted that the impacts of the 2011 floods would have been significant if they had not used sandbag walls to obstruct flood waters from reaching their rice fields (2015, pers. comm., 10 March). When asked about the impacts of the 2011 floods on her rice yields on 10 March 2015, Ms. Ratchaneekorn Jarupan, who owns 50 rai of cultivated lands divided between rice production and horticulture, indicated that the impacts of the 2011 floods were significant on her horticulture as compared to the rice crop since fruit trees were damaged immediately due to flood waters.

Climate change is intensifying water scarcity in Thailand through its impacts on the river discharge. Agricultural production has been adversely affected by climate change due to the reduced availability of water for irrigation caused by changes in precipitation patterns (Duangporn Vitoonjit 2015, pers. comm., 10 March). In this respect, climate change affects the supply of and demand for water for irrigation (Mohanty *et al.* 2013). These effects have been significant during the dry season since the increased intensity of El Nino has resulted in reduced precipitation, and has therefore decreased river discharge (Mohanty *et al.* 2013). In addition, elevated temperatures have resulted in increased patterns of water evaporation in irrigation canals (Duangporn Vitoonjit 2015, pers. comm., 10 March).

In the course of the 2015 drought, reduced water levels were observed in the Chao Phraya Dam, which is responsible for the allocation of irrigation water for the lower Chao Phraya River Basin. In addition, irrigation canals that were located at the rice fields at Chainat and Pathum Thani provinces were completely dry. Consequently, the government advised farmers to avoid the production of the second rice crop during the dry season of 2014/2015 due to the limited availability of water for irrigation (Amnat Janchoung 2015, pers. comm., 7 March). In group discussions, farmers in both Pathum Thaini and Chainat provinces indicated that they used to produce two rice crops annually because of the availability of water for irrigation (2015, pers. comm., 7&10

Source: (Mostafa 2015, pers. comm., 10 March)

Figure 1.1 illustrates reduced water levels in the Chao Phraya Dam, Chainat Province (March 2015)

March). In addition, water surplus during several years enabled them to produce a third rice crop to generate more income (2015, pers. comm., 7&10 March). They additionally pointed out that the two years that followed the 2011 floods noted increased availability of water for irrigation (2015, pers. comm., 7&10 March). However, the intensity of the 2015 drought was unprecedented. The limited availability of irrigation water prevented them from planting second rice (2015, pers. comm., 7&10 March). This drought resulted in significant water stress and it caused yield reductions by 50% according to the farmers' statements (2015, pers. comm., 7&10 March).

Dr Chitnucha Buddhaboon asserted that the intensity of droughts has increased in the recent years. The drought that occurred during the dry season of 2014/2015 resulted in substantial reduction in water supplies for rice production (2015, pers. comm., 6 March). Mr. Amnat Janchoung indicated that the impacts of the 2015 drought on the total rice production were uncertain, but if the current pattern of droughts persisted in the following years, the total rice production would be reduced due to the inability of farmers to produce a second rice crop (2015, pers. comm., 7 March). In Noppharat Sub-district, Mr. Boumsong Sutong, when asked about the impacts of this drought on his rice crops on 7 March 2015, indicated that he could not produce a second crop during the dry season of 2014/2015. He expected that he would not be able to achieve his average annual rice production of 56,000 kg/yr as a result of the drought. Mr.Nukul Namplasai, a rice farmer in the same sub-district, asserted that he produced a second crop at his own risk and water stress was adversely impacting his rice crops (2015, pers. comm., 7 March). In Ban Wat Phra Kaew village, which is located at Chainat Province, Ms. Ratchaneekorn Jarupan indicated that the unavailability of water during the dry season of 2014/2015 prevented her from exploiting 30 rai of her land to produce a second rice crop. Therefore, she was uncertain of her capability to achieve her average annual rice production of 60,000 kg/yr (2015, pers. comm., 10 March).

1.3 Impacts of climate change on the trade in rice

Climate change could induce fluctuations in the Thailand's rice exports both on the short run and the long run. Increased frequency and intensity of floods and droughts, which is attributed to climate change, could cause large-scale crop damages. These damages would, consequently, cause disruptions in the rice supply chain and short-term reductions of the rice exports would occur as a result. According to Nara *et al.* (2013, p. 139), the 2011 floods resulted in substantial damages to the first rice crop, and therefore reduced the rice export values to 13,328 million baht in late 2011 as compared to 21,486 million baht in late 2010. In addition, the 2015 drought prevented the rice farmers in most parts of Thailand from producing a second rice crop. Consequently, the production of second rice was expected to decrease as a result of this drought. According to Pensupar and Yadanar (2015), the country's exports of second rice are expected to decrease by over 30% as a result of the 2015 drought. In addition, the impacts of extreme weather events on production could force governments to impose export restrictions in the event of large-scale crop damages. Extreme weather events have caused seasonal fluctuations in the rice exports as a result of their impacts on the first or the second rice crops (Chitnucha Buddhaboon 2015, pers. comm., 6 March). Floods, for instance, are frequent during the production of the first rice crop, while droughts generally occur during the production of the second rice crop (Chitnucha Buddhaboon 2015, pers. comm., 6 March).

On a global basis, climate change and the impacts of sea-level rise are expected to cause fluctuations in the global rice supply chain. Climate-induced declines in the global rice production are expected to decrease exports of major producing countries and increase imports of net importing countries (Chen *et al.* 2012, p. 559). This would result in an increase in the total global rice trade (Chen *et al.* 2012, p. 559). Policy interventions, including export bans, are expected, however, to minimize the size of the global rice trade (Chen *et al.* 2012, p. 559). By 2030, for instance, the combined climate change impacts on yields (worst yields effect scenario) and the impacts of sea-level rise on cultivated areas are expected to decrease the global rice production by 3.29% and by 4.17% in case of a 1 m sea-level rise and a 5 m sea-level rise, respectively (Chen *et al.* 2012, p. 557). Consequently, the global prices of rice would increase by 17.06% in case of a 1 m sea-level rise and by 21.91% in case of a 5 m sea-level rise (Chen *et al.* 2012, p. 557). In that case, the total global rice trade is expected to increase by 9.58% in case of a 1 m sea-level rise and by 24.45% in case of a 5 m sea-level rise (Chen *et al.* 2012, p. 557). The enforcement of an export ban would result in an increase in the global prices of rice by 22.15% in case of a 1 m sea-level rise and by 29.24% in case of a 5 m sea-level rise (Chen *et al.* 2012, p. 557). The size of the global rice trade would change by −35.52% in case of a 1 m sea-level rise and by −29.50% in case of a 5 m sea-level rise (Chen *et al.* 2012, p. 557). Thailand's rice exports could be affected on the long run by the impacts of combined climate stresses, including heat, water, and salinity stresses on rice production caused by climate change. Climate change would result in a decrease in rice production in Southeast Asia by 2080 (Briones *et al.* 2012). Thailand, in addition to major rice exporting countries, would experience a reduction in their rice exports (Briones *et al.* 2012).

It must be noted that the impacts of the projected climate change on Thailand's trade in rice could be offset by the emergence of new cultivated areas of rice in Thailand. For instance, climate change could induce shifts in the suitability of lands for rice cultivation in Thailand. New areas that would be characterized by favourable climate conditions for rice cultivation in Thailand might emerge. The country's productive capacity of rice could, therefore, be maintained or expanded as a result of the emergence of new cultivated areas of rice. In addition, the impacts of climate change on Thailand's trade in rice could be offset by yield enhancements that would result from the implementation of certain adaptation strategies, especially developing new rice varieties that could tolerate the various abiotic stresses caused by climate change. According to Chen *et al.* (2012, p. 558), a 1% yield enhancement caused by crop adaptation in the rice exporting countries would offset the impacts of a 1 m sea-level rise on rice production, while a 15% yield enhancement would offset the impacts of a 5 m sea-level rise on rice production.

2 Climate change and the trade in wheat in Egypt

Egypt is regarded as the largest importer of wheat globally. The existence of a gap between production and consumption has driven the consecutive governments to address this gap by importing wheat. Climate change could, therefore, affect the size of the county's wheat imports through the climate-induced impacts on wheat production. This part provides some background of the country's agriculture, rice production, and the government agricultural policies. In addition, in order to determine whether or not climate change could influence the country's wheat imports, the observed impacts of climate change on wheat production in Egypt will be analysed.

2.1 Background

Agriculture is a major economic sector in Egypt. The total area of agricultural lands is estimated to be 3.5 million hectares, which represents approximately 3.5% of the total land area of Egypt (ARDC 2009). There are two categories of agricultural lands in Egypt, the old lands that are located at the Nile Delta and the Nile Valley and have been utilized for cultivation throughout history due to their reliance on the Nile for irrigation, and the newly reclaimed lands located at the Eastern Desert, the Western Desert, and the Sinai Peninsula; they rely primarily on groundwater and desert oases for irrigation (El-Ramady *et al.* 2013, p. 50). The old lands represent the major part of the total agricultural lands in Egypt amounting to approximately 80% (2.26 million hectares) of the total agricultural lands, while the newly reclaimed lands represent 20% (1.08 million hectares) of the total agricultural lands (EEAA 2010b; FAO 2011; USAID 2013). In this respect, climate and the availability of water resources are the primary determinants of the agro-ecological zones in Egypt (EEAA 2010b).

Agriculture secures the country's food requirements. The total value of food production was estimated to be $23.706 million in 2012 with an annual growth rate of 1.55% between 2007 and 2012 (FAOSTAT 2015). In addition, agriculture constitutes a major source of public revenues in which the share of agriculture's value added to the country's GDP was estimated to be 14.5% in 2012 (World Bank 2015c). Agricultural commodities represent 30% of the country's total commodity exports (El Raey 2010, p. 31). Crop production represents approximately 68% of agriculture's total GDP (Eid *et al.* 2006). The value of crop production per hectare was estimated to be $4801 in 2012 with an annual growth rate of 0.79% between 2007 and 2012 (FAOSTAT 2015). The cultivated areas of cereals increased from 2.0 million hectares between 1980 and 1984 to 2.98 million hectares between 2008 and 2009 (USAID 2013). The total value of agricultural production was estimated to be $23.902 million in 2012; the annual growth rate of the value of agricultural production was estimated to be 1.39% between 2007 and 2012 (FAOSTAT 2015).

Wheat is a winter cereal that is cultivated in the Nile Delta and the Nile Valley. The total harvested area of wheat was estimated to be

1.35 million hectares during 2013/2014 (USDA 2014a).[3] The total production of wheat was estimated to be 8.6 million tonnes during 2013/2014 as compared to 8.5 million tonnes during 2012/2013 (USDA 2014a). It is a water-intensive crop that consumes approximately 9% of the total water allocated for irrigation (Siam & Croppenstedt 2007). Wheat is a strategic crop in Egypt since it is closely related to food security. Wheat and its products are the most consumed commodities in Egypt. Average per capita consumption of wheat and its related products was estimated to be 1169 kcal per day in 2011 (FAOSTAT 2015). The total wheat consumption during 2013/2014 market year was 18.9 million tonnes as compared to 18.7 million tonnes during 2012/2013 (USDA 2014a). Wheat, therefore, represents substantial part of the total food supply in Egypt.

The government provides bread for the low-income class at a subsidized price. It maintains 5–6 months of wheat stocks for bread production (USDA 2014a). Furthermore, Egypt is currently experiencing substantial gap between production and consumption of wheat (USDA 2014a). The country resorts to importing wheat in order to secure wheat supplies for the increasing demand. During 2013/2014, the total wheat imports were estimated to be 10 million

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[3] Market Year commences at July every year in Egypt.

tonnes as compared to 8.3 million tonnes during 2012/2013 (USDA 2014a).

Table 2.1 Harvested Area, Production, Imports, and the Total Consumption of Wheat in Egypt (2010–2014)

	2010/2011	**2011/2012**	**2012/2013**	**2013/2014**
Area Harvested (1000 ha)	1,260	1,280	1,350	1,350
Production (1000 tonne)	7,200	8,400	8,500	8,650
Imports (1000 tonne)	10,600	11,650	8,300	10,000
Total Consumption (1000 tonne)	17,700	18,600	18,700	18,900

Source: (USDA 2012, 2013, 2014)

Egypt relies on a number of countries to secure its wheat supplies; Russia along with other countries in the Black Sea Region are currently the largest source of wheat imports for Egypt (Hamrick *et* *al.* 2014). China and Argentina are additionally regarded as major trade partners with Egypt in terms of wheat imports. The United States was previously the largest wheat exporter for Egypt (Hamrick *et al.* 2014).

The government plans to expand the harvested area of wheat in order to fulfil the increasing demand and reduce expenditures on wheat imports (USDA 2014a). In addition, the government conducted policy reforms between 1987 and 1999 to improve wheat production (Fischer *et al.* 2014, p. 90). These reforms resulted in the introduction of new wheat varieties and the improvement of prices of wheat (Fischer *et al.* 2014, p. 90). Consequently, increased wheat areas and yields were witnessed during the period following these policy reforms. During the recent decade, nevertheless, wheat yields became steady as the reduced price and limited profitability of wheat induced farmers to produce different crops for income generation (Fischer *et al.* 2014, p. 90).

Egypt is characterized by an arid climate and reduced precipitation patterns. The Mediterranean coast, nevertheless, experiences increased precipitation during winter (EEAA 2010b). The climate ranges between the four seasons, summer that occurs between June and September, winter that occurs between December and March, spring that occurs between April and May, autumn that occurs between October and November (FAO 2011). The arid zones in Egypt, including the Mediterranean coast and the Delta, are characterized by warm summers with average temperatures ranging between a minimum of 23°C and a maximum of 32°C (FAO 2011). In addition, they experience mild winters with average temperatures ranging between a minimum of 9°C and a maximum of 18°C (El-Ramady *et al.* 2013, p. 61; FAO 2011). In contrast, the hyper arid zones, including the desert areas, are characterized by extremely warm summers with average maximum temperatures reaching 40°C (El-Ramady *et al.* 2013, p. 61; FAO 2011). Winters in these zones are generally mild and dry with average maximum temperatures reaching 18°C (El-Ramady *et al.* 2013, p. 61; FAO 2011). Precipitation generally occurs in Egypt during winter between December and March. It varies significantly between the different parts of the country. The average annual precipitation was estimated to be approximately 80 mm/yr in most parts of the country (El-Ramady *et al.* 2013, p. 63). The average annual precipitation in the Mediterranean coast, in contrast, might reach up to 200 mm/yr (El-Ramady *et al.* 2013, p. 61; FAO 2011). Upper Egypt experiences reduced precipitation where average precipitation was estimated to be 10 mm/yr (El-Ramady *et al.* 2013, p. 61; FAO 2011).

2.2 Observed climate change in Egypt and its impacts on wheat production

Egypt has experienced increased minimum and maximum temperatures in the recent decades (EEAA 2010b). The mean maximum air temperature increased by 0.34°C per decade between 1961 and 2000, while the mean minimum air temperature increased by 0.31°C per decade during the same period (EEAA 2010b). In addition, the number of warm nights increased between 1960 and 2003 as compared to the number of cold nights (Gosling *et al.* 2011). Increased temperatures were additionally observed in the Nile Delta between 1971 and 2000 (Smith *et al.* 2013; UNDP 2009). The annual mean temperatures have increased by 0.05°C/yr during recent decades (Smith *et al.* 2013; UNDP 2009).

The Nile Delta is currently experiencing sea-level rise in the Mediterranean Sea at different levels across its coast; this could be attributed to the differences in the rate of subsidence between various parts of the coast. The rate of subsidence across the coast of the Delta ranged between 1.5 mm/yr to 2.5 mm/yr (El Raey 2010, p. 34). Combined subsidence and sea-level rise in the Mediterranean resulted in an observed relative sea-level rise by 1.6 mm/yr, 5.3 mm/yr, and 2.3 mm/yr at Alexandria (Northwest of the Delta), Portsaid (Northeast of the Delta), and Al Burullus (North of the Delta), respectively (UNDP 2009). If subsidence were disregarded, the results would indicate that the observed relative sea-level rise would be 1.6 mm/yr, 2.3 mm/yr, and 1 mm/yr at Alexandria, Portsaid, and Al Burullus, respectively (EEAA 2010b).

The increased frequency and intensity of extreme weather events is a major consequence of climate change that might affect wheat production in Egypt. Sand storms occur frequently in the Nile Delta during spring as a result of the formation of Khamasin winds between March and May every year. These winds carry warm and sandy air from desert areas towards Lower Egypt, and consequently cause extreme warm and dry conditions (Gosling *et al.* 2011). In addition, the coast of the Nile Delta experiences flash floods during winter as a result of increased precipitation (EEAA 2001). Increased frequency and intensity of extreme weather events have been observed in Egypt in the recent decades. This could be attributed to variations in global surface temperature and changes in the location of Intertropical Convergence Zone, induced by climate change (El Raey 2010, p. 38). The coast of the Nile Delta has been subject to extreme precipitation events since the last three decades. This could be associated with variations in North Atlantic Oscillation (El Raey 2010, p. 38). Increased frequency of thunderstorms has additionally been observed at the Mediterranean coast, including the northern part of the Delta, in the recent decade and this could be associated with the northward shifts of Intertropical Convergence Zone (El Raey 2010, p. 38). In addition, increased intensity and frequency of Khamasin sandstorm has been observed in Egypt (El Raey 2010, p. 38). Finally, the frequency and intensity of heatwaves has increased in Egypt in the last two decades (EEAA 2010b). The incidence of droughts is associated with variations in precipitation patterns. There has been an observed decrease of precipitation patterns during winter seasons in the Mediterranean region since the mid-1960s (Smith *et al.* 2013).

Changes in precipitation patterns in Egypt are expected to have minor impacts on wheat production since agriculture in Egypt relies mainly on irrigation from the Nile River. However, changes in precipitation patterns in the Upper White Nile and Blue Nile catchments could influence the discharge of the River Nile in the downstream countries, including Egypt (EEAA 2010a; USAID 2013). Changes in precipitation in the Ethiopian Highlands could influence the discharge of the Blue Nile, which is responsible for the majority of the River Nile's discharge. Moreover, elevated temperatures could cause subsequent increases in evaporation and evapotranspiration in the Equatorial Lakes Region from which the White Nile originates (EEAA 2010a; USAID 2013).

Various studies have attempted to analyse the sensitivity of the discharge of the Nile to changes in precipitation in the Upper Blue Nile and White Nile catchments. According to EEAA (2010b), changes in precipitation have affected the discharge of the Blue Nile as compared to the discharge of the White Nile. This study additionally indicated that an increase in precipitation in the Ethiopian Highlands by 10% resulted in an increase in the discharge of the Blue Nile by 36%, while a 10% decrease of precipitation resulted in a decrease of the discharge of the Blue Nile by 31%. The discharge of the White Nile, in contrast, is moderately influenced by changes in precipitation in the Equatorial Lakes region; a 10% increase in precipitation caused an increase in the discharge of the White Nile by 19%, while a decrease of precipitation by 10% resulted in a decrease of the discharge by 11% (EEAA 2010b). In addition, UNEP (2006) analysed changes in the discharge of the Nile based on changes in precipitation in the Ethiopian Highlands between 1907 and 1997. The study concluded that increased river discharge during the periods 1907–1961 and 1987–1997 corresponded with increased precipitation in the Ethiopian Highlands, while decreased discharge between 1962 and 1984 was associated with decreased precipitation in the Ethiopian Highlands (UNEP 2006).

These observed changes in the various climate conditions could result in various abiotic stresses that could affect the country's wheat production adversely. For instance, temperature is an essential factor affecting wheat yield and the suitability of land for wheat production. Elevated temperatures influence wheat production by causing adverse impacts on wheat yield and cultivated areas. For instance, temperature is an essential element for wheat growth (Hassanein *et al.* 2012, p. 142). There is a specific temperature threshold required for the different phonological stages of the crop (Hassanein *et al.* 2012, p. 142). Consequently, elevated temperatures could cause yield reductions by reducing the length of the growing season, the length of the grain filing periods, and the length of the flowering stage (Hassanein *et al.* 2012, p. 142). In addition, they could result in heat stress on the crop through exceeding the maximum temperature threshold tolerated by the crop (Hassanein *et al.* 2012, p. 142). Elevated temperatures, therefore, could cause yield reductions through altering the optimum climate conditions required for wheat development (Hassanein *et al.* 2012, p. 142). In addition, temperature is a primary determinant of the agro-ecological zones in Egypt. Therefore, elevated temperatures could cause spatial changes in the wheat cultivated areas in the Delta through reducing the suitability of lands for wheat production (Gosling *et al.* 2011). This could eventually result in reducing wheat cultivated areas in the Delta (Gosling *et al.* 2011).

The impacts of sea-level rise on wheat production could involve the loss of agricultural lands caused by coastal erosion and coastal flooding in addition to contributing to reductions in wheat yields caused by saline intrusion. These impacts would be exacerbated by the continuous subsidence of the Nile Delta caused by the various human activities. Heatwaves, floods, and droughts could jeopardize wheat production in the Delta through causing yield reductions, and in some cases, large-scale crop failures. Climate change could affect wheat production through its impacts on the supply of and demand for of irrigation water in the Egypt. The discharge of the River Nile, which is the primary source of irrigation water in Egypt, relies on precipitation in the major tributaries of the Nile. Changes in precipitation patterns in these tributaries could result in reduced river discharge, and therefore, reduced availability of irrigation water in Egypt. This would adversely impact the suitability of lands in Egypt for crop production since the availability of water for irrigation is a major determinant of the agro-ecological zones in Egypt.

The observed climate change in Egypt has not, nevertheless, affected the country's total wheat production. In fact, wheat production has increased during recent years due to the expansion of wheat cultivated areas. In addition, by comparing the country's total production of wheat between the years 2001 and 2014, it was observed that the total production increased from 6.2 million tonnes in 2001 to 8.6 million tonnes in 2014 as illustrated in Table 2.1 (FAOSTAT 2015; USDA 2014a). The highest annual growth rate of the country's wheat production occurred between 2001 and 2006 period; it was estimated to be 5.75% annually (FAOSTAT 2015; USDA 2014a). In addition, the highest values of wheat production were observed in the Nile Delta during 2012 (Sadek *et al.* 2014, p. 1221). Subsequent increases in yields were additionally observed in the Nile Delta during recent decades. The highest wheat yields were witnessed in the Nile Delta between 2004 and 2007 (Sadek *et al.* 2014, p. 1218). Furthermore, the observed climate change has not affected wheat cultivated areas. The government policies have resulted in the expansion of wheat cultivated areas across Egypt. As illustrated in Table 4.1, wheat harvested areas increased from 1.28 million hectares during 2011/2012 to 1.35 million hectares during 2013/2014 (USDA 2013, 2014a).[4]

[4] It must be noted that urbanization is currently considered the primary cause of the decline in cultivated lands in the Delta during the previous five years despite the existence of the legislations, including Law No. 3/1982 and the Martial Decree No.1/1996 that regulate the construction

2.3 Impacts of climate change on the trade in wheat

Climate change could affect the size of Egypt's wheat imports through its impacts on the import demand and export supply of wheat. Yield reductions induced by climate change could result in a decrease in Egypt's total wheat production. This would accordingly result in an increase in the demand for wheat imports in order to address the increasing consumption. In contrast, climate change in major wheat exporting countries will likely result in reduced wheat production in these countries, and therefore, decreased international wheat supply. In some cases, frequent and intense extreme weather events in these countries could result in policy interventions in the form of export bans. These weather events despite being local in their spatial scope, they would eventually result in trans-boundary impacts in the form of major disruptions in supply of wheat imports.

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of human settlements on cultivated lands (EEAA 2001). These legislations, however, were ineffective in reducing the unlawful construction of human settlements on cultivated lands, especially in the Nile Delta. Population growth, increasing prices of land, poor access to infrastructure, and the absence of effective control by the authorities following the 2011 revolution have collectively contributed to increased rates of unlawful construction of human settlements on cultivated lands in the Delta. Consequently, declines in cultivated areas have occurred in the Delta.

The observed impacts of climate change on the demand for wheat imports in Egypt are currently insignificant if compared with other factors, including population growth and the availability of foreign currency reserves. The government policy to reduce wheat imports and increase local wheat production through the expansion of wheat cultivated areas has succeeded to offset any climate-induced wheat yield reductions. Therefore, the government's policy is expected to induce stability in the country's total wheat production. In contrast, there is robust evidence on the observed the impacts of climate change on the supply of wheat exports. The recent years have witnessed increased frequency and intensity of extreme weather events in major wheat exporting countries; these events resulted in reduced wheat supplies in the international markets followed by decreased wheat imports to Egypt. A series of extreme weather events that occurred in major wheat exporters resulted in a deficit in the international wheat supplies and a reduced flow of wheat imports to Egypt. In 2010, Russia and Ukraine experienced severe drought and heatwaves that resulted in reducing the total wheat production by 32.7% and 19.3%, respectively (Werrell & Femia 2013, p. 7). In response to these events, the Russian government applied an export ban on wheat that reduced wheat imports to Egypt by 700,000 metric tonnes during August 2010 (USDA 2013). In addition, unprecedented intense drought occurred in the eastern part of China during late 2010, which is a major wheat producing region in the country. Precipitation decreased significantly in this region and China's wheat production decreased by 0.5% (Werrell & Femia 2013, p. 8). In an attempt to address climate-induced wheat yield failures, the Chinese government imported wheat from international markets. Consequently, wheat international markets witnessed reduced supplies and increased prices (Werrell & Femia 2013, p. 8).[5]

The projected climate change will likely cause fluctuations in the supply of exports and demand for imports of wheat in the short term and the long term. Increased temperatures coupled with a limited availability of irrigation water in Egypt would cause reductions in the wheat cultivated areas, yields, and would consequently cause reductions in the total production in the long term. The projected increase in the frequency and intensity of extreme weather events would result in yield failures and a decrease in wheat production in the short term. These climate-induced reductions coupled with population growth would result in an increased demand for wheat imports. According to Fischer *et al.*

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[5] Flash floods that occurred in Canada and Australia during 2010 resulted in reducing their wheat production by 13.7% and 8.7%, respectively; this further contributed to reductions in global wheat supplies (Werrell & Femia 2013, p. 7)

(2002), cereal imports by developing countries are projected to increase by 10–40% by 2080. Smith *et al.* (2013) concluded that a reduction of agricultural production in Egypt by 27% by 2060 would result in an increase in the agricultural imports by 49%. In addition, the adverse impacts of projected climate change on wheat production are expected to occur in major wheat producing countries. This would eventually result in policy interventions by applying export reductions and/or export bans to address increased local consumption in these countries. Global wheat supplies would, therefore, decrease and Egypt, being remarkably dependent on wheat imports, would experience reduced wheat supplies from abroad.

It must be noted that the projected climate change could result in changes in the geographic distribution of wheat production in major wheat exporters. Despite its projected impacts on the current wheat cultivated areas, climate change could result in the emergence of new areas of wheat cultivated areas since the climate of these areas would become suitable for wheat production. This would, therefore, offset the adverse impacts of projected climate change on the current wheat cultivated areas in these countries by maintaining the total wheat production as a result of new cultivated areas. For instance, Russia, which is currently a major wheat exporter, is characterized by the presence of significant unused land resources due to their unsuitability for crop production. The projected climate change could result in migration of wheat production towards new areas with more favourable climate for wheat production. Schierhorn *et al.* (2014, p. 139) concluded that increasing crop productivity and utilizing the abandoned land areas for wheat production will likely increase Russia's total wheat production by 9–32 million tonnes. This production increase could offset the reduction in Russia's wheat export supply induced by the adverse impacts of projected climate change (Scherhorn 2014, p.139).

Conclusion

This paper has analysed the observed and projected impacts of climate change on the trade in rice and wheat in Thailand and Egypt, respectively. In order to reach this analysis, the impacts of the change in the various climate parameters on production of both crops in both countries were analysed.

Both countries have experienced an increase in the annual mean, minimum, and maximum temperatures. Both crops have, therefore, experienced heat stress resulting from observed elevations of temperatures in both countries. Elevated temperatures have caused yield reductions by reducing length of growing period of both crops and by causing heat stress on both crops. In addition, elevated temperatures could result in reducing the suitability of lands in both countries for the cultivation of both crops since temperature is a major determinant of agro-ecological zones in both countries.

The major deltas in both countries, including the Chao Phraya Delta in Thailand and the Nile Delta in Egypt, are additionally vulnerable to the risks of sea-level rise. Consequently, the cultivated areas of both crops, which are located at the coastal zones of both deltas, are vulnerable to sea-level rise. Observed levels of sea-level rise have resulted in rapid erosion of coasts of both deltas. In addition, both crops have experienced salinity stress caused by saline intrusion into the soils of the coastal zones of both deltas.

Increased frequency and intensity of extreme weather events is regarded as a major observed aspect of climate change in both countries. The impacts of these events, however, were more evident in Thailand as compared to Egypt. In a period of four years, Thailand experienced two major extreme weather events, including the 2011 flood and the 2015 drought. Consequently, the impacts of increased frequency and intensity of extreme weather events were, nevertheless, more evident on rice production in Thailand as compared to their impacts on wheat production in Egypt. The increased frequency and intensity of floods and droughts have adversely affected rice yields in Thailand. In contrast, the intensity and frequency of heatwaves and sandstorms in Egypt did not significantly influence wheat yields.

Climate change additionally intensifies water stress on both crops by affecting the discharge of the major rivers in both countries, including the Chao Phraya River and the River Nile. Changes in the discharge of both rivers, which is induced by changes in precipitation patterns, causes a limited supply of irrigation water for the production of both crops. These impacts were more evident in Thailand as compared to Egypt. During the 2015 drought, a decreased discharge of the Chao Phraya River induced significant reductions in water levels in the Chao Phraya Dam. Limited availability of irrigation water in the Chao Phraya Delta prevented farmers from production of the second rice crop. It must be noted that the Chao Phraya River system exists entirely inside Thailand; the River Nile, in contrast, is a trans-boundary system in Africa where Egypt represents a downstream country of the Nile basin. Consequently, the discharge of the Chao Phraya River depends on precipitation patterns inside Thailand. In contrast, the discharge of the River Nile depends on precipitation patterns in the Upper White Nile and Blue Nile catchments.

The observed impacts of climate change on Thailand’s exports of rice have been evident in the seasonal fluctuations in the total production of rice that occurred following the incidence of floods and droughts. The 2011 floods, for instance, had resulted in damages to the first rice crop, and consequently had reduced the country’s rice export values in late 2011. In addition, the 2015 drought, which forced the farmers to postpone the production of a second rice crop, is expected to reduce the country’s exports of second rice in early and mid-2015.

Climate change could affect the size of Egypt's wheat imports through its impacts on the import demand and export supply of wheat. The observed impacts of climate change on the demand for wheat imports in Egypt are currently insignificant if compared with other factors, including population growth and the availability of foreign currency reserves. The increased government intervention in the wheat industry have mitigated the climate-induced impacts on the country’s wheat production by encouraging the expansion of wheat cultivated areas and increasing local wheat production. The impacts of climate change on the supply of wheat exports have, in contrast, been witnessed in the recent years. The increased frequency and intensity of extreme weather events in major wheat-exporting countries, including Russia, Ukraine, and China, resulted in reduced wheat supplies in the international markets followed by decreased wheat imports to Egypt in 2010.

Projected climate change is expected to result in further adverse impacts on the trade in both crops in both countries. A projected increase in temperature, sea-level rise, and an increase in the intensity and frequency of extreme weather events are expected to cause damages to the production of both crops in both countries and this would eventually influence the trade in both crops.

References

Agricultural Research & Development Council 2009, *Sustainable Agricultural Development Strategy Towards 2030*, The Ministry of Agriculture & Land Reclamation, Cairo.

ARDC, see Agricultural Research & Development Council.

Briones, RM, Chavez, EC, Durand-Morat, A & Wailes, EJ 2012, 'Climate change and price volatility: can we count on the ASEAN Plus Three Emergency Rice Reserve?', Asian Development Bank, Manila.

Chen, CC, McCarl, B & Chang, CC 2012, 'Climate change, sea level rise and rice: global market implications', *Climatic Change*, vol. 110, no. 3-4, pp. 543-560.

CIAT, see International Center for Tropical Agriculture.

Dutta, D 2011, 'An integrated tool for assessment of flood vulnerability of coastal cities to sea-level rise and potential socio-economic impacts: a case study in Bangkok, Thailand', *Hydrological Sciences Journal*, vol. 56, no. 5, pp. 805-823.

EEAA, see Egyptian Environmental Affairs Agency.

Egyptian Environmental Affairs Agency 2001, *The National Environmental Action Plan of Egypt 2002/17: environment at the center of modernizing Egypt*, The Ministry of State for Environmental Affairs, Cairo.

---- 2010a, *Egypt National Environmental, Economic and Development Study (NEEDS) for Climate Change Under the United Nations Framework Convention on Climate Change*, The Ministry of State of Environmental Affairs, Cairo.

---- 2010b, *Egypt Second National Communication under the United Nations Framework Convention on Climate Change*, The Ministry of State of Environmental Affairs, Cairo.

Eid, HM, El-Marsafawy, S & Ouda, SA 2006, 'Assessing the impact of climate on crop water needs in Egypt: the CROPWAT analysis of three districts in Egypt', *CEEPA Discussion Papers*, vol. 29, Centre for Environmental Economics and Policy in Africa, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria.

El-Ramady, HR, El-Marsafawy, SM & Lewis, LN 2013, 'Sustainable agriculture and climate changes in Egypt', in *Sustainable agriculture reviews*, Springer, pp. 41-95.

El Raey, M 2010, 'Impacts and implications of climate change for the coastal zones of Egypt', in D Michael & A Pandya (eds), *Coastal Zones and Climate Change*, The Henry L. Stimson Center, Washington, D.C., pp. 31-50.

Emde, G 2012, 'Flooding in Thailand's Chao Phraya River Basin: a study of human and environmental causes', University of Denver, Denver.

FAO, see Food and Agriculture Organization.

FAOSTAT 2015, *Country Profile: Egypt*, Food and Agriculture Organization, viewed 13 February 2015, <http://faostat.fao.org/CountryProfiles/Country_Profile/Direct.aspx?lang=en&area=59>.

Fischer, G, van Velthuizen, H, Shah, M, & Nachtergaele, F 2002, *Global agro-ecological assessment for agriculture in the 21st century: methodology and results*.

Fischer, RA, Byerlee, D & Edmeades, GO 2014, *Crop yields and global food security: will yield increase continue to feed the world?*, ACIAR Monograph No. 158, Australian Centre for International Agricultural Research, Canberra, viewed 15 January 2015, <http://aciar.gov.au/publication/mn158>.

Food and Agriculture Organization 2011, *Country Pasture/Forage Resource Profiles: Egypt*, Food and Agriculture Organization, viewed 12 December 2014, <http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Egypt.pdf>.

Gerald, N, Rosegrant, M, Palazzo, A, Gray, I, Ingersoll, C, Robertson, R, Tokgoz, S, Zhu, T, Sulser, T & Ringler, C 2010, *Food security, farming, and climate change to 2050: scenarios, results, policy options*, International Food Policy Research Institute Washington, D.C.

Gosling, SN, Dunn, R, Carrol, F, Christidis, N, Fullwood, J, Gusmao, Dd, Golding, N, Good, L, Hall, T & Kendon, L 2011, *Climate: observations, projections and impacts: Egypt*, The Met Office Hadley Centre for Climate Change.

Hamrick, D, Ahmed, G, Guinn, A, Abdulsamad, A, Goger, A, Daly, J, Morgan, J & Gereffi, G 2014, 'Comparing Egypt and Saudi Arabia's wheat GVC', Nicholas School for the Environment and the Center for Globalization, Governance & Competitiveness, Duke University, Durham.

Hassanein, M, Elsayed, M & Khalil, A 2012, 'Impacts of sowing date, cultivar, irrigation regimes and location on bread wheat production in Egypt under climate change conditions', *Nature and Science*, vol. 10, no. 12, pp. 141-150.

Hijioka, Y, Lin, E, Pereira, J, Corlett, R, Cui, X, Insarov, G, Lasco, R, Lindgren, E & Surjan, A 2014, 'Asia', in V Barros, C Field, D Dokken, M Mastrandrea, K Mach, T Bilir, M Chatterjee, K Ebi, Y Estrada, R Genova, B Girma, E Kissel, A Levy, S MacCracken, P Mastrandrea & L White (eds), *Climate change 2014: impacts, adaptation, and vulnerability. Part B: Regional aspects. contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, pp. 1327-1370.

Huang, H & Lampe, M 2011, 'Climate change and trade in agriculture', *Food Policy*, vol. 36, no. 1, pp. 9-13.

Intergovernmental Panel on Climate Change 2013, *Climate change 2013: the physical science basis: contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York.

---- 2014, *Climate change 2014: impacts, adaptation and vulnerability*: *contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, Cambridge and New York.

International Center for Tropical Agriculture 2012, *Thai agriculture and climate change*, Office of Agricultural Economics of Thailand, Bangkok.

IPCC, see Intergovernmental Panel on Climate Change.

Komori, D, Nakamura, S, Kiguchi, M, Nishijima, A, Yamazaki, D, Suzuki, S, Kawasaki, A, Oki, K & Oki, T 2012, 'Characteristics of the 2011 Chao Phraya River flood in central Thailand', *Hydrological Research Letters*, vol. 6, pp. 41-46.

Mahathanasetha, I & Pensuparb, K 2014, *Thai agricultural policies: the rice pledging scheme*, FFTC Agricultural Policy Database, viewed 13 May 2015, <http://ap.fftc.agnet.org/ap_db.php?id=260>.

Mohanty, S, Wassmann, R, Nelson, A, Moya, P & Jagadish, S 2013, 'Rice and climate change: significance for food security and vulnerability', IRRI Discussion Paper Series, International Rice Research Institute, Los Baños.

Mostafa, AlMoatassemBellah 2015, Climate change and sustainable development: *a comparative and applied study on agriculture in Egypt*, PhD thesis, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, College of Asia and Pacific, The Australian National University, Australia and Faculty of Law, Mansoura University, Egypt.

Nara, P, Mao, G-G & Yen, T-B 2013, 'Climate change impacts on agricultural products in Thailand: a case study of Thai rice at the Chao Phraya River Basin', *APCBEE Procedia*, vol. 8, pp. 136-140.

Pensupar, K & Yadanar, K 2015, *Thailand government's preparation for drought in 2015*, FFTC Agricultural Policy Database, viewed 25 May 2015, <http://ap.fftc.agnet.org/ap_db.php?id=431>.

Sadek, I, Moursy, FS, Heggi, M & Farag, A 2014, 'An Investigation of the relationship between climate change, water demand and price of wheat and maize crops in Egypt', *International Journal of Plant & Soil Science*, vol. 3, no. 10, pp. 1210-1235.

Schierhorn, F, Müller, D, Prishchepov, AV, Faramarzi, M & Balmann, A 2014, 'The potential of Russia to increase its wheat production through cropland expansion and intensification', *Global Food Security*, vol. 3, no. 3, pp. 133-141.

Siam, GM & Croppenstedt, A 2007, 'An assessment of the impact of wheat market liberalization in Egypt: a multi-market model approach', Agricultural Development Economics Division Working Paper No. 07–15, FAO Agricultural Development Economics Division, Rome.

Singhapreecha, C 2014, *Economy and agriculture in Thailand*, FFTC Agricultural Policy Database, viewed 18 March 2015, <http://ap.fftc.agnet.org/ap_db.php?id=246>.

Smith, J, Deck, L, McCarl, B, Kirshen, P, Malley, J & Abdrabo, M 2013, Potential impacts of climate change on the Egyptian economy, United Nations Development Programme, Cairo.

Thai Meteorological Department 2012, *The climate of Thailand*, Thai Meteorological Department, viewed 12 January 2015 2015, <http://www.tmd.go.th/en/archive/thailand_climate.pdf>.

Trisirisatayawong, I, Naeije, M, Simons, W & Fenoglio-Marc, L 2011, 'Sea level change in the Gulf of Thailand from GPS-corrected tide gauge data and multi-satellite altimetry', *Global and Planetary Change*, vol. 76, no. 3, pp. 137-151.

U.S. Department of Agriculture 2012, *Thailand: grain and feed annual*, TH2027, U.S. Department of Agriculture, Washington, D.C.

---- 2013, *Egypt: Grain and Feed Annual*, United States Department of Agriculture, Washington, D.C.

---- 2014a, *Egypt: Grain and Feed Annual*, United States Department of Agriculture, Washington, D.C.

---- 2014b, *Thailand: grain and feed annual*, TH4021, U.S. Department of Agriculture, Washington, D.C.

---- 2015, *Thailand: grain and feed annual*, TH5030, U.S. Department of Agriculture, Washington, D.C.

UNDP, see United Nations Development Programme.

UNEP, see United Nations Environment Programme.

United Nations Development Programme 2009, *3748: Adaptation to climate change in the Nile Delta through Integrated Coastal Zone Management,* The Ministry of Water Resources and Irrigation, Cairo.

United Nations Environment Programme 2006, *Facing the facts: Assessing the vulnerability of Africa's water resources to environmental change*, UNEP/Earthprint, Nairobi.

USAID 2013, *Impact of climate change on agricultural cropping patterns in the MENA Region*, USAID, viewed 23 December 2014, <http://pdf.usaid.gov/pdf_docs/pa00jpp7.pdf>.

USDA, see U.S. Department of Agriculture.

Werrell, CE & Femia, F 2013, *The Arab spring and climate change: A climate and security correlations series*, The Center for American Progress, Stimson, and The Center for Climate and Security, Washington, D.C.

World Bank 2015a, *Agriculture, value added (% of GDP)* World Bank, viewed 19 July 2015, <http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS/countries>.

---- 2015b, *World Bank country data: Thailand*, World Bank, viewed 19 July 2015, <http://data.worldbank.org/country/thailand>.
---- 2015c, *World Development Indicators: Egypt*, World Bank, viewed 4 January 2015, <http://databank.worldbank.org/data/reports.aspx?Code=EGY&id=556d8fa6&report_name=Popular_countries&type=country&ispopular=y>.