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The Importance of Weather Forecasts and Meteorological Information in Adaptation to Climate Change in Agricultural Production: Some Preliminary Findings

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Many studies have increasingly emphasized adaptation to climate change in agricultural production. Most of them have recognized that agronomic strategies such as shifting agricultural calendar, changing crop varieties and types, crop diversification, income diversification and improving irrigation infrastructure are the commonly used adaptive strategies to climate change. What these strategies have missed, however, is the critical role of meteorological information for farmers in coping with climate variability and change. This paper provides a synthesis of the issues raised in the literature related to the major role and importance of weather forecast and meteorological information in coping with climate change. A number of these issues were related to improving weather forecast and providing meteorological services as adaptive strategies to climate change. The findings of these studies on improving quality of weather forecast and meteorological information has shown that the strategies have been very beneficial for different stakeholders who are constantly facing risks and uncertainties from natural disasters. For decision makers, the benefits from using this information include improved risk management practices and better-targeted policies. For farmers, the use of such accurate meteorological information can result in higher output, productivity and income or lower avoided cost or losses. However, there are constraints and challenges in applying meteorological information in coping with climate change. The most challenging issue is how to ensure the accuracy of weather forecasts. A number of recommendations were proposed to ensure a more efficient and beneficial use of weather forecast and meteorological information in coping with climate change in agricultural production. These include: (1) enabling different institutions and stakeholders involved in weather forecast to ensure the accuracy of forecast results, (2) developing integrated research framework in using meteorological information, (3) strengthening and enriching farmer's meteorological knowledge, and (4) providing user-oriented features to increase the economic benefits of meteorological information to the public.

Key Words: climate change, adaptation to climate change, weather forecast, meteorological information

INTRODUCTION

Climate change has become a threat to human society (Ramirez-Villegas et al. 2012; Kibue et al. 2015), particularly in developing countries where smallholder farmers are greatly affected and are becoming increasingly vulnerable to extreme weather events caused by climate change (Lotze-Campen and Schellnhuber 2009; Altieri and Nicholls 2013; Comoé and Siegrist 2015). Thus, adaptation to climate change is now gaining wide recognition and is a focal concern around the world (Smit and Skinner 2002; Wilbanks et al. 2007; Thornton and Comberti 2013). However, developing countries have lower adaptive capacity and do not have the essential technology for adaptation to climate change (Lotze-Campen and Schellnhuber 2009).

Agriculture as the major means of man for providing food sustainability is highly dependent on and strongly affected by weather and climate as well as extremely related events (Mjelde et al. 1989; Das 2005; Motha and Murthy 2007; Sivakumar 2011; CIE 2014). In addition, adverse impacts of climate change on agricultural production lead to high poverty level (Mendelsohn et al. 2006) and food insecurity (Das 2005; Rosenzweig and Tubiello 2007; Nelson et al. 2009; Misra 2012; Connoly-Boutin and Smit 2015). Thus, adaptation to climate change is necessary to reduce losses in agricultural production (Wilbanks et al. 2007; Hirota et al. 2011). In addition, improvement of adaptive capacity to climate change in agriculture is not only a societal priority but also an imperative task to ensure food security and improve livelihood of smallholder farmers (Smit and Skinner 2002; Verchot et al. 2007; Bryan et al. 2009; Kibue et al. 2015).

Many studies have mentioned adaptive strategies to climate change in agricultural production. In these studies, adaptive strategies could be classified into different categories such as agricultural systems, location, and climate change scenarios (Rosenzweig and Tubiello 2007). They also include different options such as crop management, land management, irrigation management, income diversification, and rituals (Esham and Garforth 2013). Generally, mentioned adaptive strategies are mainly the coping methods that mostly relate to technical aspects of farming activities. However, technical adaptive strategies are not always effective for farmers to cope with future change in climate variability (Rosenzweig and Tubiello 2007; Marshall et al. 2011; Qiu and Prato 2012; Trærup and Stephan 2014). Thus, there is a need for alternative adaptive options to help farmers cope effectively with climate change in their agricultural production.

Weather forecast and meteorological information are useful not only in decision making for farm management but also in coping with natural disaster risks and uncertainties caused by climate change (Sivakumar et al. 1998; Sivakumar 2011). Thus, weather forecast and meteorological information have increasingly become important for countries to adapt to climate change (Rogers and Tsirkunov 2013). Improving seasonal weather forecast and providing meteorological information could provide a valuable tool for different stakeholders to reduce the adverse impacts of climate change (Patt and Gwata 2002; Ziervogel and Downing 2004; Amissah-Arthur 2005; Klopper et al. 2006; Archer et al. 2007; Hamin and Gurran 2009; Marshall et al. 2011). For instance, farmers can use weather forecast information to change or modify their plan/program in agricultural production, which results in the reduction of losses or adaptation cost to climate change (Murphy 1990; Keller et al. 2007; Trærup and Stephan 2014). In addition, by using accurate meteorological information, farmers could adjust their production activities and therefore maintain high crop yield under changed climate conditions (Williamson et al. 2002; Amissah-Arthur 2003; Amissah-Arthur 2005; Keller et al. 2007; Tena and Gómez 2009; Das 2010; Furman et al. 2011). To date, however, there has been no attempt to put together all available information on the importance and need for improving weather forecast and providing meteorological information for climate change adaptation that would most especially be useful for farmers and decision makers. Hence, this paper aimed to determine how improving weather forecast and providing meteorological information are necessary and important for farmers in coping with climate change.

MATERIALS AND METHODOLOGY

This paper is based on secondary information gathered from the literature searches. The study searched documents by using the websites of Science@Direct, ISIKnowledge, SpringerLink and Proquest Central. The search terms were “climate change adaptation in agriculture”, “meteorological information in climate change adaptation”, and “weather forecast in climate change adaptation”. This study also screened documents through examination of the title, abstracts, methodology, full contents, and conclusion of the papers to find related topics.

A total of 175 related papers were gathered from these literature searches, most of which were journal articles (164/175 or 94%). There were 58 identified papers regarding the role and importance of information, weather forecast and meteorological information in climate change adaptation. In addition, the study areas of these papers were mostly Africa and Asia, which are most vulnerable to climate variability and change (Table 1). The papers covered the period 1999 to 2015, although most of them were during the period 2007 to 2015 (Fig. 1).

The literature search sought to find answers to the following questions: (1) How do smallholder farmers adapt or cope with climate variability and change in agricultural production?; (2) What strategies are used by smallholder farmers to adapt or cope with climate variability and change in agricultural production?; and (3) How do weather forecast and meteorological information help smallholder farmers in climate change adaptation in agricultural production?

A systematic review was undertaken in seeking

Table 1. Number of related papers by location

Item	No. of Papers	Frequency (%)
Total no. of papers	175	100
By location of study		
Africa	59	34
Asia	47	27
America	19	11
Europe	12	7
Oceania	9	5
Joint place	29	17

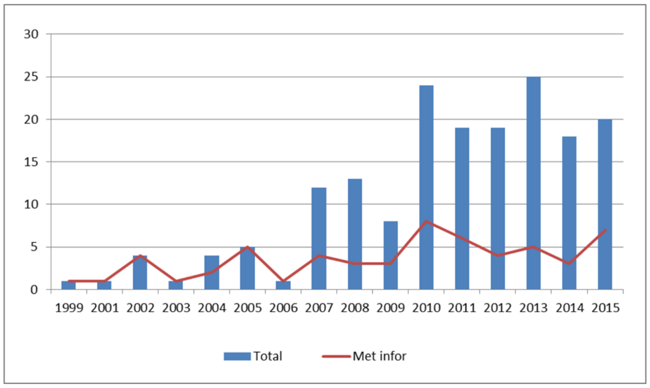

Fig. 1. Number of related papers classified by year published

answers to the research question regarding the importance of weather forecast and meteorological information in coping with climate change. "A systematic review attempts to collate all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question" (Green et al. 2011). In addition, it "define(s) a research question, search for studies, assess their quality and synthesize findings qualitatively or quantitatively through using a transparent and systematic process" (Armstrong et al. 2011). According to Khan et al. (2003), the five steps in undertaking a systematic review include framing questions for a review, identifying relevant work, assessing the quality of studies, summarizing the evidence, and interpreting the findings.

RESULTS

Prevailing Adaptive Options to Climate Change in Agricultural Production

Climate change has increasingly affected adversely crop production and yields in important agricultural regions of the world (Almaraz et al. 2008; Reidsma et al. 2009). Thus, adaptation to climate change in agricultural production has been increasingly considered by most of the countries, organizations and individuals (Smit and Skinner 2002; Wilbanks et al. 2007; Thornton and Comberti 2013). This explains why many studies have mentioned adaptive strategies to climate change in agriculture in the different regions of the world. Many adaptive strategies have been mentioned in these studies. Of these adaptive options, technical adaptation strategies are the most common practices of farmers in coping with climate change (Table 2). A large number of selected papers (72%) emphasized the importance of technical strategies in climate change adaptation.

Technical or agronomic adaptive strategies include different adjustments related to farming techniques, irrigation infrastructure/technology improvement, soil conservation, land and water management, and other related issues (Rosenzweig and Tubiello 2007; Below et al. 2014). Improving farming techniques had significant effects on farmers' adaptation to climate change in many countries and regions such as the Middle East (Iglesias et al. 2011), North America (Grasso and Feola 2012), and Vietnam (Bastakoti et al. 2014).

At present, adaptive strategies related to cultural practices such as shifting agricultural calendar, changing cultivar variety and type, and crop rotation and diversification have been widely adopted in climate change adaptation (Rosenzweig and Tubiello 2007; Lotze-Campen and Schellnhuber 2009; Esham and Garforth 2013; Keshavarz et al. 2014; Below et al. 2014). Among the different cultural practices, the most often mentioned in the papers was changing the agricultural calendar (Table 2). The importance of other farming techniques (changing crop systems and varieties, switching to new cultivars, and production diversification) was also mentioned by many researchers such as Bradshaw et al. (2004), Rosenzweig and Tubiello (2007), Reidsma et al. (2010), Birkmann (2011), Arbuckle Jr. et al. (2013), Jamir et al. (2013), Bonzanigo et al. 2014), and Westengen and Brysting (2014).

Soil conservation and land management were also mentioned as efficient technical strategies for smallholder

Table 2. Common adaptive options to climate change in agricultural production.

Adaptive strategy	No. of Papers	Frequency (%)
Total no. of papers	**141**	**-**
1. Technical adaptation strategies	**101**	**72**
Change agricultural calendar	39	28
Change crop variety	29	21
Diversify crop or production system	22	16
Improve irrigation infrastructure/technology	22	16
Change or modify crop system/ Crop rotation	14	10
Change cultivar type	13	9
Improve water management	12	9
Improve soil/land conservation	10	7
Change farming practice	3	2
Adopt agroforestry system	6	4
Use smart-farming approach	4	3
2. Social adaptation strategies	**18**	**13**
Develop knowledge/skills	4	3
Use indigenous knowledge	5	4
Develop social networks	6	4
Strengthen institutional capacities	6	4
3. Financial and economic adaptation strategies	**22**	**15**
Access to credits	17	12
Access to markets	4	3
Income diversification	5	6

*Multiple choices

farmers to minimize negative impacts of climate change in agricultural production (Rosenzweig and Tubiello 2007; Eakin et al. 2014; Aleksandrova et al. 2015). This was also mentioned in the studies of Ebi et al. (2011) in Mali, Bonzanigo et al. (2014) in Italia, and Klein et al. (2013 and 2014) in Switzerland. Improving irrigation infrastructure and water management practices were also found to be useful for farmers in confronting climate change (Yang et al. 2007; Wantanabe and Kume 2009; Sowers et al. 2011; Sissoko et al. 2011; Dono et al. 2013; Sima et al. 2015). There were also similar findings in Ethiopia (Demeke et al. 2011), Mali (Ebi et al. 2011), Itali (Bonzanigo et al. 2014), and Thailand (Koontanakulvong et al. 2014).

Other technical adaptation strategies such as agroforestry techniques and climate-smart agriculture techniques were also found to be effective adaptive strategies in several studies. Agroforestry could maintain agricultural production activities (Verchot et al. 2007; Nguyen et al. 2013) and provide food during shortage or cash source for weather-related crop failure under changed climate conditions (Fisher et al. 2010). This is similar to findings of Thorlakson and Neufeldt (2012) in Kenya, and Rahn et al. (2014) in Nicaragua. Climate-smart agriculture could also facilitate climate change adaptation or provide the basis for development of the capacity for farmers to respond and adapt to climate change (Kenny 2011; Scherr et al. 2012; Zhang et al. 2015). The importance of climate-smart agriculture technique for farmers in coping with climate change was mentioned in the studies of Wantanabe and Kume (2009) in Japan, Murungweni et al. (2015) in Zimbabwe, and Zhang et al. (2015) in China.

Social adaptation strategies or soft strategies also play an important role in addressing adverse impacts of climate change (Hallegatte 2009). Social adaptive strategies relate directly to improving the household's social capital (Sowers et al. 2011; Esham and Garforth 2013; Kassie et al. 2013). Improving social capital of the household could help farmers in many countries such as Australia (Marshall et al. 2011), Ghana (Antwi-Agyei et al. 2013), Kenya (Jalón ét al. 2015), and Tanzania (Mutabazi et al. 2015) to cope effectively with climate change in their agricultural production. Social adaptation strategies include improving human recognition and knowledge on climate change, strengthening social network and institutional capacity, providing information and extension services, and building capacity for farmers (Sowers et al. 2011; Esham and Garforth 2013; Kassie et al. 2013). The efficiency of improving farmers' recognition and knowledge in coping with climate change was mentioned in a number of studies such as those of Reidsma et al. (2010) in Europe, Marshall et al. (2011) in Australia, Newsham and Thomas (2011) in Namibia, and

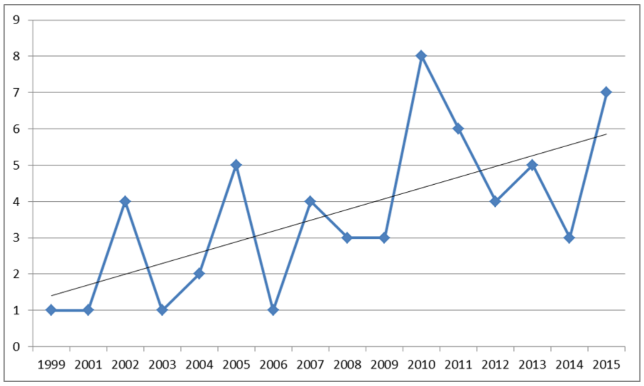

Fig. 2. Number of studies related to information and meteorological information in climate change adaptation.

Pennesi et al. (2012) in the Arctic. Strengthening social network, institutional capacity and community participation is also another significant strategy for farmers to cope with climate change. This is consistent with the findings of several studies in different countries and regions such as India (Prabhakar and Shaw 2008), Ghana (Westerhoff and Smith 2009; Yaro 2013; Antwi-Agyei et al. 2013 & 2014), Mesoamerica (Eakin et al. 2011), Slovakia, Tajikistan and Ukraine (Bizikova et al. 2014), Malawi and Kenya (Brooks 2014), and Nicaragua (Rahn et al. 2014).

Economic and financial adaptive strategies that relate to income diversification and access to market and credit are also useful for farmers in climate change adaptation. Income or livelihood diversification (off-farm employment, leased cropping land, etc.) is an effective solution for smallholder farmers in climate change adaptation (Thomas et al. 2007; Esham and Garforth 2013; Keshavarz et al. 2014). This was used in several countries such as Canada (Bradshaw et al. 2004), Tanzania (Paavola 2008), India (Jamir et al. 2013), and Ghana (Antwi-Agyei et al. 2013 & 2014). Better access to market could help farmers cope effectively with climate change in their agricultural production. Similar findings were mentioned by Hassan and Nhemachena (2008) in Africa, Steffen et al. (2011) in Australia, Eakin et al. (2011) in Mesoamerica, Tambo and Abdoulaye (2012) in Nigeria, Kassie et al. (2013) in Ethiopia, and Koopman et al. (2015) in the Netherlands. Facilitating access to credit could also help farmers adapt more efficiently to climate change in agricultural production (Hassan and Nhemachena 2008; Ebi et al. 2011). This was similarly found in many countries and regions such as Mesoamerica (Eakin et al. 2011), Kenya (Tambo and Abdoulaye 2012), Uganda (Hisali et al. 2011), Nigeria (Tambo and Abdoulaye 2013), Ethiopia (Di Falco et al. 2012; Kassie et al. 2013), and Ghana (Fosu-Mensah et al. 2012; Yaro 2013).

The Importance of Weather Forecast and Meteorological Information in Climate Change Adaptation

Information is a key asset for society and has increasingly played an important role in socio-economic analysis (Arrow 1999; Higson and Waltho 2010). However, information normally has characteristics of the public goods (Teisberg et al. 2005; Houghton 2011; Bernknopf and Shapiro 2015). It is because information is scarce and costly to both individuals and the whole society (Arrow 1999). In addition, information is always imperfect or asymmetric (Varian 1992; Arrow 1999; Stiglizt 2000). Asymmetric information occurs because one economic agent could know something that another economic agent does not (Varian 1992), or one party cannot obtain freely (or at all) information available to another (Arrow 1999). Asymmetric information causes market failure and therefore may not yield Pareto efficiency that is the basis for socio-economic policy-making (Schotter 2009; Krugman and Wells 2012). Thus, providing accurate or perfect information is very important for policy making as well as in solving social and economic issues.

Meteorological information is useful for farmers not only in decision making for farm management but also in coping with natural disaster risks and uncertainties (Sivakumar et al. 1998; Hansen 2002; Sivakumar 2011). In addition, meteorological information has played an important role in recommending appropriate agricultural management practices to ensure sustainable production under climate change (Murthy and Stigter 2004; Rathore et al. 2011; Saroar and Routray 2012; Roco et al. 2014; Jalón et al. 2015). By using accurate meteorological information, farmers could adjust their production activities (Williamson et al. 2002; Amissah-Arthur 2003; Amissah-Arthur 2005; Keller et al. 2007; Tena and Gómez 2009; Cardoso et al. 2010; Furman et al. 2011), and therefore their crop yields could be stabilized under climate change conditions (Das 2010).

Providing information could benefit farmers in coping with climate change in agricultural production. This was justified in the studies of Tarnoczi and Berkes (2010) in Canada, Kassie et al. (2013) in Ethiopia, Yaro (2013) in Ghana, Monterroso et al. (2014) in Mexico, and Fisher et al. (2015) in sub-Saharan Africa. Providing information on climate change has also been a core adaptive strategy for smallholder farmers in agricultural production (Smit and Skinner 2002). This supports for findings of Di Falco et al. (2012) in Ethiopia, Tambo and Abdoulaye (2012, 2013) in

Nigeria, and Le et al. (2014) in Mekong Delta, Vietnam. These concluded that the key driver of climate change adaptation of smallholder farmers was access to quality and timely information on future climate change. Moreover, Bonzanigo et al. (2014) identified that information on climate change had a significant and positive impact on adaptive plans to climate change of farmers. This is similar to the conclusion of Acosta-Michlik and Espaldon (2008), Deressa et al. (2009), Fosu-Mensah et al. (2012), and Gebrehiwot and Veen (2013) that lack of reliable information on climate change would be a barrier to farmers in coping with climate change in agricultural production. However, Patt and Schröter (2008) revealed the opposite finding that adaptive behavior did not change in Mozambique farmers although they receive information on climate change.

Improving quality of weather forecast and providing accurate meteorological information has been increasingly the focus in climate change adaptation strategies. This explains why the number of papers that mentioned the importance of improving the quality of weather forecast and meteorological information in climate change adaptation has been increasing in recent years (Fig. 2). Results of these papers revealed that improving seasonal weather forecast could provide a valuable tool for different stakeholders to reduce adverse impacts of climate change. This was found in various papers of Patt and Gwata (2002), Ziervogel and Downing (2004), Amissah-Arthur (2005), Klopper et al. (2006), Archer et al. (2007), Hamin and Gurran (2009), Marshall et al. (2011), Ebi et al. (2011), Jamir et al. (2013), and Kunimitsu et al. (2015). In addition, improving weather forecast could also help farmers in different countries to have plausible adaptive planning in response to climate change in their agricultural production. This was demonstrated in many countries and regions such as Brazil (Lemos et al. 2002), South Africa (Boone et al. 2004), Burkina Faso (Roncoli et al. 2009), USA (Crane et al. 2011), the Mediterranean region (Grasso and Feola 2012), and Côte d'Ivoire (Comoé et al. 2014).

Providing precise information on climate change was a useful adaptive strategy for farmers to cope with climate change in their agricultural production. This was mentioned in the various papers such as studies of Smit and Skinner (2002), Das (2005), Guerreiro (2005), Meinke and Stone (2005), Acosta-Michlik and Espaldon (2008), Hassan and Nhemachena (2008), Deressa et al. (2009), Fosu-Mensah et al. (2012), Batisani and Yarnal (2010), Goddard et al. (2010), and Munang et al. (2010), Esham and Garforth (2013), and Gebrehiwot and Veen (2013). Farmers may improve their adaptive capacity to climate change if they can have access to relevant meteorological information (Challinor et al. 2007). This is in line with conclusions of Risbey et al. (1999) in Australia, Amissah-Arthur (2005) in sub-Saharan Africa, Klopper et al. (2006) in South Africa, Roncoli et al. (2009) in Burkina Faso, Sissoko et al. (2011) in West African Sahel, Saroar and Routray (2012) in Bangladesh, Gebrehiwot and Veen (2013) in Ethiopia, Baudoin et al. (2014) in Benin, Roco et al. (2015) in Chile, and Jalón et al. (2015) in Kenya. This finding is also justified in many countries and regions such as Canada (Tarnoczi and Berkes 2010), Nigeria (Tambo and Abdoulaye 2012 & 2013), Ethiopia (Di Falco et al. 2012; Kassie et al, 2013), Ghana (Yaro, 2013), Italia (Bonzanigo et al. 2014), Mexico (Monterroso et al. 2014), Vietnam (Le et al. 2014), and sub-Saharan Africa (Fisher et al. 2015). Moreover, providing precise meteorological could also help farmers to reduce risks caused by climate change in their agricultural production. This is similar to conclusions of Templeton et al. (2014) in the US, and Debela et al. (2015) in Ethiopia, that indicated that agricultural risks caused by climate change would be reduced if farmers were provided accurate meteorological information.

DISCUSSION

The most common adaptive strategies to climate change in agricultural production, that were mentioned in many papers, are mainly related to adjusting farming activities such as changing the farming calendar, shifting to new cultivars, changing crop varieties and crop diversification. However, many studies showed the disadvantages of the adaptive strategies associated with adjusting farming activities. Bradshaw et al. (2004) revealed that crop diversification was unlikely adopted as adaptive option by farmers in Canada. According to Brooks (2014), there were more conflicts than synergies between applying new crop varieties and crop diversification in climate change adaptation in Malawi and Kenya. In addition, crop switching has not been generally captured in the context of climate change adaptation in in South America (Seo and Mendelsohn 2008), and could not reduce adverse economic impacts of climate change on crop producers in the USA (Qui and Prato 2012). Changing sowing dates was also an ineffective adaptive strategy (Tingem and Rivington 2008; Srivastava et al. 2015) and did not bring any significant changes in the households' capacity to reduce losses caused by climate change (Gioli et al. 2013). The reason is that shifting the agricultural calendar is only an emergency response adopted on a seasonal basis (Gioli et al. 2013). Changing cultivar type was also not effective in reducing adverse impacts of climate change in

Ethiopia (Kassie et al. 2015). Mentioned also were social, economic, and financial limitations of the adaptive strategies. Thomas et al. (2007) and Eakin et al. (2014) concluded that income or livelihood diversification is not an effective strategy for farmers to cope with climate variability and change. According to Jalón et al. (2015), access to credit did not affect farmers' adaptive behavior to climate change.

In recent years, improving weather forecast and providing accurate meteorological information have been increasingly determined as significant strategies for farmers in coping with climate change in agricultural production. Improving quality of seasonal weather forecast could provide a valuable tool for different stakeholders to reduce adverse impacts of climate change. This is consistent with the findings of Patt and Gwata (2002), Ziervogel and Downing (2004), Amissah-Arthur (2005), Klopper et al. (2006), Archer et al. (2007), Hamin and Gurran (2009), Marshall et al. (2011), Ebi et al. (2011), Jamir et al. (2013), and Kunimitsu et al. (2015). Improving quality of weather forecast could also help farmers in different countries in coming up with more plausible adaptive planning to climate change in their agricultural production. This finding was found in many countries and regions such as Brazil (Lemos et al. 2002), South Africa (Boone et al. 2004), Burkina Faso (Roncoli et al. 2009), USA (Crane et al. 2011), Côte d'Ivoire (Comoé et al. 2014), and the Mediterranean region (Grasso and Feola 2012).

The importance of improving weather forecast for farmers in coping with climate change has been recognized in many studies. According to Lemos et al. (2002), weather forecasting provided potential opportunity for different bureaucracies in Brazil to make plausible adaptive planning to climate change. This agrees with findings of Boone et al. (2004) in South Africa, Roncoli et al. (2011) in Uganda, Ebi et al. (2011) in Mali, Grasso and Feola (2012) in the Mediterranean region, and Yaro (2013) in Ghana. Based on accurate weather forecasts, farmers could adjust their existing adaptive strategies and therefore reduce adverse impacts of climate change (Ziervogel and Downing 2004; Klopper et al. 2006; Marshall et al. 2011). This is consistent with findings of many researchers in different countries and regions such as Patt and Gwata (2002) in Zimbabwe, Amissah-Arthur (2005) in Sub-Saharan Africa, Archer et al. (2007) in Southern Africa, Hamin and Gurran (2009) in the U.S. and Australia, Crane et al. (2011) in USA, Jamir et al. (2013) in India, and Kunimitsu et al. (2015) in Japan.

Providing timely and accurate meteorological information could help farmers cope effectively with the adverse effects of climate change in agricultural production (Das 2005; Guerreiro 2005; Batisani and Yarnal 2010; Goddard et al. 2010). This is similar to the findings in many countries and regions such as South Africa (Klopper et al. 2006), Uganda (Roncoli et al. 2011), West African Sahel (Sissoko et al. 2011), Bangladesh (Saroar and Routray 2012), Ethiopia (Gebrehiwot and Veen 2013), Ghana (Yaro 2013), USA (Templeton et al. 2014), and Benin (Baudoin et al. 2014). Availability of accurate meteorological information may also help farmers reduce risks caused by climate change (Risbey et al. 1999; Munang et al. 2010; Debela et al. 2015) or have optimal adaptive strategies (Amissah-Arthur 2005; Challinor et al. 2007; Hassan and Nhemachena 2008; Roco et al. 2015; Jalón et al. 2015). Thus, all countries should consider the policies that encourage improving quality of weather forecast and meteorological information in climate change adaptation (Perarnaud et al. 2005). This finding agrees with the conclusions of Sivakumar et al. (2005) in Africa, and Ustrnul et al. (2015) in Poland.

In addition, improving weather forecast and providing accurate meteorological information could also bring empirical economic value for farmers in coping with climate change (Amissah-Athur 2005). This is consistent with the finding of Bernknopf and Shapiro (2015). Generally, the value of meteorological information could be an outcome of the choice in uncertain situations (Macauley 2005). In reality, many studies showed the economic value of weather forecast and meteorological information in different countries. Based on the estimates of the Center of International Economics (CIE) in 2014, the potential economic value of weather forecast to the agriculture industry in Australia was around AU$1.567 million.

Economic value of weather forecast and meteorological information in climate change adaptation could be the gains in output, productivity or profit from using additional information (Macauley 2005; Hay 2007). This is similar to conclusions of Borisova et al. (2009), Tena and Gómez (2009), and Hansen et al. (2011). This is also justified in different countries such as Brazil (Cardoso et al. 2010), and USA (Solí and Leton, 2013). Rao and Manikandan (2008) revealed that Indian farmers who used weekly meteorological information got 6.3–19.2%, 6.4–12.2% and 7.3–8% increase in yield of rice, banana and coconut, respectively, compared with other farmers who did not. In Australia, the potential economic value of meteorological information was around $10–12/ha with respect to perfect forecast of rainfall (Wang et al. 2009).

Farmers in Zimbabwe who used meteorological information in planning had higher benefit (9%) than farmers who did not apply forecast information (Hansen et al. 2011). Economic value of weather forecast and meteorological information in climate change adaptation could also include a reduction in losses caused by climate change or a decrease in avoided cost (Katz and Murphy 1997; Hansen 2002; Hay 2007). This is similar to the findings of Wang et al. (2009), Hubbard and Millar (2014), Trørup and Stephan (2014), and Häggquist and Söderholm (2015). Many studies revealed economic value of weather forecast and meteorological information in the context of reducing losses caused by climate change or decreasing avoided cost. The agricultural sector of the U. S. saved an additional $40 million per year in avoided irrigation costs through using more accurate short-term weather forecast (Williamson et al. 2002). According to Teisberg et al. (2005), U. S. electricity generators saved $166 million annually through using the meteorological information obtained from the forecast of National Weather Services. The potential economic value of climatological information was around $400/ha, about $54/ha in nitrogen reduction, and $10–12/ha with respect to perfect forecast of rainfall (Wang et al. 2009). Rathore et al. (2011) indicated that the use of agrometeorological information reduced the cost of cultivation up to 25% for paddy, wheat, fruits and vegetables in some selected areas in India.

CONCLUSION

Adaptation to climate change in agricultural production has increasingly been considered by individuals, organizations, and countries in the world. During the early stage, adaptation to climate change in agriculture mainly focused on agronomic strategies. These strategies include shifting agriculture calendar, changing crop variety and type, crop diversification, income diversification and improving irrigation infrastructure. However, these strategies have increasingly been found not to be always useful for farmers in coping with climate variability and change.

In recent years, many studies have increasingly focused on the importance of improving weather forecast and meteorological information in adaptation to climate change in agricultural production. The number of studies that focused on the importance of improving weather forecast and meteorological information in coping with climate change has also significantly increased. Accurate weather forecast and meteorological information are substantial for decision making in both farm management and coping with natural disaster risks and uncertainties. In addition, decision makers can improve risk management practices or get better-targeted policies by using meteorological information (Meinke and Stone 2005). Based on accurate meteorological information given by weather forecasts, farmers could have more effective adaptive strategies or improve their adaptive capacities to climate change. Farmers could also gain tangible economic values (e.g., gains in outputs, productivities, profits, or value added; or decrease in avoided cost, or reduction in losses caused by climate change) by using accurate meteorological information in coping with climate change in their agricultural production.

Although weather forecast and meteorological information have been useful in climate change adaptation, improving access to climatological information is only half of the battle to adapt to climate change (Chikozho 2010) because of the many constraints and challenges faced in applying meteorological information in coping with climate change (Patt and Gwata 2002; Ziervogel et al. 2010). Optimal use of seasonal weather forecasts would also be limited by constraints such as the method of providing, interpreting and applying forecasts in a variety of decision-making processes (Klopper et al. 2006). Furthermore, it is not easy to determine the impact of full integration of the weather forecast with other information on decision strategies (Goddard et al. 2010). The most challenging issue in applying meteorological information in adaptation to climate change is ensuring weather forecast accuracy (Rathore et al. 2011). Therefore, the first prerequisite in using climatological information in climate change adaptation is that forecasted information must be real and perceived (Hansen 2002). In addition, government policies on climate change adaptation should focus on providing plausible weather forecasts (Comoé et al. 2014). To do so, it should better enable different institutions and stakeholders involved in weather forecast (Archer et al. 2007).

Furthermore, in order to achieve benefits from using meteorological information in coping with climate change, an integrated research framework is required. This framework comprises multiple disciplines including climate science, agricultural system science, rural sociology and many other disciplines (Meinke and Stone 2005). In addition, strengthening and enriching farmer's agrometeorological knowledge is also necessary to ensure that they can benefit from applying meteorological information in climate change adaptation (Winarto et al. 2013). Finally, there is a need for user-oriented features including more content and a technical infrastructure to increase the economic benefits of meteorological information to the public (Lee et al. 2014).

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