Journal of Integrative Agriculture
2014, 13(4): 698-712

Available online at www.sciencedirect.com
ScienceDirect

April 2014

REVIEW

Financing Sustainable Agriculture Under Climate Change

HUANG Ji-kun[1] and WANG Yang-jie[1, 2]

[1] Center for Chinese Agricultural Policy, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, P.R.China
[2] University of Chinese Academy of Sciences, Beijing 100049, P.R.China

Abstract

Agriculture is facing great challenge in meeting global food security and is expected to face even greater challenge under climate change. The overall goal of this paper is to examine how finance can be used to achieve the joint objectives of development, mitigation of and adaptation to climate change in agriculture in developing world based on literature review. The results show that agriculture is much under invested and foreign aid also has not increased appropriately to assist developing countries to maintain sustainable agriculture under climate change. There are a wide range of areas in mitigation of and adaptation to climate change that need substantial investment. Major areas and successful cases mitigation of and adaptation to climate change in agriculture that have worked in developing countries are examined. A list of areas that have worked, could work and be scaled up or transferred is identified and discussed. This study concludes that mainstreaming agricultural mitigation and adaptation into agricultural development programs, enhancing local capacity, and considering different stakeholders' needs are major experiences for successfully financing sustainable agriculture under climate change.

Key words: finance, climate change, agriculture, developing countries

INTRODUCTION

Hundreds of millions of people have been suffering from food insecurity and hunger. The total number of undernourished people in the world reached 925 million in 2010 (FAO 2010b). Most of the world's hungry live in developing countries. Moreover, the global food security is likely facing even greater challenges in the coming decades. According to FAO's estimates, the global food production must increase by 70% in the first half of this century to meet the growing food demands of a world population that is expected to surpass 9 billion in 2050 (FAO 2009). However, the growth of agricultural productivity has been falling. For example, average annual growth rate of cereal yield has decreased from about 2-3% in the 1970s and 1980s to 1-2% in recent decade (World Bank 2007).

Agriculture and food security may even face more challenges under climate change. By 2050, it is projected that developing countries may experience a decline of between 9 and 21% in overall potential agricultural productivity as a result of global warming (FAO 2009). In addition to the long term change of climate, global and regional weather conditions are also expected to become more variable than at present, with increases in the frequency and severity of extreme events (IPCC 2012). Such long term climate change and extreme weather events will bring greater

Received 15 October, 2013 Accepted 9 January, 2014
Correspondence HUANG Ji-kun, Tel: +86-10-64889440, Fax: +86-10-64856533, E-mail: jkhuang.ccap@igsnrr.ac.cn

doi: 10.1016/S2095-3119(13)60698-X

fluctuations in crop yields and local food supplies and higher risks of food insecurity (FAO 2009; IPCC 2012), particularly in developing countries such as China (Holst *et al.* 2013; Wang *et al.* 2013).

To what extent the impacts of climate change on agriculture will highly depend on whether such impacts can be countered by investments in agriculture. Even ignoring climate change, the required amount of investment in agriculture in developing countries will be tremendous and must be greatly increased to address the food insecurity issues (FAO 2009). Considering climate change, it is expected that much more additional efforts are needed in the coming decades.

However, investment in agriculture is not promising. It is estimated that the current investment and commitment to invest fall far short of the requirements which are necessary to meet the growing needs, especially in the developing world (Islam 2011). In addition, there has been a decline in the share of the agricultural sector in the foreign aid. For example, while the share of aid to agriculture in total aid increased from 13.0% in 1973-1975 to 23% in 1979-1981, it has started to decline continuously since mid-1980s (Table 1).

The international community has called for incorporating climate change adaptation into national development plans (World Bank 2010a). In the food and agriculture sector, IPCC (2012) and FAO (2007) has highlighted some practices for adaption to climate change. However, all those adaptations need large amount of investment to implement in developing countries on the ground.

While agriculture is the most sensitive and vulnerable sector to climate change, it is also one of major contributors of greenhouse gas (GHGs) emissions (IPCC 2007b). Projections indicate that these emissions will increase if agricultural development will be continued under a ‘business-as-usual’ model. According to the data released by IPCC, agriculture accounted for 13.5% of global GHGs in 2004 (IPCC 2007b).

Mitigation and adaptation, however, obviously need investment. Recently, with rising awareness of consequence of climate change, while climate change is likely to approach international and national action plans, the design and implementation of effective mitigation and adaptation strategies in agriculture is still at its infancy. The measures to implement the plans and actions are not clear. A series of questions need to investigate. How agricultural mitigation and adaptation plans could be funded (including both domestic finance and foreign aid)? What kind of financing in agricultural mitigation of and adaptation to climate change has been shown to be worked well in real world? What are the programs that have not work well but could work with appropriate improvement? And what finance practices are scalable (be scaled up in the same region) and transferable (be successfully transferred from one region to other regions)?

The overall goal of this paper is to examine how finance can be used to achieve the joint objectives of development, mitigation and adaptation in agriculture in developing world. The analysis is based on a literature review of overall finance and successful finance practices. As a review paper, the primary limitation to this approach is that the financial mechanism and the effects and scales of finance programs can not be explicitely examined because there is little information related to these issues in the literatures. The paper is organized as follows. The next section provides overview of financing

Table 1 Average annual bilateral and multilateral agricultural and total aid[1)]

Aid	1973-1975	1979-1981	1991-1993	2000-2002	2003-2005	2006-2008
In US$ billion (constant 2007 price)						
Bilateral agriculture commitments	3.4	6.7	5.4	3.0	4.0	3.4
Multilateral agriculture commitments	2.1	4.7	2.4	2.0	2.3	2.1
Bilateral plus multilateral agriculture commitments	5.5	11.4	7.8	5.1	6.3	5.5
Total aid to all sectors	42.5	50.5	69.7	92.9	104.8	42.5
In percentage (%)						
Bilateral agriculture commitments	7.9	13.2	7.8	5.4	3.3	3.8
Multilateral agriculture commitments	5.0	9.3	3.4	2.8	2.2	2.2
Bilateral plus multilateral agriculture commitments	12.9	22.5	11.2	8.1	5.4	6.0
Total aid to all sectors	100	100	100	100	100	100

[1)] Sources: OECD/DAC and OECD/CRS, various years. Cited from Islam (2011).

sustainable agriculture under climate change. Sections 3 and 4 present potential areas for financing mitigation of and adaptation to climate change, respectively. We discuss the cases that have worked in practices or could work and the cases that may be scaled up in the same region and transferred from a region to another. The last section concludes and discusses policy implications.

FINANCING AGRICULTURE UNDER CLIMATE CHANGE

Overall financing agriculture

Agriculture has been largely under-invested. A global assessment of agricultural development by the World Bank concluded that insufficient investment in agriculture was one of primary causes of falling agricultural productivity since the 1980s (World Bank 2007). Lack of incentive, largely due to low agricultural prices and market failure, to invest in agriculture came from both public and private sectors.

Until the recent global food crisis, investment in agriculture through foreign aid had also experienced a declining trend in the past two decades. For example, according to OECD, while average annual foreign aid to agriculture, including bilateral and multilateral agricultural aid measured in constant 2007 price, increased to US$11.4 billion in 1979-1981, it had decreased to US$7.8 billion in 1991-1993 and US$5.5 billion only in 2006-2008 (Table 1). Measured in the relative term, aid to agriculture accounted for 22.5% of total aid to all sectors in 1979-1981; it reduced to 5.4% in 2003-2005. Although there was a recovery during the global food crisis period (2006-2008), the share of aid to agriculture in total aid was only 6.0% (Table 1).

Financing agriculture is going to face much more challenge in the future. To increase global agricultural production by 70% by 2050, it is estimated that net investments to agriculture must top US$83 billion per year, which is about 50% higher than current levels (FAO 2009).

Climate change funds for agriculture

Facing the challenges of climate change, international communities have initiated several global-level funds for "climate finance" in developing countries (NEPAD Secretariat 2009). Climate finance has been raised through both bilateral and multilateral channels. Under the United Nations Framework Convention on Climate Change (UNFCCC), three multilateral funds have been established to address climate-related needs and are managed by the Global Environment Facility (GEF). They are the Adaptation Fund, the Least Developed Countries Fund, and the Special Climate Change Fund (SCCF). Moreover, climate change funding initiatives outside of the UNFCCC (non-Convention Funds) have been also rising. These funds are used either in general areas or specific areas (e.g., forest) to address both adaptation and mitigation challenges. Despite of recent climate change funds are emerging, they are still far away from the funds needed to effectively mitigate and adapt to climate change (World Bank 2009a).

However, current climate-related financial flows to agriculture (e.g., adaptation and mitigation) in developing countries cover only a tiny fraction of the total climate change funds (Climate Focus 2011). By 2008, the average total aid on agriculture was less than US$6 billion (Table 1), yet considering annual agricultural adaptation investment needs are about US$7 billion (Nelson *et al*. 2010), climate finance is unlikely to meet most of developing countries' mitigation and adaptation needs.

On the other hand, it is estimated that the potential increase in global investment flows on agriculture, forestry and fishers will reach US$14 billion per year by 2030, of which US$7 billion per year was anticipated in developing countries (SEI 2008). However, the projections for agriculture mitigation costs will reach at about US$20 billion in 2030. The amount of investment flows on agriculture will be significantly less than the expected mitigation and adaptation needs for agriculture (Louis 2007).

FINANCING MITIGATION OF CLIMATE CHANGE IN AGRICULTURE

The extent of mitigation of GHGs emission from agriculture depends on potential and marginal cost of

Table 2 Potential areas for finance in mitigation of climate change in agriculture in developing world[1)]

Areas for finance in mitigation	Work	Could work	Scalable	Transferable
Reduce nitrous oxide emissions from soils: For examples, improve efficiency of fertilizer uses through better technology extension service and training		+++	+++	++
Reduce methane from ruminants and paddy field				
(1) Reducing methane emission from ruminants by reducing animal number in degraded grassland		+	+	+
(2) Reducing methane emission from paddy field through better farm management	++		+++	++
Reduce CO_2 emission from soil				
(1) Soil carbon sequestration through injection		++	+	+
(2) Soil carbon sequestration through conversion of land use or conversation	++		++	+
(3) Reduce CO_2 emission from change farm practices such as less or zero tillage, alternative fallow and tillage, etc.	++		++	++
Reduce CO_2 emission from energy saving technology: For examples, saving energy use through water saving technology, less land preparation, etc.		++	++	++

1) +, ++ and +++ indicate that the probability of "what work" (column 1) or "could work" (column 2) or "what is scalable" (column 3) or "what is transferable" (column 4) for finance is small, middle, and large, respectively. The same as below. Source: Authors' analysis.

reducing the emissions. The main sources of emission from agriculture are nitrous oxide from soils, methane from enteric fermentation in ruminants and paddy field, and CO_2 from conversion of land uses (IPCC 2007b). Table 2 summarizes four major potential areas for financing in mitigation of climate change in agriculture.

Reduce nitrous oxide emissions from soils

Nitrous oxide emissions can be effectively reduced through increasing efficiency of nitrogen use and therefore a reduction of nitrogen application. While it has been a major transition of nitrogen use in many developed countries, it has not often occurred in developing world. For example, the overuse of synthetic nitrogen fertilizers was common in the UK in the 1970s and early 1980s with significant nitrous oxide emissions and other serious environmental consequences. Since then regulatory changes and investment have brought about improvements in nutrient management and agricultural technology that have allowed application rates of synthetic nitrogen fertilizer to stop increasing or decline slightly whilst crop yields have been rising (SAIN 2010). In developing countries, problem typically has been that farmers are credit constrained (or something else) and so they do not use enough synthetic nitrogen fertilizer. However, there are also exceptions such as China (Hu *et al.* 2007).

China is one of those countries in developing world that have high potential to reduce nitrous oxide emissions in crop production. The manufacture and use of synthetic nitrogen fertilizer is estimated to have accounted for about 10% of fossil energy use by the industrial sector and is near 5% of China's total GHGs emissions (SAIN 2010). While chemical fertilizers play an important role in increasing agricultural production and ensuring food security in China, farmers use much more fertilizer per hectare than do farmers in many other countries (Huang *et al.* 2012). Overuse of chemical N fertilizer is estimated to be at least 30% (SAIN 2010). If appropriate technology to improve N fertilizer utilization could be adopted by farmers, a decrease in overuse of N fertilizer could reduce China's total GHGs emissions by more than 1% and nitrous oxide emissions by 30% or more (SAIN 2010).

The pilot experiments found that a significant reduction of N fertilizer by farmers is possible through training programs. A serious of training programs conducted by the Center of Chinese Agricultural Policy (CCAP) of the Chinese Academy of Sciences, China show that delivering information and knowledge on the efficiency of N fertilizer to farmers can significantly lower N fertilizer utilization in grain production by 15-30% without affecting crop yield (Hu *et al.* 2007; Huang *et al.* 2008, 2012; Peng *et al.* 2010). Improving efficiency of N fertilizer application is a clear win-win action with both economic and environmental benefits.

Reducing nitrous oxide emissions from improving efficiency of N fertilizer utilization through training farmers based on the case study discussed above shows that it is workable and easily to be scaled up and transferred within the country. To make it works, it needs substantial investment in agricultural extension for training hundreds of millions of small farmers in China. However, transferability among countries may be limited because chemical fertilizer use in many other developing countries, particular the least developed countries, is often insufficient.

Reduce methane from ruminants and paddy field

Methane emissions are mainly from ruminants of animal and paddy field of crop sector. However, reducing methane emission from ruminants is not easy as it can only be reduced significantly by a reduction in animal numbers. As income increases in developing countries, demand for beef, mutton and dairy products is expected to grow and therefore methane emission from ruminants will continue to present an upward trend. Mainstreaming mitigation of methane into ruminant development could work mainly in those regions where overgrazing has been presented.

However, the possibility and potential to reduce methane emission from paddy field are high. Rice is fundamental for food security with approximately three billion people, about half of the world population, eating rice every day and about 144 million ha of land is cultivated under rice each year (IRRI 2010). The waterlogged and warm soils of rice paddies make this production system a large emitter of methane (Corton *et al.* 2000). Previous studies show that methane accounted for 21-22% of the additional greenhouse effect accumulated since industrialization and the atmospheric concentration of methane has shown an upward trend (Oberthür and Ott 1999; Tyler *et al.* 1999). The literature has shown that with appropriate irrigation and other farm management, methane emissions could be significantly reduced in paddy field (FAO 2010a). Improvements in water management practices can also lead to a decrease in methane emissions from rice paddy.

Mitigating methane emissions through new irrigation schemes in rice production in Bohol, the Philippines, is a good practice that has worked and could be scaled up and transferable. Bohol Island is one of the biggest rice-growing areas in the Visayas region of the Philippines. The region has experienced declining crop productivity under the existing irrigation systems. In 2007, the National Irrigation Administration started the Bohol Integrated Irrigation System (BIIS). The project included the construction of a new dam and the implementation of a water-saving technology, alternate-wetting and drying (AWD) developed by IRRI in cooperation with the national institutes. The BIIS project has showed that adoption of AWD facilitated an improved use of irrigation water so that the cropping intensity could be increased. Meantime, modification of irrigation regime also reduced methane emissions by about 40% (Wassmann *et al.* 2009). The project therefore generates multiple benefits in term of mitigating methane emission, reducing water use, increasing productivity, and contributing to food security (Bouman *et al.* 2007).

Several experiences could be learnt from the BIIS project. First, the project shows that if a program aimed at reduction of the GHGs emission, it should be well incorporated into agricultural development agenda. That is, how to incorporate GHGs emission objective into the existing agricultural development programs is critical important for a successful investment in agricultural mitigation of climate change. Second, adapting the technologies to local conditions is necessary. Third, involving local farmers, extension agents, and research institutions in technology design and dissemination is critical. Reducing methane from rice production is an area that should be considered as a high priority for both domestic and foreign finance.

Sequestrating CO_2 in and reducing CO_2 emission from soil

The Kyoto Protocol (1997) recognizes that net emissions may be reduced either by slowing the rate at which GHGs are emitted to the atmosphere or by increasing the rate at which GHGs are removed from the atmosphere through sinks. Agricultural soils are among the planet's largest reservoirs of carbon and hold potential for expanded carbon sequestration, and thus provide a prospective way of mitigating the increasing atmospheric concentration of GHGs (FAO 2001). It is estimated that soils can sequester around 20 Pg C in 25 yr, more than 10% of the anthropogenic emissions.

The main mitigation potential lies in soil carbon sequestration and preserving the existing soil carbon in arable soils. While cost effective technologies for soil carbon sequestration are still needed to be developed, there are a number of efforts that have been initiated to increase soil carbon sequestration or reduce CO_2 from conversing land uses. For example, in 2000 an international network was created, the DMC (direct sowing, mulch based systems and conservation tillage) now already includes 60 international and national institutions. The German government has established a partnership with the African tillage network. The French Agricultural Research Centre for International Development (CIRAD) joined this network and with different French cooperation funding set up a plan of action in several developing countries (Brazil, Madagascar, Mali, Laos, Tunisia), where different agricultural practices are tested with measurement of stocks and fluxes of CO_2 and N_2O emission sat benchmark sites.

Here we would like to introduce the Three Rivers Grassland Carbon Sequestration Project in Qinghai of China. It is a pilot project launched in 2009 using carbon financing to facilitate grassland restoration and increase livestock productivity. The project introduced improved grassland management practices. These practices included improving the rotation of grazing animals between summer and winter pastures, limiting the timing and number of grazing animals on degraded pastures, and restoration of severely degraded lands by replanting with perennial grasses and ensuring appropriate management over the long-term. Based on the changes of the livestock system from a low-input, low-output, degradation-inducing system to a high-productivity, sustainable land management system, the project made a contribution to carbon sequestration (FAO 2010a).

Sequestration in and reducing CO_2 emission from soil can also be enhanced by conservative management practices. For example, using alternative fallow and tillage practices can address climate change-related moisture and nutrient deficiencies. These measures have been widely used in areas such as Missouri, Iowa, Nebraska, Kansas (Easterling *et al*. 1993). Other examples include crop rotation with legumes or grass-clover leys, application of organic fertilizers, and less or zero tillage practices. In recent years, the World Bank has also strongly involved in diffusion and extension programs on direct sowing and associated practices in developing countries, especially in Brazil (FAO 2009). Conservation tillage in crop production is also popular in many parts of China (Wang *et al.* 2010b).

Table 2 summarizes three potential areas of reducing CO_2 emission from soil. Until now, soil carbon sequestration is rarely applied, but it could work if new technologies can be developed to lower the cost of implementation. In the coming years, more financing should invest in new technologies of soil carbon sequestration. Reducing CO_2 emission through land conservation has been working in small scale and can be scaled up and transferred in the regions where land is relatively abundant. The examples of investment mentioned above such as the DMC and the restoration of degraded grasslands in Qinghai of China could be scaled up in the countries where the projects are implemented. Soil carbon sequestration through conversion of land use and reducing CO_2 through changing farm practices such as less or zero tillage and crop rotation and organic fertilizer application should be encouraged. Carbon finance can be used to compensate the temporary loss of income from fallow or reduction in herd size.

Reducing CO_2 emission from direct energy use in farm operations

CO_2 emission can be reduced by saving energy use in farm operation (e.g., mechanization, land preparation and irrigation). Energy saving machinery and reducing land preparation by machinery through changing farm practices (e.g., zero tillage) as mentioned above are the examples that have been often discussed in the literature. Pumping water for irrigation also consumes large energy (Lal 2004; Mushtaq *et al*. 2009), however, to date this source of GHGs emissions has been largely neglected. A recent empirical study from China shows that emissions from groundwater pumping for irrigation reached 33.1 $MtCO_2e$ in the late 2000s, which was about half a percent of the national total emission (Wang *et al*. 2012). Direct saving energy such as gasoline, diesel and electricity used in farm operations could be achieved through investment in energy saving technologies in land preparation,

Table 3 Potential areas for finance adaptation to climate change in agriculture in developing world

Areas for finance in adaptation	Work	Could work	Scalable	Transferable
Investment in water conservation infrastructure				
(1) Develop/improve irrigation infrastructure	+++		+++	+++
(2) Water transfer or diversion projects among regions within a country	+		+	+
(3) Land contouring, terracing, water storage, etc.	++		++	++
(4) Development of integrated drainage systems	++		+++	+++
Investment in agricultural science and technology				
(1) Investing research to have better understanding of climate change impacts and vulnerability	++		+++	+++
(2) Developing new crop varieties. For examples, drought-resistant or flood-tolerant varieties	++		+++	+++
(3) Facilitating international technology transfer and local technology extension service	++		+++	+++
(4) Others (e.g., biotech, water saving technology, ecological and organic agriculture in some areas, etc.)	++		+++	+++
Investment in capacity-building program				
(1) Capacity to develop/implement adaption plans by national and local government	++		+++	+++
(2) Community planning and management capacity		++	++	++
(3) Improving farmers' capacity through farmers' associations (e.g., water users associations and cooperatives) and training	++		+++	++
Investment in risk management				
(1) Subsidized agricultural insurance		++	++	++
(2) Natural disaster release and food aid program	+++		+++	+
(3) Early warning and information systems to provide timely weather predictions and forecasts	++		+++	+++
(4) Restore the natural capacity to buffer climate impacts	++		++	++

irrigation, harvest, storage, and transportation.

FINANCING ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE

Facing with the global warming, adaptation through appropriate measures and investment is essential. In this section, based on the review of literature and various adaptation programs and practices, we summarize four broad categories of agricultural adaptations to climate change. Under each category, we present successful adaptation projects or practices that have been implemented in developing countries in recent years and areas that finance could work and there is possibility to scale up and transfer in the future (Table 3).

Investment in water conservation infrastructure

Investment in water conservation infrastructure is one of primary instruments to improve agricultural productivity and a priority financing area for agricultural adaptation to climate change in the developing countries. The change of climate and its variability influences many aspects of the society, of which, the concerns on the impacts of climate change on water security have been growing. In recent years, numerous reports have provided assessments of the potential impacts of climate change on global and regional water resources and conclude that the impacts are going to be significant in many parts of developing world (e.g., Shiklomanov 2000; Arnell 2004; Shen *et al*. 2008). More importantly, the pressure of climate change on water will lead to significant socio-economic losses.

In this paper, we identify four specific areas of investments in water conservation infrastructure that have been and could be considered for financing agriculture under climate change. They are irrigation infrastructure, water transferring or diversion project, land terracing and water storage, and integrated drainage infrastructure (Table 3). Irrigation infrastructure investment is the most prioritized area that international or regional financial organizations have been focusing on (Rosenzweig and Parry 1994). The other three areas in water conservation infrastructure related to agriculture have also attracted increasing attention in investment (Easterling 1996). Developing and improving reservoirs and dams, improving the water storage capacity, construction of water saving facilities such as canals, pump stations, construction of recharge/irrigation areas, and development of water drainage system all can mitigate the risk of flooding and drought, increase domestic water supply and agricultural productivity, and smooth the impacts of climate change in both short run and long run (World Bank 2010b).

In financing water conservation infrastructure under climate change, there are a number of successful examples. Here, we use an investment project as a case to illustrative how climate change adaption investment program can be effectively incorporated into the traditional irrigation project in China. The Mainstreaming Climate Change Adaptation in Irrigated Agriculture is a project implemented by the World Bank and China in 2008-2010 and supported by the GEF-managed SCCF and focused in the Huang-Huai-Hai River Basin (3H Basin), a major grain production region and also one of the most serious water shortage regions and vulnerable to climate change in China. The project is to help mainstream climate change adaptation measures, techniques, and activities into the national Comprehensive Agricultural Development (CAD) Program which is China's largest national investment program in irrigated agriculture (Conrad and Li 2012).

The project consisted of three parts with different targets. The first part identified and prioritizes different adaptation measures. The second part was the demonstration and implementation of adaptation measures. This component was to introduce, demonstrate and implement the specific adaptation measures in selected demonstration areas, and adjust and integrate appropriate adaptation measures into the implementation of the Third Irrigated Agriculture Intensification Loan Project (IAIL3) of China, in order to reduce vulnerability to climate change in the 3H Basin. Finally, the third component was the mainstreaming adaptation into national CAD program and institutional strengthening. The component aimed at integrating and mainstreaming climate change adaptation into the national CAD program includes a series of capacity building, technical assistance, knowledge sharing, public awareness activities, and preparation of a national climate change adaptation plan for CAD by State Office of CAD, with the cooperation of Chinese Academy of Sciences (CAS), the National Development and Reform Commission (NDRC), China and Ministry of Finance (MOF), China.

The project has created a first lie of defense in five provinces across the 3H Basin by exploring and demonstrating how the achievements of IAIL3 and other CAD initiatives can be safeguarded against climate change impacts. It introduced climate change adaptation activities into a wide range of ongoing IAIL3 activities and promoted the mainstreaming of adaptation into the CAD program. The project also found that the key to resilience is increased local ability (e.g., establishing water users associations and farmer associations) to react to changing circumstances. Through the SCCF and IAIL3 projects, communities have been better informed about climate threats – but, more important, their ability to keep and raise that level of information and use it as a basis for future coping choices is increased.

The experience of aid for improving the adaptation to climate change in agriculture is scalable and transferable. Factually, in view of the success of the project on the mainstreaming climate change adaptation in irrigated agriculture, the World Bank approved another loan of US$80 million (Water Conservation Project II) to China in 2012-2017 to help improve agriculture water management and to increase agriculture water productivity and incomes for 1.3 million farmers in Ningxia Hui Autonomous Region, Hebei and Shanxi provinces, China (Conrad and Li 2012; World Bank 2012).

As climate change adaptation in water conservation is consistent with agricultural productivity growth and sustainable agriculture, financing adaptation to climate change can play an important role in this area (Table 3). Besides the case of mainstreaming climate change adaptation in irrigated agriculture in 3H Basin presented above, there are a number of cases in financing irrigation and drainage infrastructure under climate change that can be scaled up with both domestic and foreign aid (FAO 2010a; World Bank 2010a) . The experience gained from the current investment programs in irrigation and infrastructures could also be transferred from one region to another with similar risks from climate changes. On water diversion and land terracing projects, there could be some roles for domestic and foreign investment but long term environmental implications of these kinds of projects should be investigated prior to making any action plan.

Investment in agricultural science and technology

Technology will have to be a primary source of agricultural growth in the future. In the coming decades, the world is expected to use less natural resource to produce much more food. In developing countries, according to an FAO (2009) report, 80%

of the production increases are projected to come from increases in yields and cropping intensity in the first half of 21st century. In land scarce countries, almost the whole of the production increases would be achieved through yield improvement. However, improving agricultural productivity is expected to face greater challenge under climate change (World Bank 2007).

Financing climate change in agricultural technology is essential as the research capacity in developing world is general low. Table 3 lists four major investment areas, including investing research to have better understanding of climate change impacts and vulnerability, developing new crop varieties that could be better adapted to climate change, facilitating international technological transfer and accession to new technologies, and others (for examples, innovation and adoption of modern biotechnology and water conservation technology in developing countries as well as ecological farm and organic agriculture in some areas where there is rising internal or external demand).

Understanding the impacts of climate change on agriculture is pre-condition for making any meaningful adaptation plan and investment. However, impacts of climate change on agriculture are complicated and uncertain. There are direct impacts of climate change such as the impacts on crop growth or yield, cropping system, soils, pests and diseases, and water supply and demand as well as animal production, there are also indirect impacts of climate change on agricultural prices and therefore production, consumption, trade, income, food security, and man and woman' likelihood, particular the poor (IPCC 2007a; FAO 2008). Moreover, the impacts differ among regions and over time. While impacts of climate change and appropriate adaptation strategies have become hot research topics, more efforts and resources are still needed for the studies in developing world.

Investment in research to develop drought-resistant or flood-tolerant varieties is often considered as an appropriate area for financing agriculture under climate change. Recognizing the difficulties of developing varieties for the poor and of distributing technologies to the poor under unfavorable environment, the Rockefeller Foundation initiated a multi-years and multi-countries program to support research and technology transfer of drought-tolerant rice in Asia in 1998. On research, the Foundation invested in numerous types of research in Asian countries such as China, India, and Thailand as well as in the International Rice Research Institute. On technology transfer, Rockefeller Foundation also helped to provide training and networks for scientists, capital for improved screening facilities on experiment stations, and invested in the diffusion of drought tolerant rice. Pray *et al.* (2011) show that the program has generated drought-tolerant varieties already grown by farmers in India, China and Thailand. In other countries in Asia, new varieties are in the testing stage. If these drought-tolerant rice varieties could be largely adopted by farmers in Asia, it is expected that they could improve farmers' ability to mitigate the risk resulted from climate change, particular from the extreme drought event.

The Drought Tolerant Maize for Africa (DTMA) is the other successful story of investment in agricultural science and technology. The project was jointly funded by the Bill & Melinda Gates Foundation, the Howard G. Buffett Foundation, USAID, and the UK Department for International Development and has been coordinated by the International Maize and Wheat Improvement Center (CIMMYT) and the International Institute for Tropical Agriculture (IITA) since 2006 (la Rovere *et al.* 2010). Recent studies suggest that the return to the investment of this project is impressive high. Farmers in the 15 countries covered in this study have already accessed to seed of 34 drought tolerant varieties and hybrids by 2012 (DTMA 2012). The yields of drought tolerant maize advantage over normal varieties have been improved by a range of 3-34%, depending on the severity of actual drought, which has significantly improved farmers' income, household food security and local food supply. An impact assessment report by la Rovere *et al.* (2010) shows that "at the most likely rates of adoption, based on several recent studies and expert advice, drought tolerant maize can generate US$0.53 billion from increased maize grain harvests and reduced risk over the study period, assuming conservative yield improvements."

Investing in technology transfer is the other area that could not only improve agricultural productivity but also facilitate farmers' adaptation to climate change. Traditionally, most of technology transfers have followed North-South cooperative framework. Agricultural technological transfers have also been arranged by international organizations such as FAO, World Bank and CGIAR (formerly the Consultative Group on International Agricultural Research). While these channels of investment are important and should be enhanced in the future, the recent South-South cooperative programs in technology transfer are encouraging.

In recent years, the emerging countries such as Brazil, China and India have attempted to develop their collaborations in agricultural technology with other South countries in Africa and Asia. One of these South-South cooperative programs worth to mention is the China-Africa agricultural technology program. China has established 14 agro-technical demonstration centers (ADCs) by 2012. Currently, China is constructing the other six ADCs in Africa. In 2012 there were more than 100 senior agricultural experts dispatched to 33 African countries (e.g., Morocco, Sierra Leone, Namibia). Moreover, more than 4 200 agricultural officers and agricultural experts from African countries had been trained in China in 2004-2011. While the impacts of China-Africa agricultural technology program are yet to be evaluated, the South-South cooperation does provide an avenue of new foreign aid to improve food security in the developing world and mitigate the adverse impacts of climate change.

To facilitate South-South cooperation, FAO launched South-South Cooperation (SSC) Initiative in 1996 and has facilitated the implementation of numeral SSC agreements. The SSC Initiative is mainly aimed to support country and regional-level action on food and nutrition security. In this area, by 2012 FAO has facilitated the fielding of more than 1 500 SSC experts and technicians to demonstrate how hunger and malnutrition can be reduced and productivity can be improved through adoption of new technologies and reduce year-to-year production variability due to extreme weather events (FAO 2012).

Other major investment areas in agricultural technology include biotechnology, water saving technology, and technologies supporting ecological agriculture (Table 3). Recent investment on biotechnology by the Bill & Melinda Gates Foundation in CGIAR, Africa and South Asia for improving food security and poverty reduction in the less developed countries is impressive. Kostandin *et al*. (2009) documented the ex-ante impact of transgenic research to mitigate drought in maize, rice, and wheat rain-fed areas of India, Indonesia, Bangladesh, Philippines, Kenya, Ethiopia, Nigeria, and South Africa. Their results showed that the biotech drought tolerant crops are "very promising for the millions of poor in the more marginal rain-fed agricultural areas of developing countries." Water saving technology is also a potential area that required more funding from foreign aid (Howden and Meinke 2003). In Senegal, in responding to increasing desertification under climate change, IFAD supported a successful project on drip irrigation (World Bank 2010a). There are also some programs aimed at developing ecological farm and organic agriculture (Tirado and Cotter 2010).

In sum, there are substantial rooms for investment to assist developing countries to generate, scale up and transfer agricultural technology under climate change. More domestic finance and foreign aid are needed to invest on agricultural technology adaptation as presented above. Investment in scaling up within a country and transferring technologies among developing countries also require new investment because agricultural performance is often subject to local production environment and the impacts of climate change also vary among regions and countries.

Investment in capacity-building programs

There is a rising call for increase of investment to improve capacity of developing countries adaptation to climate change, but little meaningful investment has been made. Adaptive capacity covers a wide range of issues such as adaptability, coping ability, planning capacity, management skill, robustness, flexibility, and resilience (Smit and Wandel 2006). Based on the literature review and personal interviews with experts and officials, Table 3 presents three key areas which we consider to be paid more attention for finance in the future. These include: 1) investment to improve the national and local government capacity in developing and implementing their adaptive strategy and plan in both the long run and short run; 2) investment to improve local community's ability of adapting to climate change and the extreme weather events in the short run; and 3) investment to improve farmers' adaptation capacity to the extreme weather shocks or national disasters through training and/or establishing self-managed organizations (e.g., farmers' associations and water users associations (Wang *et al*. 2010a; Conrad and Li 2012).

As examples, here we introduce some successful cases on capacity-building program. One case is the Mainstreaming Climate Change Adaptation in Irrigated Agriculture project in 3H Basin in China mentioned early. The capacity-building has been made for decision makers in designing their national and provincial development programs that integrates climate change adaptation strategies. In addition, the project also improved agricultural water management capacity of irrigation management staff, water use association, and farmers through participatory irrigation management and training programs. The other example is about improving food security through capacity-building in fighting against natural disaster programs by the European Commission (EU Focus 2010). The capacity building programs include sharing knowledge and expertise, ability to flight against natural disasters, and improving agricultural productivity. To date these programs have covered a number of developing countries such as Burma, Ethiopia, Mongolia, and Philippines and improved the capacity of poor people in combating food insecurity related to climate change.

Investment in risk management

Adaptation to climate change to some extent is to better manage risks resulted from climate variability or the extreme weather events. While these risks are not new as agriculture has been developed under these situations in its long history, there is evidence of increasing frequency and severity of climate variability and the extreme weather hazards (IPCC 2007c). Therefore climate-related risk management should build on and enhance existing disaster risk management efforts. These efforts include all forms of activities, such as structural and non-structural measures to avoid or prevent and mitigate adverse effects of hazards (Howden *et al.* 2007).

In this paper, we identify five major areas of investments in risk management related to climate change (Table 3). They are: 1) subsidized agricultural insurance program; 2) market based private insurance program for some of agricultural products; 3) mitigating the impacts from climate risks through disaster release and food aid program; 4) restoring the natural capacity to buffer climate impacts; and 5) early warning and information systems to provide timely weather forecasts.

Roles of domestic and foreign aid differ among these five areas. Disaster release and food aid programs are traditional measures that have helped millions of poor to mitigate their impacts from the nature disasters. These foreign aid and supports have worked well in mitigating the impacts of climate related hazards. They have been regularly used by WFP, FAO, UNDP, and other organizations of the United Nations, major international and regional development banks and donors, private sector, individual country, humanitarian agencies, and NGOs.

Agricultural insurance is an area that needs substantial finance in developing countries. Currently, crop and livestock insurance programs are highly subsidized by government and have been mainly implemented in developed countries (Simithers 1998; OECD 2011). In developing countries where farmers are normally more vulnerable to natural disasters than those in developed countries, but they often receive little subsidized agricultural insurance from government due to finance constraint. Market-based private agricultural insurance is also rare in developing world because most of farms are small-scale, and private insurance companies normally are lack of incentive to operate the costly insurance for millions of small farmers. On these regards, financial mechanisms and public policy should be deployed strategically through instruments that leverage private capital and exploit opportunities to create enabling conditions for their investments in agricultural insurance.

Early warning and information systems related to climate and crop production have provided useful information for national decision making on agricultural production and marketing. For example, FAO has developed its Global Information and Early Warning System on Food and Agriculture and, through this system, also improved its crop forecasting methodology to supply updated information on crop conditions in developing countries (FAO 2007). More efforts may need to transfer and invest this system to developing countries.

Here we introduce a recent study on the roles of disaster warning information service on mitigating impacts of extreme weather (drought) in China (Chen *et al.* 2013). Over the past two decades, drought has resulted in an annual grain production loss of more than 27 million tons in China (MWR 2010). Based on large-scale field surveys conducted in six provinces in China, Chen *et al*. (2013) examined farmers' practices when they face drought in crop production and then identified the major factors that affect farmers' decision on whether or not to take adaptation measures against drought. Their analysis showed that the government disaster information services such as releasing early warning and preventing information to farmers significantly facilitate farmers' decision to take adaptation measures against drought. In the studies areas, about 40% of villages can access to this disaster information service, while others can't. Econometric analysis shows that after controlling for all other effects, the farmers who can access to this service have much higher probability to take appropriate adaptation measures and therefore significantly reduce their yield losses due to drought. Additionally, they also showed that the social capital of farm households has significantly positive effects on their adaptation capacity against drought (Chen *et al.* 2013).

National financing institutions, donors and climate change funds recently also initiate pilot programs to restore the natural capacity to buffer climate impacts. For example, in Sri Lanka, International Fund for Agricultural Development (IFAD) and the GEF are supporting a program to rehabilitate three key coastal ecosystems along the tsunami-devastated east coast. In eastern Morocco, the World Bank sponsored a rehabilitation program that has improved rangeland productivity and soil cover, regenerated medicinal and aromatic plants, and improved soil water infiltration (World Bank 2009b). These projects not only increase local capacity to coping with climate change but also enhance agricultural productivity and improve farmer's livelihood.

CONCLUSION

While agriculture is one of major sources of GHGs, it is also the most sensitive and vulnerable sector to climate change. Agriculture development is going to face great challenge in meeting global food security and is expected to face even greater challenge under climate change. Mitigation of and adaptation to climate change for sustainable agriculture need substantial investment.

This paper examines how to finance mitigation and adaptation in agriculture in developing world. The results show that agriculture is much under invested and both domestic and foreign aid has not increased appropriately to maintain sustainable agriculture in developing countries. While recent climate change funds are emerging, little fund has been actually raised.

Raising climate change fund is important, and effectively using the fund is equally important. Recently, funding agencies and donors have been trying to explore innovative approaches in agricultural mitigation of and adaptation to climate change in developing countries. The review of literature and case studies show that there are a wide range of areas in mitigation of and adaptation that need substantial financing and investment. Major cases on agricultural mitigation of and adaptation to climate change that have worked or could work in developing countries are examined at the same time. A list of areas that could be scaled up or transferred is identified and discussed.

We identify four general categories of mitigation measures that are suggested to be potential areas for financing agricultural mitigation. They include reducing nitrous oxide emissions from soils (e.g., improve efficiency of fertilizer uses through better technology extension service and training), reducing methane from ruminants and paddy field, soil carbon sequestration through conversion of land use or conversation, reducing CO_2 emission from changing farm practices (e.g., zero tillage), and reducing CO_2 emission from energy saving technology. In each category, we also list major areas for interventions. Some of these areas could be scaled up and/or transferred, but the extent of scale-up or transferability differs among different mitigation measures.

The proposed finances for agricultural adaptation to climate change also cover four major categories. They include investment in water conservation infrastructure (e.g., irrigation, water transferring, land terracing, water storage, and integrated drainage systems), investment in agricultural science and technology (e.g., better understanding of climate change impacts and vulnerability, new crop varieties, international technology transfer and local technology extension service, biotechnology and water saving technology), investment in government, community and farmers' capacity to adapt to climate change, and investment in risk management (e.g., agricultural insurance, natural disaster release and food aid program, early warning and information systems, and restore the natural capacity to buffer climate impacts). Many of the above investment have been working in practices and could be scaled up and transferred to other regions with appropriate domestic finance and foreign aid.

In sum, to finance agriculture successfully under climate change, it needs to consider the joint objectives of development, mitigation and adaptation in agriculture. Mainstreaming agricultural mitigation into global and national climate change mitigation action plans and mainstreaming agricultural adaptation into the existing agricultural and rural development programs are essential for a successful finance.

Acknowledgements

The authors acknowledge the financial support of the National Basic Research Program of China (973 Program, 2012CB955700), the World Institute for Development Economics Research of United Nations University (UNU-WIDER), and the International Development Research Center (107093-001).

References

Arnell N W. 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change*, **14**, 31-52.

Bouman B, Lampayan R M, Tuong T P. 2007. *Water Management in Irrigated Rice*: *Coping with Water Scarcity*. The International Rice Research Institute, Los Baños, Philippines.

Chen H, Wang J, Huang J. 2013. Policy support, social capital and farmers' adaptation to drought in crop production of China. *Global Environmental Change*, **24**, 193-202.

Climate Focus. 2011. Carbon market and climate finance for agriculture in developing countries. In: *Report for Agriculture & Carbon Market Assessment*, *DFID Climate Change*, *Agriculture and Food*. Climate Focus North America Inc., Washington, D.C., USA.

Conrad B, Li Q. 2012. *Building a Line of Defense Against Climate Change*: *From Reactive Coping to Adaptive Capacity in China's Irrigated Agricultural Development*. The World Bank, Washington, D.C., USA.

Corton T M, Bajita J, Grospe F, Pamplona R, Wassmann R, Lantin R S. 2000. Methane emission from irrigated and intensively managed rice fields in Central Luzon (Philippines). *Nutrient Cycling Agroecosystems*, **58**, 37-53.

DTMA (Drought Tolerant Maize for Africa). 2012. Five years of addressing the needs drought tolerant of smallholder farmers in Africa. In: *DTMA Brief*. International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya.

Easterling W E, Crosson P R, Rosenberg N J, McKenney M S, Katz L A, Lemon K M. 1993. Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) region. *Climate Change*, **24**, 23-61.

Easterling W E. 1996. Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology*, **80**, 1-54.

EU Focus. 2010. *The EU and Food Security*. The Delegation of the European Union to the United States, Washington, D.C.

FAO (Food and Agriculture Organization). 2001. Soil carbon sequestration for improved land management. In: *World Soil Resources Reports 96*. FAO, Rome.

FAO (Food and Agriculture Organization). 2007. Crop and food supply assessment mission to Ethiopia. In: *Special Report for Global Information and Early Warning System on Food and Agriculture*. World Food Programme, FAO, Rome.

FAO (Food and Agriculture Organization). 2008. *Enabling Agriculture to Contribute to Climate Change Mitigation*. FAO, Rome.

FAO (Food and Agriculture Organization). 2009. *How to Feed the World in 2050*. FAO, Rome.

FAO (Food and Agriculture Organization). 2010a. "*Climate-Smart*" *Agriculture*: *Policies*, *Practices and Financing for Food Security*, *Adaptation and Mitigation*. FAO, Rome.

FAO (Food and Agriculture Organization). 2010b. *The State of Food Insecurity in the World: Addressing Food Insecurity in Protracted Crises*. FAO, Rome.

FAO (Food and Agriculture Organization). 2012. *Report of The Secretary-General on Transfer and Dissemination of Environmentally Sound Technologies*. FAO, Rome.

Holst R, Yu X H, Grun C. 2013. Climate change, risk and grain yields in China. *Journal of Integrative Agriculture*, **12**, 1279-1291.

Howden S M, Meinke H. 2003. Climate change: challenges and opportunities for Australian agriculture. In: *Proceedings of the Conference on Climate Impacts on Australia's Natural Resources*: *Current and Future Challenges*. Standing Committee on Natural Resource Management, Queensland, Australia, Canberra. pp. 53-55.

Howden S M, Soussana J F, Tubiello F N, Chhetri N, Dunlop M, Meinke H. 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 19691-19696.

Hu R, Cao J, Huang J, Peng S, Huang J, Zhong X, Zou Y, Yang J, Buresh R J. 2007. Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China. *Agricultural Systems*, **94**, 331-340.

Huang J, Hu R, Cao J, Rozelle S. 2008. Training programs and in-the-field guidance to reduce China's overuse of fertilizer without hurting profitability. *Journal of Soil and Water Conservation*, **63**, 165-167.

Huang J, Xiang C, Jia X, Hu R. 2012. Impacts of training on farmers' nitrogen use in maize production in Shandong, China. *Journal of Soil and Water Conservation*, **67**, 321-327.

IPCC (Intergovernmental Panel on Climate Change). 2007a. Climate change 2007: Impacts, adaptation and vulnerability. In: *Contribution of Working Group II to the Fourth Assessment Report of IPCC*. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 2007b. Climate change 2007: Mitigation of climate change. In: *Contribution of Working Group III to the Fourth Assessment Report of IPCC*. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 2007c. Climate Change 2007 – the physical science basis. In: *Contribution of Working Group I to the Fourth Assessment Report of IPCC*. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change). 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Special Report. Cambridge University Press, Cambridge.

IRRI (International Rice Research Institute). 2010. *Rice in the Global Economy*: *Strategic Research and Policy Issues for Food Security*. The International Rice Research Institute, Los Baños, Philippines.

Islam N. 2011. Foreign aid to agriculture – Review of facts and analysis. In: *IFPRI Discussion Paper 01053*. International Food Policy Research Institute, Washington, D.C., USA.

Kostandini G, Mills B F, Omamo S W, Wood S. 2009. *Ex ante* analysis of the benefits of transgenic drought tolerance research on cereal crops in low-income countries. *Agricultural Economics*, **40**, 477-492.

Lal R. 2004. Carbon emission from farm operations. *Environment International*, **30**, 981-990.

Verchot L V. 2007. Opportunities for climate change mitigation in agriculture and investment requirements to take advantage of these opportunities. In: *UNFCCC Report*. Climate Focus North America Inc., Washington, D.C., USA.

Mushtaq S, Maraseni T N, Maroulis J, Hafeez M. 2009. Energy and water tradeoffs in enhancing food security: A selective international assessment. *Energy Policy*, **37**, 3635-3644.

MWR (Ministry of Water Resources, P.R.China). 2010. *Bulletin of Flood and Drought Disaster in China 2010*. China Water Power Press, Beijing, China. (in Chinese)

Nelson G C, Rosegrant M W, Koo J, Robertson R, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, *et al*. 2010. The costs of agricultural adaptation to climate change. In: *Development and Climate Change Discussion Paper 4*. The World Bank, Washington D.C., USA.

NEPAD Secretariat. 2009. Financial resources and investment for climate change. In: *The Africa Partnership Forum Paper on Climate Change*. Addis Ababa, Ethiopia.

Oberthür S, Ott H E. 1999. *The Kyoto Protocol: International Climate Policy for the 21st Century*. Springer Verlag, Berlin.

OECD (Organization for Economic Co-operation and Development). 2011. *Managing Risk in Agriculture*: *Policy Assessment and Design*. OECD Publishing. [2013-01-06]. http://dx.doi.org/10.1787/9789264116146-en

Peng S, Buresh R J, Huang J, Zhong X, ZouY, Yang J, Wang G, LiuY, Hu R, Tang Q, *et al*. 2010. Improving nitrogen fertilization in rice by site-specific N management. A review. *Agronomy for Sustainable Development*, **30**, 649-656.

Pray C, Nagarajan L, Li L, Huang J, Hu R, Selvaraj K N, Napasintuwong O, Chandra Babu R. 2011. Potential impact of biotechnology on adaption of agriculture to climate change: The case of drought tolerant rice breeding in Asia. *Sustainability*, **3**, 1723-1741.

Rosenzweig C, Parry M L. 1994. Potential impact of climate change on world food supply. *Nature*, **367**, 133-138.

la Rovere R, Kostandini G, Abdoulaye T, Dixon J, Mwangi W, Guo Z, Bänziger M. 2010. *Potential Impact of Investments in Drought Tolerant Maize in Africa*. CIMMYT, Addis Ababa, Ethiopia.

SAIN (the China-UK Sustainable Agriculture Network). 2010. Improved nutrient management in agriculture – A neglected opportunity for China's low carbon growth path. In: *Policy Brief*. SAIN, Beijing.

SEI. 2008. Scoping paper for climate change adaptation in Africa for the ministerial session and expert group:

Segments of the dialogue on climate adaptation. In: *African Ministerial Conference on Environment*. SEI Africa, Tanzania.

Shen Y, Oki T, Kanae N, Hanasaki N. 2008. Projection of future world water resources under SRES scenarios: Water withdrawal. *Hydrological Sciences*, **53**, 11-34.

Shiklomanov I A. 2000. Appraisal and assessment of world water resources. *Water International*, **25**, 11-32.

Smit B, Wandel J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16**, 282-292.

Smithers C. 1998. Crop insurance and farm management. Msc thesis, Department of Geography, University of Guelph, Guelph, Ontario.

Tirado R, Cotter J. 2010. *Ecological Farming*: *Drought-Resistant Agriculture*. Greenpeace Research Laboratories, Greenpeace International, the Netherlands.

Tyler S C, Ajie H O, Gupta M L, Cicerone R J, Blake D R, Dlugokencky E J. 1999. Stable carbon isotopic composition of atmospheric methane: A comparison of surface level and free tropospheric air. *Journal of Geophysical Research*, **104**, 13895-13910.

Wang J X, Huang J K, Yan T T. 2013. Impacts of climate change on water and agricultural production in ten large river basins in China. *Journal of Integrative Agriculture*, **12**, 101-108.

Wang J, Huang J, Zhang L, Huang Q, Rozelle S. 2010a. Water governance and water use efficiency: The five principles of WUA management and performance in China. *Journal of the American Water Resources Association*, **46**, 665-685.

Wang J, Huang J, Zhang L, Rozelle S, Farnsworth H F. 2010b. Why is China's blue revolution so "blue"? The determinants of conservation tillage in China. *Journal of Soil and Water Conservation*, **65**, 113-129.

Wang J, Rothausen S, Conway D, Zhang L, Xiong W, Holman I, Li Y. 2012. China's water-energy nexus: greenhouse-gas emissions from groundwater use for agriculture. *Environmental Research Letters*, **7**, 014035.

Wassmann R, Jagadish S, Heuer S, Ismail A, Redoña E, Serraj R, Singh R K, Howell G, Pathak H, Sumfleth K. 2009. Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. *Advances in Agronomy*, **101**, 59-122.

World Bank. 2007. *World Development Report 2008*: *Agriculture for Development*. The World Bank, Washington, D.C., USA.

World Bank. 2009a. *Monitoring and Reporting on Financial Flows Related to Climate Change*. The World Bank, Washington, D.C., USA.

World Bank. 2009b. *Morocco – Country Partnership Strategy for the Period FY2010-13*. The World Bank Report No. 50316-MA, Washington, D.C., USA.

World Bank. 2010a. *Economics of Adaptation to Climate Change*: *Synthesis Report*. The World Bank, Washington D.C., USA.

World Bank. 2010b. *World Development Report 2010: Development and Climate Change*. The World Bank, Washington, D.C., USA.

World Bank. 2012. *China – Third Irrigated Agriculture Intensification Project and Mainstreaming Climate Change Adaptation in Irrigated Agriculture Project*. Report No: ICR500. The World Bank, Washington, D.C., USA.

(Managing editor WENG Ling-yun)