Chapter 13
Climate Change Adaptation and Agrichemicals in the Mekong Delta, Vietnam

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Abstract Since the implementation of economic reforms in 1986, the Mekong Delta has experienced an extensive transformation process in its agricultural sector. This transformation has been characterized by agricultural intensification, the enhanced use of agrichemicals (fertilizer, pesticides), and emerging concerns for human health and the environment. The predicted impacts of climate change such as sea level rise, greater seasonal variability in precipitation and river flows, and elevated temperature and CO_2 concentration will all likely also influence the agricultural landscape and thus agrichemical use. Against the background of the anticipated climate change impacts in the Mekong Delta, this chapter aims to draw a scenario for future agrichemical use and attendant environmental problems. This scenario is achieved through a review of the main climate change-mediated drivers for agrichemical use, with a focus on land-use changes and changes in pest and disease patterns. In addition, the chapter identifies possible adaptation measures that may be implemented by the agricultural sector in the Mekong Delta and explores the potential environmental effects of these adaptation strategies.

Keywords Adaptation • Agrichemicals • Agriculture • Climate change • Mekong Delta

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13.1 Introduction

13.1.1 Physical Conditions and Agriculture in the Mekong Delta

The Vietnamese portion of the Mekong Delta covers an area of 4.06 million ha and is home to 17.7 million people, of which 79% live in rural areas (GSO 2008). It is a flat and low-lying area (<4.0-m above mean sea level) with a complex network of rivers and channels. The hydrology of the Delta is influenced by tides from the South China Sea and to a lesser extent from the Gulf of Thailand. The climate is tropical monsoonal with a rainy season from May to October and a dry season from November to April. Average annual temperature is about 27°C. Mean annual rainfall is about 1,600 mm, of which more than 80% falls during the rainy season (Statistical Office of Can Tho City 2000, 2005, 2008). During this period, a large part of the Delta is inundated. In the dry season, the low discharge of the Mekong, tides from the South China Sea and from the Gulf of Thailand, and high water extraction rates cause salinity intrusion in the Delta (White 2002).

To date, the hydrology of the Delta is largely managed by sea dykes, embankments, sluice gates, and pumping stations used for irrigation purposes. These large-scale hydraulic structures have been established mainly to control floods in the upstream part of the Delta and saline intrusion in the coastal areas. The consequence has been a largely human-regulated water regime. Existing hydraulic control structures, soil fertility and productivity, and, since the implementation of economic reforms in 1986, agricultural modernization have successfully stimulated rice production in Vietnam. Once a rice importer, it is now the world's second largest rice exporter. Similarly, rapid growth of the aquaculture sector has enabled Vietnam to become one of the largest fishery export countries in the world (FAO 2008). To date, 63% of the Delta is used for agricultural production, a very high rate compared with 28% for the entire country and 38% for the Red River Delta (GSO 2008). The region supplies 55% of national rice production (2007, all three rice seasons) and 82% of the farmed shrimp production (GSO 2009a, b). This rapid growth was a direct result of intensification processes such as the introduction of three annual rice seasons instead of two in some areas of the Delta (Dang and Danh 2008) and the adaptation to the production of exportable goods (e.g., *Pangasius*). This success is based to a large extent on the enhanced use of agricultural chemicals such as fertilizers and pesticides in rice production (Meisner 2005; Dang and Danh 2008) and the use of processed feed, pesticides, and veterinary drugs in the aquaculture sector (Trong et al. 2002). The drawbacks of this development are widely recognized as environmental degradation and pollution (IRIN 2009), concerns about drinking water and food safety (Holland 2007; Neubacher 2007), failures in meeting international standards of exported goods (Yen 2006), and health concerns (Margni et al. 2002; Dasgupta et al. 2007).

13.1.2 Climate Change in the Mekong Delta

Climate change is an ongoing process in the Mekong Delta. Possible impacts can already be projected by reviewing the recent climate history of the Delta. In the past 10 years, the Delta experienced high floods in 2000, 2001, and 2002, including the historic high flood in 2000 and drought for four successive years (especially the drought combined with low river flow in 2004 and early 2005). Most recently, in early 2010, the Delta was hit by a severe drought with saline intrusion into areas which were never before impacted.

The Vietnamese Ministry of Natural Resources and Environment (MONRE) published recent climate change scenarios for Vietnam in 2009. According to the medium emission scenario [IPCC SRES B2, reference period 1980–1999 (IPCC 2007)] the annual mean temperature will increase by 0.6°C in South Vietnam by 2030. Temperature increase will be 0.5–0.6°C during the dry season (Dec–May) and 0.6–0.7°C during the wet season (Jun–Nov). For the same area and period the annual rainfall is predicted to increase by 0.4%. However, in the dry season (Dec–May) annual rainfall is predicted to decrease by 4.3% in average, while rainfall will increase during September–November by 1.7% on average, which will lead to enhanced seasonal variability. Sea level is predicted to rise by 17 cm by 2030 and 75 cm by the end of the century. Sea water intrusion in the southwest coastal provinces already influences 1.77 million hectares of land (45% of the region). Although sea water intrusion into low lying deltas is a natural phenomenon, sea level rise, climate influenced changes in river flow, and human activities such as increasing water extraction from aquifers of the Mekong Delta are predicted to expand greatly the area affected by sea water intrusion. A sea level rise of 75 cm by the end of the century would lead to an inundation of about 7,600 km² – that is, 19% of the Delta (MONRE 2009).

Using a regional climate model (PRECIS) under IPCC SRES A2 scenario (high emission scenario, reference period 1980s) Tuan and Suppakorn predict a higher average maximum and minimum temperature and a longer and drier dry season (2011, this publication, Chap. 11). Annual precipitation is predicted to decrease by 10–20%. The altered precipitation pattern would lead to an altered flood regime with an increasing annual maximum water depth and a wider area of the Delta impacted by floods. At the same time, the flooding period will be shorter in the upstream provinces of the Delta as compared to the 1980s.

13.1.3 Possible Climate Change Impacts on Agriculture

Croplands occupy about 18% of the earth's surface and are increasingly exposed to threats from climate change induced climatic variability. Changes in air temperature and rainfall pattern and resulting increases in the frequency and intensity of drought and flood events, as well as altered hydrological cycles, will all have implications for agricultural productivity (FAO 2007). A considerable number of publications discuss important expected impacts of climate change on agriculture such as changes in the production area, the migration of agro-ecosystems, physiological effects on crops influencing yield quantity and quality (Peng et al. 1995; IRRI 2007; Wassmann and Dobermann 2007; Battisti and Naylor 2009; Gregory et al. 2009; Padgham 2009), changes in soil and water resources, and the changing occurrence and severity of pest and disease outbreaks (Coakley et al. 1999; Chakraborty et al. 2000; Chakraborty and Pangga 2004; IRRI 2007). Despite the large number of studies of particular aspects of climate change impacts (e.g., on CO_2 fertilization), our understanding of climate change impact on agriculture is still limited. One of the reasons is that the processes described above all interact with one another through feedback loops. For example, water scarcity causes plants to be water-stressed and thus more susceptible to pests and diseases. In addition, climate change will likely trigger adaptation, i.e., changes in agricultural practices (e.g., planting more flood resistant or salt resistant varieties of rice, implementing better irrigation practices, increased use of agrichemicals). Some of these adaptation measures will likely have unwanted effects such as increasing water pollution and soil degradation. Holistic studies, which consider a broader range of changing parameters and possible feedback loops, are thus far largely missing. Additionally, there is a lack of information on climate predictions at the smaller scales (field scale), where most of the yield-relevant processes take place. We therefore face large uncertainties when attempting to determine the effects of climate change on aquiculture. Being aware of these limitations, this chapter aims to sketch a scenario for future agrichemical use and attendant environmental problems by reviewing the main climate change-mediated drivers for agrichemical use with a focus on land-use changes and changes in pest and disease patterns. In addition, the chapter identifies possible adaptation measures that may be implemented by the agricultural sector in the Mekong Delta and explores the potential environmental effects of these adaptation strategies.

13.2 Possible Impacts of Climate Change on Agrichemical Use

Climate change may influence agrichemical use in many ways. Temperature and rainfall patterns have been shown to directly influence the amount of pesticides used in the US (Chen and McCarl 2000). Climatic conditions also influence the efficiency of agrichemicals directly by, for example, influencing their retention time on the foliage. Climate change also affects the net area of crop production by inundation and saline intrusion in the Delta.

13.2.1 Possible Impacts on the Production Area in the Mekong Delta

Production area may be influenced by climate change in direct and indirect ways. Sea level rise (SLR) and changing flood patterns will result in a direct net loss of arable land in the Delta. A sea level rise of about 30 cm is expected by 2050 and of about 75 cm by the end of the twenty-first century based on a medium emission scenario (MONRE 2009). Inundations in the Mekong Delta caused by 20–40 cm of SLR would significantly affect all three rice cropping seasons by limiting the number of rice crops per year (Wassmann et al. 2004; White 2002). Beside inundation and permanent salinization, temporary saline intrusion will increasingly affect arable land. As a result of saline intrusion into arable land, salt will need to be washed-out with fresh water at the beginning of the rainy season. With an increasing extent (duration and area) of saline intrusion, it might prove difficult to reduce salinity which could result in salinity accumulation in soils. Saline intrusion was found to be the major factor leading to regional differences in rice cropping systems and land use patterns in the Delta (Kotera et al. 2008). Should there be no implementation of further structural adaptation measures, predicted inundation of about 19% of the Delta and increasing salinization of water and soil resources would lead to a significant limitation of land resources suitable for agriculture in the region. These limitations would likely lead to an enhanced pressure on the remaining arable land in terms of yield per hectare in order to maintain food and income (export) security which in turn would likely require further agricultural intensification with corresponding high pesticide and fertilizer use.

The Vietnamese government plans to undertake significant investments into the construction and upgrading of sea-dykes and sluice gates to respond to sea level rise (SRV 2008). Thus, predictions for the impacts of sea level rise on land use and agricultural production need to take into account a considerable number of technical adaptation measures. Such technical solutions are already applied in large areas of the Delta as a response to existing saline water intrusion. A series of dykes and sluice gates have been constructed in the Ca Mau Peninsula (southern part of the Mekong Delta) to enhance the production area of rice since 1993. The establishment of saline-intrusion control measures was a response to the Mekong Delta Master Plan (NEDECO 1993) and the Mekong Delta Water Resources Project's six provincial cross-boundary subprojects in the late 1990s (Evers and Benedikter 2009). The impacts of these measures on land use, management practices, and resulting impacts on the environment are already assessable. Reduced saline intrusion and the prolongation of the cropping season behind the sluice gates lead to progressive expansion of the area suitable for rice production and to intensification of the production by having two or three rice crops per year instead of one (Kam et al. 2001). This level of intensification increases the pressure on soil resources and favors pest outbreaks which then lead to drastically increased pesticide and fertilizer use. Since freshwater behind the sluices is limited and mainly stagnant in the dry season, water pollution by agrochemicals becomes a threat for human health, for aquatic ecosystems, and for agricultural production other than rice paddies. Aquaculture especially is affected by pollution with agrichemicals; this adds to the existing conflicts on water allocation between freshwater users for crop farming and brackish water users for shrimp aquaculture (Nhan et al. 2007). Additionally, leaching from acid sulfate soils tends to acidify the water behind closed sluice gates. In saline water-protected areas, acidic water and water scarcity in the dry season were found to be the limiting factors for rice production (Aizawa et al. 2007). Overall, intensification in agriculture behind water-control structures challenges the environmental sustainability of the Mekong Delta.

13.2.2 Possible Climate Change Impacts on Rice Plants

Influence of climate change, especially global warming and elevated CO_2 (ECO_2) on the growth and development of rice plants has been well documented (Baker et al. 1992, 1996; Peng et al. 1995; De Costa et al. 2006). Enhanced CO_2 concentrations alter physiological processes in rice plants such as photosynthetic rate or stomatal conductance. In an investigation, doubled CO_2 concentration from 330 to 660 μmol mol^{-1} increased total aboveground and root biomass and final yield due to an increase in net photosynthesis and tillering (Baker et al. 1996). These kinds of changes will have positive effects on rice production such as shortening the growth period by 10–12 days due to shorter vegetative phase and increasing the grain yield by 10–70% (Imai 1995; Allen et al. 1995; Ainsworth 2008) through carbon fertilization. However, global warming – without considering parameters such as carbon fertilization – is likely to influence rice production negatively (Baker et al. 1996; Peng et al. 2004; IRRI 2007) e.g., through more frequent occurrences of acute and chronic heat stress events for the plants (Ingram et al. 1995) or because of changes in evapotranspiration and the availability of water used for irrigation (Tao et al. 2008). Since global warming and ECO_2 are predicted to co-occur, investigations on the interactions between these two climatic variables are extremely important. Ingram et al. (1995) demonstrated that the interactions between CO_2 and temperature would be specific for rice varieties and production locations. For example, adverse effects of a warmer temperature coupled with enhanced CO_2 environments are likely to be greater for the tropics (in the Mekong Delta, for example) than for temperate regions. Benefits from the carbon fertilization process on rice can be overshadowed by a negative impact of higher temperature, which in turn leads to a greater sink demand due to increased growth and respiration rate (Gesch et al. 2001). In the sensitive development stages of rice such as the reproductive phase, higher night temperatures can significantly reduce fertilized spikelet percentage and consequently grain yield, even when the atmospheric concentration is doubled (Cheng et al. 2009). In comparison, ECO_2 coupled with higher temperature might lead to an increase in rice yield in sub-humid tropical climates (De Costa et al. 2006). The degree of response to climate change factors vary with rice cultivars (Shimono et al. 2009) and thus selection and breeding programs should consider adaptation qualities.

The impact of climate change on rice production has been extensively studied using simulation models (Horie et al. 2005), which has made it possible to predict changes at large scales. In an attempt to assess the impact of climate change in rice production in Asia, Masutomi et al. (2009) input future climate change scenarios based on the projections of many general circulation models (GCMs) for three SRES scenarios (18 GCMs for A1B, 14 GCMs for A2, and 17 GCMs for B1, reference period 1990s) into a crop model M-GAEZ and calculated the average change in rice production, taking into account the effect of CO_2 fertilization. The results showed that rice production would be affected in all atmospheric CO_2 scenarios and estimates of the impact of climate change significantly depend on the GCMs used. According to these simulations, rice production in Vietnam would decrease largely in the 2020s and 2080s but slightly increase in the 2050s for all scenarios used, although the degree of change in each period of these three SRES scenarios would be different.

In addition, climate change also affects plant pests and pathogens and agrichemical-use efficiency, and the inter-relationship between these factors would need to be taken into account for a more holistic assessment of climate change impacts on rice production.

13.2.3 Possible Impacts on Rice Pests and Pathogens

Damage caused by pests and diseases in general is one of the most important limiting factors in agriculture production. Yield losses due to pathogens and pests are estimated at around 16–18% of total worldwide production (Oerke 2006) of which losses to pathogens were estimated to around 220 billion US dollars (Agrios 2005). In rice production alone, global potential losses due to pathogens and pests account for 13–25% of attainable yield, and the actual losses vary considerably according to agro-ecological regions (Oerke 2006).

Numerous pests and pathogens cause different levels of damage to rice crops. The most common and important pests for rice are stem borers, brown planthoppers (BPH), rice leaf folders, and rice thrips (Pathak and Khan 1994). These pests can occur in one, several, or all stages of rice growth and cause great losses. Diseases with economic importance in rice are blast disease, sheath blight, sheath rot, brown spot, bakanae, bacterial leaf blight, and viral diseases, such as rice grassy stunt virus (RGSV). In the Mekong Delta, the most important pests and diseases in terms of economic loss are BPH, rice thrips, stem borers, leaf folders, rice blast and sheath disease, sheath rot, brown spot, and RGSV, as reported by the Plant Protection Department – Ministry of Agriculture and Rural Development (PPD – MARD).

Among the various factors affecting pest and disease incidence and development, weather conditions play a significant role and influence all stages of growth and development of host plants as well as the occurrence and severity of the disease (Chakraborty et al. 2000). The predicted changes in climate will likely alter the geographical and temporal distribution of plants, which in turn affect disease infection and development processes. Changes in temperature have significant effects on pest and disease distribution and development in most locations. Higher temperature favors population development of some pests and pathogens by increasing the number of life cycles per year. Higher temperature promotes plant growth in cool regions and thus provides more food and nutrient for pests and pathogens, whereas the impact is opposite in warmer locations. Thus, the effects will vary among different agro-ecological zones (Coakley et al. 1999). ECO_2 in the atmosphere will alter physiology and morphology of the host, resulting in changes in light interception, canopy structure, and microclimate, which will in turn affect disease epidemiology (Chakraborty et al. 2000; Ghini et al. 2008). Interactions between climate, plant host, and pathogens will determine the degree of impact on agriculture (Chakraborty and Pangga 2004), but will also be influenced by the effectiveness of applied management strategies (Chakraborty et al. 2000).

The effects of climate change on pests and diseases have been investigated in numerous regions of the world and these are reviewed in the following sections for some of the most important pests and diseases. However, studies on the effect of climate change on rice pests and diseases in Vietnam do not exist to the best of our knowledge.

13.2.4 Global Warming and Pests, Diseases – Examples

13.2.4.1 Rice Blast Disease

The impacts of global temperature change on rice blast disease *Pyricularia grisea* (sexual stage *Magnaporthe grisea*) in three agro-ecological zones, including the cool subtropics (Japan and northern China), subhumid and warm humid subtropics (southern China), and humid tropics (Philippines and Thailand) was studied by Luo et al. (1998a), using a combined simulation model (Coupling of CERES-Rice with BLASTSIM). The simulations suggested that temperature changes had significant impacts on disease development in most regions. In the cool subtropics such as Japan and northern China, warmer temperature resulted in more severe blast epidemics. In warm/cool humid subtropics, rising temperature reduced blast epidemics significantly. In contrast, lower temperature caused small difference in disease epidemics compared with currently prevailing temperatures. The effect of temperature change in the humid tropics was opposite to that in cool regions where daily temperature changes by –1°C and –3°C resulted in significantly more severe blast epidemics, and temperature increases of +1°C to +3°C reduced blast severity.

Using a similar simulation method, the effect of global temperature changes on risk of yield loss caused by rice blast disease was analyzed for five Asian countries (Japan, Korea, China, Thailand, and the Philippines). It was demonstrated that changes in temperature have a significant impact on the disease compared to that caused by changes in rainfall. The influence varied with agro-ecological zones but the disease would become more severe in cool, subtropical regions like Japan while the model predicted disease inhibition in humid tropics and subtropics such as in the Philippines (Luo et al. 1998b). As the Mekong Delta has a similar monsoon climate to the Philippines, a reduction of blast epidemics due to global warming would be expected. However, the interaction of global warming with other production factors such as ECO_2, land use, and pesticide-use patterns makes it difficult to predict the effects under real field conditions.

13.2.4.2 Rice Pests

Global warming would likely result in a redistribution and altered abundance of rice arthropod communities with a degree of influence depending on pest species and populations. A change in temperature can affect any stage of the life cycle of a pest, which in turn can affect pest survival, reproduction, and development. For example, adult survival of BPH remained unchanged between 25°C and 35°C but was significantly reduced at 40°C. It was demonstrated that warmer temperatures would increase BPH abundance in areas with temperatures below 30°C (Heong et al. 1995).

As temperature increases, insects that are directly limited by temperature will be able to expand to temperate regions rapidly. Insects of many tropical and subtropical species might move pole-ward from their current locations as long as their cold hardiness allows, because they usually lack diapause in their life cycles (Kiritani 2006). For example, it was predicted that the rice stem borer *Chilo suppressalis* would shift northward in Japan by about 300 km if the temperature rises by 2°C (Morimoto et al. 1998). Analysis of long-term insect population in Japan showed that an increase in winter temperature increased population of the rice stem borer and the green rice leafhopper (*Nephotettix cincticeps*). The degree of change was much larger for the green rice leafhopper than for the rice stem borer, indicating a difference in the number of generations per year (Yamamura and Yokozawa 2002). The rice stem borer is an important rice pest in the Mekong Delta (DARD Dong Thap 2006), but the effect of global warming on this pest under Mekong Delta conditions has not yet been studied. A study carried out by Kiritani (2006) in Japan predicted that rice stem borer may spread northward and will be more prevalent in the cooler time of the year, such as during the winter–spring crop (December to March) in the Mekong Delta.

Many rice pests are vectors for destructive viral diseases. Hence, changes in pest population due to global warming also influence the prevalence of some viral diseases associated with those pests. For example, the geographical occurrence of the rice strip virus disease (RSV) which is transmitted by the small brown planthopper (*Laodelphax striatellus*) could be shifted due to the synchronization of planthoppers with the cultivation of rice plants. The occurrence of this disease, therefore, is determined by the interactions among three organisms: the rice plant, RSV, and the vector. Global warming will change the time when planthoppers occur by accelerating their development. Thus, it is expected that the geographical area that is potentially vulnerable to disease prevalence will shift (Yamamura and Yokozawa 2002).

13.2.4.3 Natural Enemies of Pests

Global warming may also work in favor of natural enemies by increasing the number of generations more than in their host species irrespective of the type of agroecosystem. For example, the attack rate of *Cyrtorhinus lividipennis*, a natural egg predator of the BPH, increased in temperature range between 20 and 32°C. Thus, it was predicted that in areas with such temperatures there will be an increase in predation on BPH eggs. However, in areas with temperatures higher than 35°C – such as in the Mekong Delta in most times of the year – the ability of *C. lividipennis* to influence BPH population could be reduced (Song and Heong 1997). Biological control utilizing native natural enemies is expected to become a more important control tactic in the future (Kiritani 2006).

13.2.4.4 Brown Planthopper (BPH) and Rice Grassy Stunt Virus (RGSV)

In the last 5 years, the Mekong Delta has witnessed severe outbreaks of BPH and the virulent disease RGSV. BPH outbreaks occurred in almost all provinces in the Mekong Delta and caused infections of hundred thousand of hectares. The percentage of infected area of rice caused by some major rice pests and diseases in the Mekong Delta in the period 2004–2009 is illustrated in Fig. 13.1. There was a

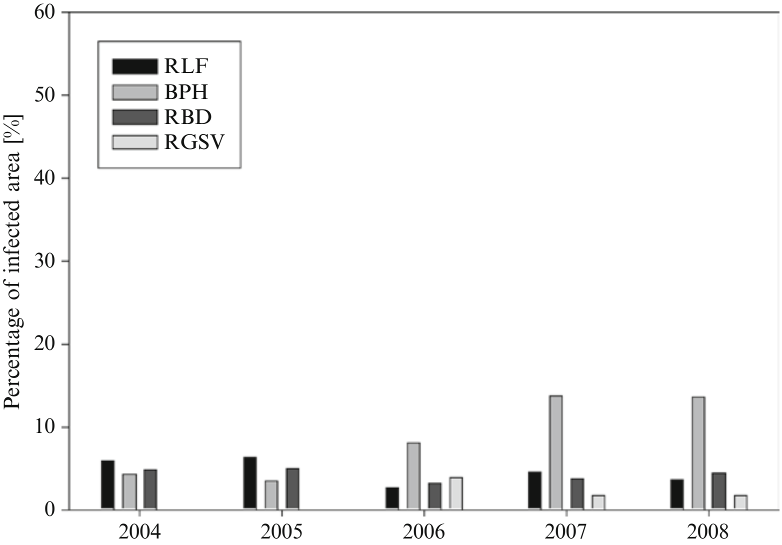

Fig. 13.1 Percentage of cultivated area affected by some important rice pests and diseases in Southern Vietnam in the period of 2004–2008. (Data collected by the Southern Plant Protection Centre). *BPH* brown planthopper, *RBD* rice blast disease, *RGSV* rice grassy stunt virus, *RLF* rice leaf folder

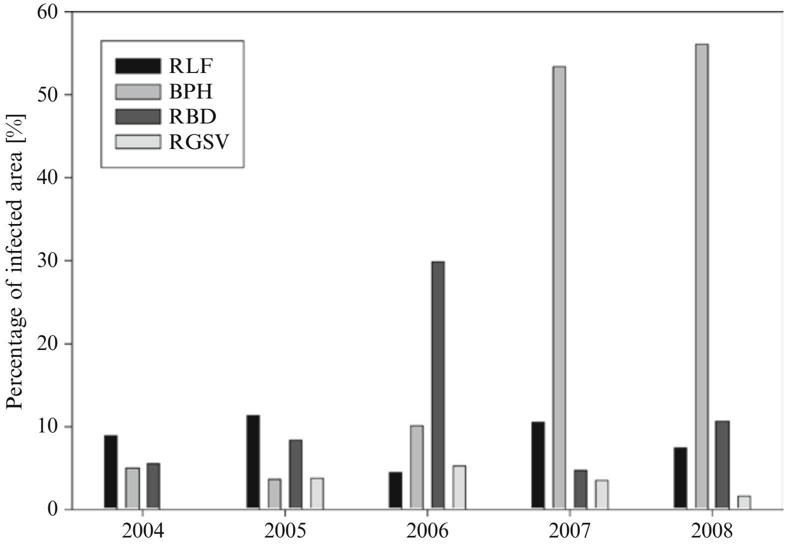

Fig. 13.2 Percentage of cultivated area affected by some important rice pests and diseases in Dong Thap province in the period of 2004–2008. (Data collected by the Department of Agriculture and Rural Development, Dong Thap province). *BPH* brown planthopper, *RBD* rice blast disease, *RGSV*, rice grassy stunt virus, *RLF* rice leaf folder

significant increase in the areas affected with BPH from 2006 to 2008. The viral disease RGSV also became prevalent in this period due to an increase in the area infected with BPH, the vector of the viral disease. Outbreaks of BPH and RGSV were even more severe in some provinces with intensive rice production such as Dong Thap, An Giang, and Tien Giang. Figure 13.2 refers to the percentage of infected areas caused by major pests and diseases of rice in Dong Thap province. The area infected by BPH increased drastically and reached 56% in the year 2008. Similarly, the area infected with RGSV also increased significantly.

The prevailing hot and humid weather in the Mekong Delta favors the development of BPH in general. However, under low population densities BPH is normally not considered as a pest, and the outbreak of this pest is generally rare (Heong 2008). Although climate change has often been quoted to play an important role in the recent severe outbreaks (Đào Xuân Học 2009), the reasons are probably manifold, and it is challenging to work out the share of climate change on these developments. First of all, intensive rice production with up to seven crops in 2 years creates a constant food supply for BPH. Second, management practices such as over-fertilization with urea, high seeding density, and the use of susceptible varieties favor pest development and distribution (Lam 2007). Third, intensive use of insecticides in the early stage of rice development harms natural enemies of BHP while developing a resistance to pesticides, and thus decreases the effectiveness of pesticides used (Heong et al. 2008). Fourth, extreme weather events such as abnormally low or high temperatures, severe rainfall, or drought periods may contribute to the pest outbreaks (Chakraborty et al. 2000). The more frequent occurrence of El Niño events, warmer temperature with a larger difference between minimum and maximum temperature in the Mekong Delta in general or in Dong Thap province in particular in the period of 2001–2008, was considered to play a role in the pest outbreaks (DONRE Dong Thap 2008). The strong northeast or southwest monsoon winds in 2006 also spread BPH to other uninfected areas (Agriviet.com 2008). In addition, interactions between two or more of the above mentioned factors can accelerate pest occurrence. For example, global warming can accelerate the life cycle of BHP and increase survival of nymphs' and adults' fecundity and egg hatch ability significantly, along with the higher nitrogen content of the rice host (Lu et al. 2005).

Similar severe outbreaks of BPH have been also observed in several rice growing regions of India and China in 2008. Recent abnormal weather patterns and the misuse of pesticides may have contributed to the unusual outbreaks of BPH (IRRI 2009). In Thailand, BPH outbreaks have caused significant yield losses in some rice-producing regions. Losses were estimated around 7–8 million tons of rice, which is equivalent to about 400 million US dollars in 2010 (excluding indirect costs like environmental pollution due to the enhanced use of pesticide) (Heong 2010). Results obtained from experimental and field research showed that BPH outbreaks are caused by the deterioration of ecosystem services which can be influenced by climatic events, drought or rainfall, pesticide applications, and agricultural practices (Heong 2008).

13.2.5 Elevated CO_2 (ECO_2)

The impacts of ECO_2 on pathogens are not easily determined due to the dynamic interactions between the host, the environment, and the pathogens (Ghini et al. 2008). In a recent review by Chakraborty and Pangga (2004), it was reported that of the 26 diseases studied, severity of 13 diseases would increase under ECO_2 whereas 4 remained unchanged and 9 would decrease. Lake and Wade (2009) demonstrated that doubled CO_2 concentration facilitated infection of the fungus *Erysiphe cichoracearum* (a causal agent of powdery mildew) on marrow whilst increased the susceptibility of the host to the pathogen infection through changes in stomatal density under controlled conditions. Barley powdery mildew was also in an earlier study demonstrated to cause more severe reduction in yield under higher CO_2 levels than the normal CO_2 concentration under controlled experiments (Hibberd et al. 1996). Some pathogens expressed higher fecundity or aggressiveness under elevated CO_2 environments (Chakraborty et al. 2000). In addition, ECO_2 or changes in temperature would also impact the resistance/susceptibility of the host.

The impact of ECO_2 on some important diseases of rice has been demonstrated in many studies. Rice plants grown under higher CO_2 concentrations were more susceptible to leaf blast than those in ambient CO_2, probably because of their lower leaf silicon content which may contribute to the increased susceptibility to leaf blast. The percentage of sheath blight diseased plants was also higher under ECO_2 condition compared to that under ambient CO_2 concentration. This was probably due to the higher number of tillers observed under ECO_2 concentration which may have increased the chance for the fungal sclerotia to adhere to the leaf sheath at the water surface (Kobayashi et al. 2006). Therefore, the positive effect of climate change on rice yield caused by carbon fertilization could be overshadowed by the negative influence of global warming on rice growth and more abundant and severe infestations of pests and pathogens. Most of the available studies have been conducted under controlled conditions; the effects might be different under field conditions (Ghini et al. 2008). Furthermore, most of the studies have been carried out on the effect of a single meteorological variable on the host or pathogen rather on the interactions between two or more factors (Coakley et al. 1999). Studies considering a combination of more than two climatic factors are not available. Based on the available information on the effect of climate change on rice pests and diseases elsewhere, it is difficult to draw any clear conclusions at the moment for the Mekong Delta. Therefore, comprehensive research needs to be carried out on this topic in the region.

13.3 Possible Impacts on Agrichemical Use Efficiency

Paddy rice production in the Mekong Delta increased steadily at a rate of 5.1% in the period of 1986–1995; pesticide use increased at a rate of 5% per annum. National demand for pesticides is around 50,000 tons, equivalent to about 500 million US dollars (BVSC 2010). Pesticide use in rice accounted for 65.5% of the total amount of pesticide use in agriculture, and insecticide use alone accounted for 85% of the total volume (Dung and Dung 1999).

Climate change will likely affect agrichemical use efficiency in several ways. First of all, warmer temperatures and high rainfall may change the dynamics of pesticide residues on crop foliage. High-rainfall intensity could reduce the retention of pesticide on the foliage by increasing wash-off rates (Schepers 1996). Higher temperature can reduce the effectiveness of certain classes of pesticides such as pyrethroids and spinosad (US GCRP 2009). The complex interaction between rainfall intensity, temperature, and host and disease will determine pesticide-use efficiency (Coakley et al. 1999). Statistical analyses of pesticide use in relation to higher temperature and rainfall in the US showed that the effect varied greatly among different crops. For some crops such as corn, cotton, soybeans, and potatoes, higher temperatures resulted in the increased use of pesticide. In contrast, the use of pesticides was reduced for wheat. More rainfall increased pesticide-usage costs for corn, wheat, soybeans, and potato (Chen and McCarl 2000).

Morphological and physiological changes in the host plants under changing climate would also have an impact on pesticide-use efficiency. Increases in canopy thickness and biomass under ECO_2 conditions would reduce the effectiveness of pesticides on the foliage and consequently would increase the amount of pesticide needed. Furthermore, changes in leaf morphology such as a thicker, epicuticular-wax layer on leaves could slow or reduce the uptake of pesticide and thus reduce pesticide-use efficiency (Coakley et al. 1999).

In general, the main climate drivers for changing pesticide efficiency would be most likely the predicted changes in rainfall intensity by causing an increased rate of pesticide applications to replace those removed from the plant surfaces and increased temperatures leading to faster degradation of the chemicals.

13.4 The Agrichemical Dimension of Climate Change Adaptation in the Mekong Delta

As reviewed in this chapter, climate change will likely decrease the area available for rice production in the Delta. As a consequence, food and income (export) security could be met only by increasing yields per unit of land (IPCC 2007). This will likely put the remaining production areas under pressure, which will lead to an intensification of agricultural practices – i.e., also via enhanced use of pesticides and fertilizers. This development could be amplified by direct negative impacts on crops and climate-driven changes in some host and pest/disease relationships leading to an increase in the occurrence and severity of some diseases and pests by a potentially decreasing efficiency of pesticides at the same time. Similarly, weeds that are adapted to hotter climates could potentially increasingly compete with crops (see e.g., Tungate et al. 2007 for an example from the US) leading to an increased use of herbicides. Our surveys conducted in 2008 and 2009 in the Mekong Delta revealed that farmers rely almost exclusively on chemical responses to any threats to their crops. This results in large amounts of pesticides applications as opposed to using alternative strategies such as integrated pest management (Toan et al. unpublished data). Thus again, the enhanced use of pesticides would be a likely response of the farmers to the expected yield losses induced by pests. These projections deserve attention since recent pesticide use and management practices in the Delta are already not sustainable from environmental and human health perspectives. Ongoing studies at two study sites in the Delta revealed that a broad range of recently-used pesticides is co-occurring at detectable levels in field discharges and channels used for irrigation, aquaculture, and personal hygiene throughout the year (Toan et al. 2009). The frequent detection of pesticides in the water systems of rural areas of the Delta indicates that surface water quality deserves special attention in these land-use settings, particularly because surface water often serves in rural areas as a drinking water source (GSO 2007).

However, surveys conducted in 2008 and 2009 showed that the improvement of water quality requires changes in farmers' practices in the use of pesticides and the management of pesticide waste (Toan et al. 2009). Farmers – not only in the Mekong Delta – tend to increase pesticide use in order to compensate for crop losses due to pests and diseases. This practice is economically not justified due to higher pesticide-use costs and the resulting pollution in the environment (Oerke 2006). Thus, investments in the training and education of farmers will be necessary to promote alternative management strategies and train farmers on effective and safe pesticide use. However, farmer schools and training in integrated pest management are already in place in the Delta and are strongly promoted by plant protection departments and extension offices. Although farmers usually claim to be aware of and apply these methods, their everyday practices show otherwise. The reasons for the gap between theory and practice are probably deep-rooted and should be overcome to enhance the impact of future training and education programs.

Beside the promotion of integrated pest management via training and education, further improvement in information generation and sharing will be necessary. This includes better seasonal and small-scale forecasts of weather together with crop models that can predict yield a few months ahead of the harvest. The information needs to reach the farm level possibly also via innovative communication ways such as text messages on mobile phones.

In terms of production areas, there is a need for a balance between protections of arable land on the one hand and the costs for the establishment of these protection measures (dykes, sluice gates) on the other hand. Protected areas need to have a long-term strategy to deal with the most probable enhanced pressure in terms of expected yield per land area. Soil exploitation and pest outbreaks are likely to occur if no adaptation strategies are put in place.

Concerning crops, the development of new rice varieties which are better adapted to a changing climate (e.g., more drought and/or salt tolerant varieties) and resist better to major pests and diseases such as BPH and RGSV would be advantageous with respect to decreasing or stabilizing pesticide demand. Also, an improvement in agricultural practices such as crop rotation instead of three rice crops per year would decrease the number of pest outbreaks by creating times where food and hosts are not available for pests.

For some regions a promotion of organic farming could be a viable adaption strategy and would reduce pesticide use at the same time. Organic farming tends to increase soil fertility and water retention capacity in the long run (Niggli et al. 2007). However, products from organic farming are generally more expensive to produce and thus the market capacity for these products will be most likely the limiting factor for their planting area.

While some of the above mentioned adaptation strategies will be likely taken up by farmers as a first-order response, other strategies need to be supported, facilitated, or even regulated. Table 13.1 summarizes the most likely climate change impacts, adaptation, and possible facilitation options in the agricultural sector.

Table 13.1 Selected adaptation options with a link to agrichemical use

Changing climate parameter	Possible impact	Possible adaptation at farm level	Possible impact of the adaptation on the environment	Facilitation, support, regulation
Increased frequency of extreme events (drought, heavy rains)	Crops more susceptible to pests and diseases	Increased use of pesticides, introduction of new pesticides	Negative impacts on water quality, biodiversity	Training, education on integrated pest-management, pest and disease-resistant crops
Increased mean temperatures, changes in rainfall patterns, humidity	Increased occurrence of diseases, pests, weeds, and vectors carrying diseases	Use of crop varieties resistant to pests and diseases	Positive impacts on water quality	Provide seasonal and small scale weather forecasts at farm level
	Increased occurrence of secondary infections			Improved pest and disease monitoring and surveillance
	Increased risk of severe outbreaks			Support pest predators and competitors e.g. through the use of field margins
Increased rainfall intensity	Reduced top soil quality due to increased runoff and soil erosion. Nutrient and pesticide loss	Increased use of fertilizers and pesticides	Negative impacts on water quality, biodiversity	Use of buffer strips to reduce runoff. Consider organic farming
	Reduced efficiency of pesticides (wash up from foliage)			Training on selection of pesticides used, integrated pest management, organic farming
Sea level rise	Inundation or salinization of soils and water recourses, loss of arable land	More saline-tolerant rice varieties and shrimp farming in the area of saline intrusion	Negative impacts on water quality, biodiversity	Balance the needs for shrimp farming and rice production, flexible water-management systems
		Agricultural intensification in the remaining area with enhanced use of pesticides and fertilizers		Crop rotation or rice-aquaculture instead of three crops of rice

13.5 Conclusions

The consequences of climate change will likely lead to increased pesticide use in the Mekong Delta. The significant limitation of arable land driven by inundation and soil salinization in the future would likely lead to an enhanced pressure on the remaining arable land in terms of yield per hectare. Rice production, it needs to be remembered, is a matter of national policy in Vietnam (Ryan and Garrett 2003). Yield optimization will in turn likely require further agricultural intensification with corresponding high pesticide and fertilizer use. On the other hand, the impacts of climate change will increase the risk for some pest and disease outbreaks, while decreasing it for others. The risk will be probably most pronounced when several influencing factors co-occur and lead to unanticipated outbreaks accompanied by growing uncertainty in the function of the production systems. One consequence, particularly in view of current practices and trends, will be an increase in agrichemical use and the resulting increased pollution of the environment in general and water systems in particular. It is thus timely to improve pest-management strategies in the Delta as one of many different approaches (development of new varieties, crop rotations, changes in farming systems, etc.) to adapt to the potential effects of climate change. The benefits would be immediate, resulting in more targeted pest management, reduced costs at the farm level, and reduced pollution of land and water systems. The latter would then directly reduce the exposure of humans and freshwater ecosystems, and therefore afford increased protection of the most vulnerable communities in the Delta who rely on the freshwater system for their everyday livelihoods. On the other hand, agricultural systems and prevailing pests and diseases may change more dynamically in the future. More research and policy attention will be required to be able to keep pace with the challenges the future will bring to agriculture in the Mekong Delta.

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