World Bank Regional Agricultural Pollution Study

An Overview of Agricultural Pollution in Vietnam: The Crops Sector

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An Overview of Agricultural Pollution in Vietnam: The Crops Sector

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CONTENTS

Figures

Tables

ABBREVIATIONS

1M5R	1 Must and 5 Reductions
3R3G	3 Reductions and 3 Gains
4c	Common Code for the Coffee Community
ai	Active Ingredients
AEZ	Agroecological Zone
As	Arsenic
ARP	Agricultural Restructuring Plan
AWD	Alternate Wetting and Drying
BC	Black Carbon
BHC	Benzene Hexachloride
CH	Central Highlands
CH_4	Methane
CL	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DAP	Diammonium Phosphate
DARD	Department of Agriculture and Rural Development
DDGS	Distiller's Dried Grains with Solubles
DDT	Dichloro-diphenyl-trichloroethane
DOH	Department of Health
DOIT	Department of Industry and Trade
ET	Ecological Technologies
F	Fluoride
FAO	Food and Agriculture Organization
FO	Farmer Organization
GAP	Good Agricultural Practice
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GM	Genetically Modified
GMP	Good Manufacturing Practices
GSO	General Statistical Office
H_2S	Hydrogen Sulfide
HCMC	Ho Chi Minh City
HH	Household
ICM	Integrated Crop Management
IGES	Institute for Global Environmental Strategies
INM	Integrated Nutrient Management
IPM	Integrated Pest Management

IUCN	International Union for Conservation of Nature
K	Potassium
K_2O	Potassium Oxide
MARD	Ministry of Agriculture and Rural Development
MDI	Mekong Delta Development Research Institute (at Can Tho University)
MOH	Ministry of Health
MONRE	Ministry of Natural Resources and Environment
MOIT	Ministry of Industry and Trade
MKD	Mekong Delta
NGO	Nongovernmental Organization
NH_3	Ammonia
NH_4NO_3	Ammonium Nitrate
NMHC	Non-methane Hydrocarbon
NO_x	Oxides of Nitrogen
O_3	Ozone
OC	Organic Carbon
P	Phosphorus
P_2O_5	Phosphorus Pentoxide
PPP	Public-Private Partnership
RI	Resistance Index
RRD	Red River Delta
SA	Ammonium Sulfate
SAN	Sustainable Agriculture Network
SO_2	Sulphur Dioxide
SRI	System of Rice Intensification
SRP	Sustainable Rice Platform
TSP	Total Suspended Particles
USAGIC	Global Investment Center, USA
VLCRP	Vietnam Low Carbon Rice Project
VOC	Volatile Organic Compound
WHO	World Health Organization
WTO	World Trade Organization

FOREWORD

Between July 2015 and December 2016, the World Bank carried out a regional study of agricultural pollution in East Asia with a focus on China, Vietnam, and the Philippines, in cooperation with each country's ministry of agriculture. This effort aimed to provide a broad overview of agricultural pollution issues associated with farming in these countries and the region: their magnitude, impacts, and drivers; and what is currently being done about these. It also sought to outline potential approaches to addressing these issues going forward. The study aimed to examine how the structural transformation of the agricultural sector and the evolving nature of agricultural production are shaping agricultural pollution issues and mitigation opportunities. It also set out to identify knowledge gaps, pointing to directions for future investment and research. Ministries of agriculture and environment are the study's primary audience. Its secondary audience consists of development organizations, industry associations, and other actors with an interest in sustainable agriculture, and environmental health and protection.

The "study" constitutes the totality of the work and includes multiple components, including national overviews of agricultural pollution for the three focus countries, thematic working papers, and an overall synthesis report. The present report corresponds to the national overview of agricultural pollution in Vietnam, and specifically, to the background paper on crop-related pollution. It provides a broad national overview of (a) the magnitude, impacts, and drivers of pollution related to the crop sector's development; (b) measures that have been taken by the public sector to manage or mitigate this pollution; and (c) existing knowledge gaps and directions for future research.

The report was prepared on the basis of a desk review of existing literature, recent analyses, and national and international statistics. It did not involve new primary research and did not attempt to cover pollution issues that arise in crop value chains more broadly, outside the farm gate—such as from processing, transportation, and the manufacturing of agricultural inputs and machinery. An earlier version of the report was circulated to stakeholders representing national government agencies, nongovernmental organizations (NGOs), and research institutions, and discussed at a stakeholder consultation workshop in December 2016. It was finalized by consolidating and addressing comments from various stakeholders and the World Bank task team.

This report was written by Tin Hong Nguyen and edited by Emilie Cassou and Binh Thang Cao.

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INTRODUCTION

1

1.1 Background

The agricultural sector is one of the key contributors to the Vietnamese economy. It shared approximately 20 percent of total Vietnamese gross domestic product (GDP) between 2010 and 2015 (GSO 2015). Agriculture in Vietnam includes crop systems, livestock, forestry, and fisheries. Of these, crop systems play an important role in national food security, poverty reduction, and livelihood opportunities generation to local inhabitants as well as for export earnings.

Vietnam's agriculture in general and crop production systems in particular are facing many problems and challenges. These include diseases, pests, and climate change impacts (that is, saline intrusion, drought, and so on). In addition, environmental problems such as land and soil pollution caused by farming activities are emerging issues. In crop production systems, soil pollution generally comes from excessive fertilizer application and pesticide residues. Water pollution is mainly due to discharge of agrochemicals and pesticides into canals and rivers. Air pollution (that is, greenhouse gas [GHG] emissions) is caused by farming activities and burning of residues and wastes.

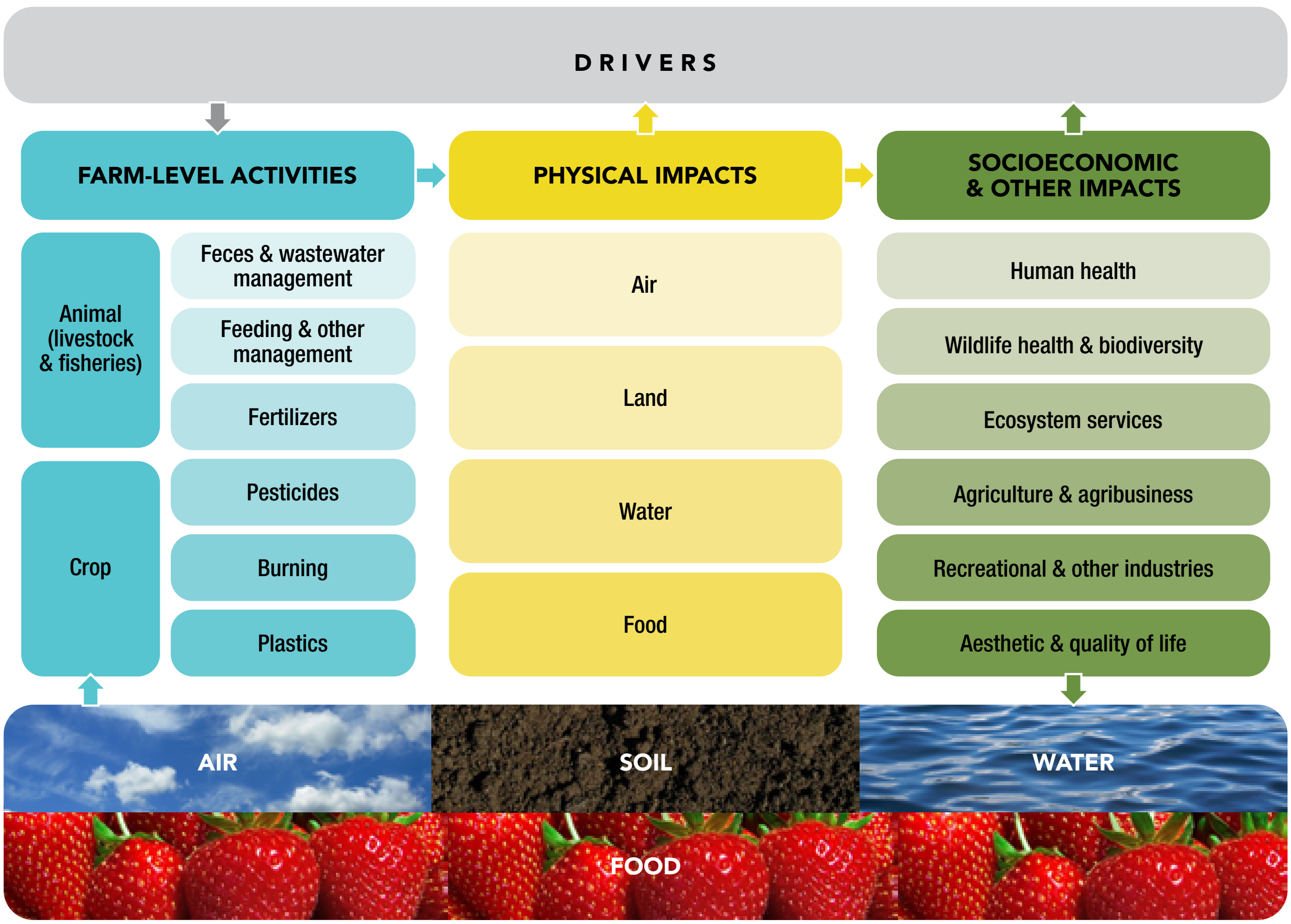
Studies on agriculture pollution so far are limited; therefore, a desk study on these aspects was necessary. This study aimed at providing a broad, national overview of pollution problems along with the primary food production in the crop subsector. First, the study broadly reviewed key pollution forms directly affecting land, water, air, and food products caused by farming activities in major food crops. The study then focused on selective crops, including pollution drivers, for (a) the excessive and improper use of fertilizers, (b) the excessive and improper use of pesticides, (c) other poor cropland management practices, and (d) burning practices of agricultural residues. Where appropriate, case studies were included to highlight key issues.

This paper is structured into seven main sections. Section 1 includes the background and analytical framework; Section 2 reviews the intensification and expansion of the agricultural sector through various development stages, with a special focus on selected crops of rice, maize, and coffee; Section 3 discusses the use of inputs in crop systems as well as waste management practices, with a special focus on the use of fertilizers and pesticides in the selected crops; Sections 4 and 5 review the physical and socioeconomic impacts (that is, water, soil, and air pollution and impacts on ecosystems and public health); Section 6 discusses the driving factors contributing and responding to agricultural pollution; Section 7 presents the solutions and knowledge gaps; and Section 8 summarizes the findings and recommendations. The primary audience of this study includes the Ministry of Agriculture and Rural Development (MARD), Department of Agriculture and Rural Development (DARDs), and Ministry of Natural Resources and Environment (MONRE), as well as NGOs, practitioners, and scientific communities.

1.2 Analytical framework

Figure 1 presents the analytical framework that guided this study.

Figure 1. Analytical framework



Note: Under socioeconomic and other impacts, wildlife health & biodiversity includes flora and fauna; ecosystem services include climate stability / climate change.

1.3 Findings and discussion

The literature review was structured around the following guiding questions:

- Key crop farming systems causing major pollution in Vietnam
- Crop waste management practices in each production system in relation to waste pollution
- Causes and impacts of crop pollution on physical and socioeconomic aspects
- Driving factors contributing and responding to pollution
- Knowledge gaps and measures to fulfil those gaps

CROP INTENSIFICATION AND EXPANSION

2

2.1 Changes in crop production systems in Vietnam

From the 1980s to the present, Vietnam's agricultural sector and crop production systems have evolved in four distinct stages. Many of these changes have been policy-led.

> **1960–1980s:** Before 1960, crop production was mainly traditional and extensive. This began to change with the Green Revolution in the 1980s, and when the 1986 sixth Party Congress of the Communist Party initiated sweeping economic reforms (*Doi Moi*). As part of broader reforms, the government allowed diversification of crop varieties. These changes helped Vietnam reduce hunger and to rapidly become an exporter of rice.
>
> **1990–2000s:** During this period, significant investments in irrigation systems and rural infrastructure were made to increase agricultural production both for export and domestic consumption. Many projects and programs on agricultural development were promulgated to reclaim poor-fertility and unused lands to expand rice farming. Intensification and specialization in crop production increased. Many places moved from two to three rice crops per year, helped by protective dykes. Farmers' income increased, food security ceased to be an issue for many households, and a rice surplus was exported. However, besides the positive economic gains, pollution associated with agricultural intensification and expansion also emerged.
>
> **2001–2010:** A key characteristic of this period was the high intensification of agricultural crops to increase production volumes to meet the demands of socioeconomic development. Crop production systems were maximized to meet export, national food security, and rural development goals. Policies on increasing crop production were issued particularly on breeding crop varieties with high-yield potential. At this stage, Vietnam became the world's third-

largest rice exporter. However, it did not come without costs. High agricultural intensification resulted in more serious pollution impacts on soil and water environments due to the excessive use of fertilizer and pesticides. Natural resource degradation, diversity reduction, and problems in soil fertility became more common than ever.

2010–present: Recognizing the above problems, the government starting placing more emphasis on the sustainability of agriculture. Diversification from rice and integrated farming systems have been encouraged to reduce pollution and natural resource degradation. Policies to control agricultural pollution were introduced. The Agricultural Restructuring Plan (ARP) was adopted to increase value added of agricultural products, focusing more on quality than quantity and getting more from less. Good agricultural practice (GAP) standards and climate-smart agriculture were introduced. Vertical and horizontal linkages between and within actors in crop value chains (such as production partnerships) were promoted. Markets for organic foods and food safety products started to grow. However, it is taking time to change farmer behavior with respect to the use of agro-inputs. At present, majority of farmers still use more inputs than required.

In the past 20 years, Vietnam's harvested area has increased steadily. This has resulted from both agricultural intensification and expansion. Cropped areas increased from approximately 7,300,000 ha in 1995 to 9,000,000 ha in 2014. The annual growth rate was about 1 percent (Table 1).

2.2 Main crop systems

Rice is the most important staple food in Vietnam, so the government always gives its highest priority to maintain the rice area to ensure food security for the country. Rice farming is also the main livelihood of rural people. In 2014, around 7.8 million ha of land were devoted to harvesting rice. The annual value of rice exports is around US$3 billion, which is about 20 percent of total agricultural exports. In the last few years, the government relaxed its control over land-use planning for rice, and this has allowed some unproductive rice land to be converted to other crops.

Maize is the second most important food crop with regards to harvested area, production, and rural livelihoods, especially in mountainous areas. It is also an important source of feed for livestock and aquaculture. This is an important crop in hunger elimination and poverty reduction programs. The grown area and production of maize in 2014 were about 1.2 million ha and 5.2 million tons, respectively. At present, maize production in the country satisfies only about 50 percent of demand; the remainder of demand is met through imports. Maize production is likely to increase in the coming years because government policies are promoting it to substitute part of the imported volume.

Coffee is the main economic tree crop and main source of rural income in the Central Highlands (CH). At present, the coffee area is reported to be over 600,000 ha, 90 percent of which is located in the Gia Lai, Dak Lak, Dak Nong, and Lam Dong Provinces. About one-third of existing plantations are aging and will require replanting or rejuvenation between now and 2020.

Table 1. Harvested area for food crops, 1995–2014

Unit: 1,000 ha

Agroecological zones (AEZs)	1995	2000	2005	2010	2014
Red River Delta (RRD)	1,336.3	1,359.5	1,274.6	1,247.8	1,211.6
Northern midlands and mountainous	823.0	922.3	1,033.5	1,127.5	1,204.3
North Central and South Central Coast	1,297.3	1,389.3	1,370.6	1,427.5	1,451.9
Mekong Delta (MKD)	3,212.7	3,964.9	3,861.2	3,983.6	4,284.6
Vietnam	7,324.3	8,399.1	8,383.4	8,615.9	8,992.3
Vietnam growth rate every five years (%)		**1.15**	**1.00**	**1.03**	**1.04**

Source: Based on GSO data.

Table 2. Key indicators for rice, maize, and coffee systems, 2014

Crops	Current harvested area (2014) (1,000 ha)	Future planned areas (2020)[a] (1,000 ha)	Production (1,000 tons)	Export value (US$, millions)	High inputs required	Job creation for local inhabitants	Environmental issues (agricultural pollution risks)
Rice[b]	7,813	7,000	44,975	2,950	√	√	√
Maize	1,177.5	1,200	5,191.7	Imported	√	√	√
Coffee[b]	550	550	1,224	2,752	√	√	√

Sources: Based on GSO 2015; MOIT 2015; MARD 2014.

Note: a. Data based on land-use planning projected to 2020 of MARD 2015; b. Data in 2013.

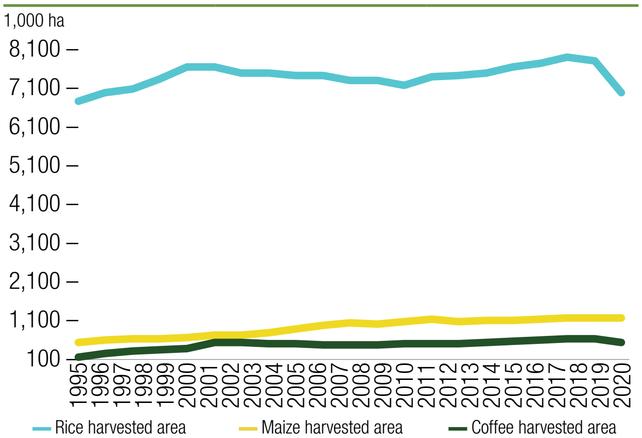
Rice, coffee, and maize were selected to be the focus of this study based on harvested area, production volume and value, the use of inputs, and coverage of different agroecological regions (Table 2). Other crops including fruit trees, vegetables, and tea are also important crops but were not the focus of the study. Additional information about the agricultural zones and major crop systems in the country is presented in the Annex.

In the past 20 years, the harvested area for rice, maize, and coffee has steadily increased. The rice-harvested area rose from around 6,765,000 ha in 1995 to 7,666,000 ha in 2000, and stabilized at 7,813,000 in 2014 (average growth rate was 0.76 percent per year). The maize-harvested area grew from around 556,000 ha in 1995 to 730,000 ha in 2000, before reaching 1,177,000 ha in 2014 (average growth rate was 0.04 percent per year). For coffee, the harvested area climbed steeply from around 186,000 ha in 1995 to 562,000 ha in 2000, and up to 641,000 ha in 2014 (average growth rate was 5 percent per year) (Figure 2 and Figure 3).

Production volumes have also increased. Between 1995 and 2014, rice, maize, and coffee production grew by an average of 0.03 percent, 8 percent, and 9 percent per year, respectively. The total production of rice, maize, and coffee in 1995 was 26,359 thousand tons (95 percent of which was rice). It then increased steadily to 51,562 thousand tons in 2014. The increase in production volumes of these crops, especially of rice, was largely due to yield improvements, themselves a result of improved sowing density, fertilizer use, and pesticide application techniques (Nhan 2009). The production of rice, maize, and coffee is predicted to stabilize at 49,750 thousand tons in 2020.

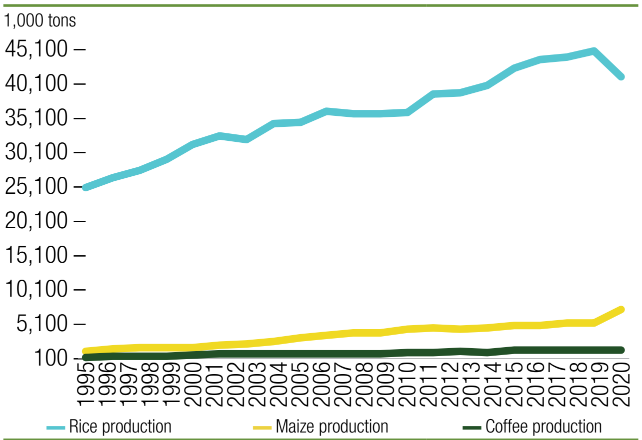
In the next decades, rice, maize, and coffee production is likely to continue intensifying. According to the land-use plan for 2020 and vision for 2030 proposed by MARD (2015b), the harvested area for rice, maize, and coffee were set to be reduced to around 7,000,000 ha, 1,200,000 ha, and 550,000 ha, respectively, in 2020 whereas their production volumes would continue increasing (Figure 3). As usual, in these planning exercises, the government paid attention to

Figure 2. Harvested area for rice, maize, and coffee, 1995–2020



Source: Based on GSO and DARD data.

Figure 3. Production of rice, maize, and coffee, 1995–2020



Source: Based on GSO and DARD data.

commodity production targets than quality and their competitiveness.

2.2.1 Rice production

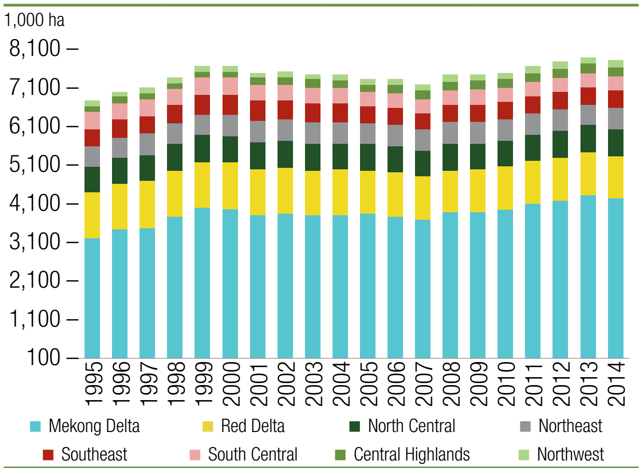
The MKD is the main rice-producing region in Vietnam, critical to both food security and rice exports. Every year, the MKD contributes more than 90 percent of Vietnam's exported rice. In the 1990s, the MKD accounted for about 50 percent of the country's total rice area and production, and these increased to approximately 60 percent in 2014 (Figure 4 and Figure 5). In 1995, MKD rice production was around 13 million tons, and it increased to around 25 million in 2014. Kien Giang, An Giang, and Dong Thap are the three most important production provinces in the MKD both with regard to rice growing area and production volume (Figure 6).

In the past 20 years (1995–2015), rice production in the MKD has steadily increased at an average rate of 0.02 percent per year in terms of planted area,[1] and 0.04 percent per year in terms of production volumes. From 1995 to 2000, the rice area in the MKD increased from 3.2 million ha to 4 million ha. During this period, Vietnam's rice production was driven more by by a focus on meeting production targets than by a focus on raising quality. Subsequently, the planted area in the MKD declined slightly through 2007 (3.68 million ha) before climbing again to reach about 4.3 million ha in 2013 (Figure 7). From now to 2020, the rice area is expected to decline slightly as the government shifts its focus from increasing quantity to improving quality and value addition in rice value chains.

2.2.2 Maize production

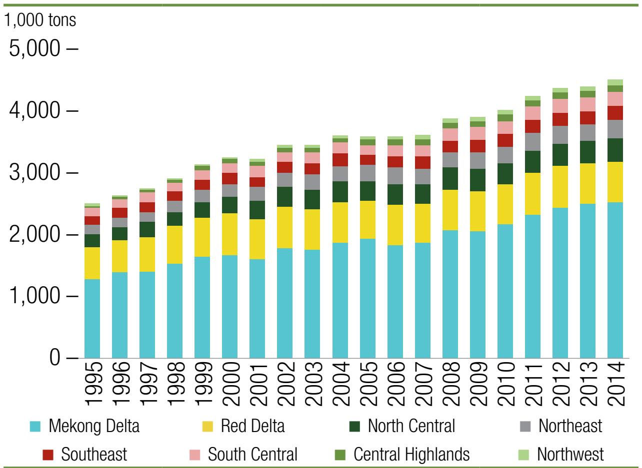
In Vietnam, maize is the second largest annual crop after rice in terms of harvested area (GSO 2015). Its production increased rapidly from 1990 to 2014 (Figure 8 and Table 3). The maize-harvested area increased 2.73 times from 0.43 million ha in 1990 to 1.18 million ha in 2014, equivalent to 4.36 percent per year. Maize production increased 7.74 times in the same period, from 0.67 million tons to 5.19 million tons. Maize yields also increased from 1.55 tons/ha to 4.41 tons/ha in 1990–2014. Major factors contributing to this rapid increase included the improvement of market access and intensification in upland agriculture systems, increased demand for maize to feed animals, strong support from the government (particularly through policies supporting research and extension activities to expand hybrid maize production), and technical and financial support from international organizations (Tran 2015; Hồ, Nhỏ, and Lê 2015).

Figure 4. Rice harvested area by region, 1995–2014



Source: Based on GSO data.

Figure 5. Rice production by region, 1995–2014

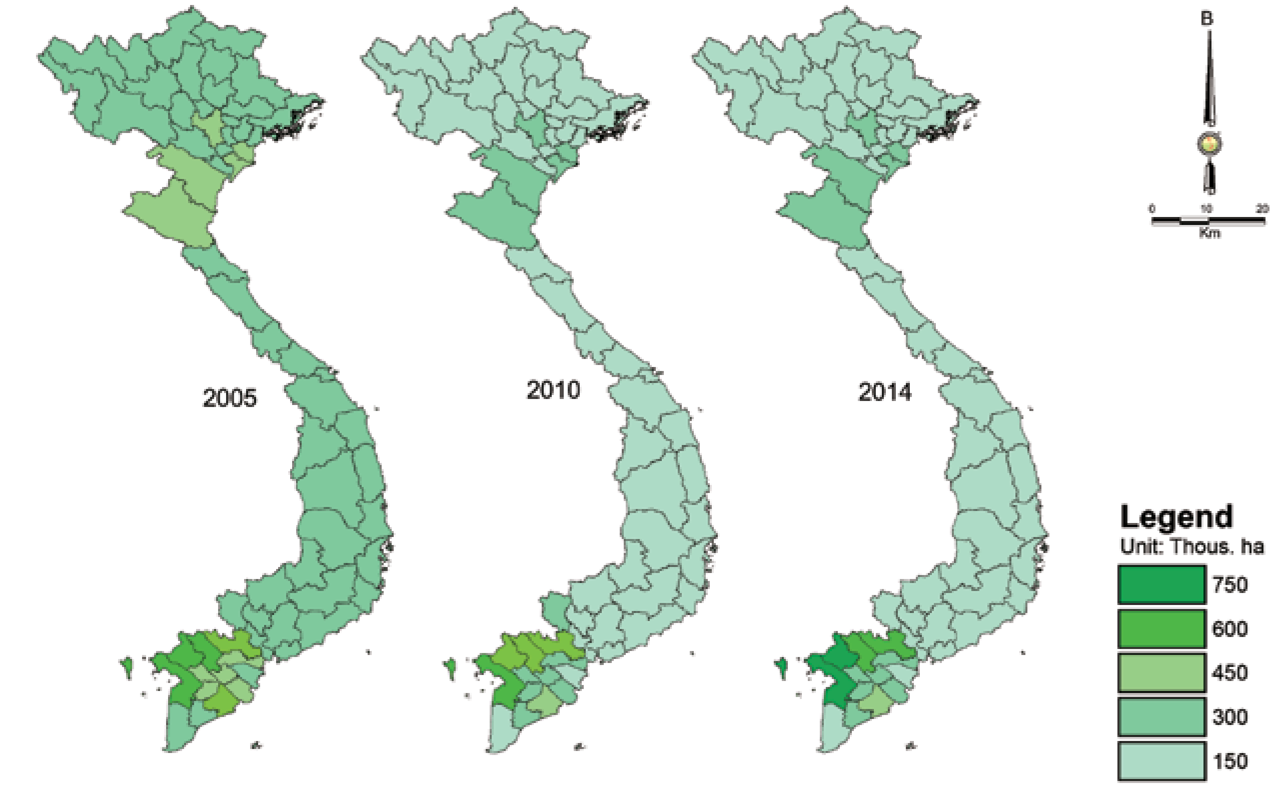


Source: Based on GSO data.

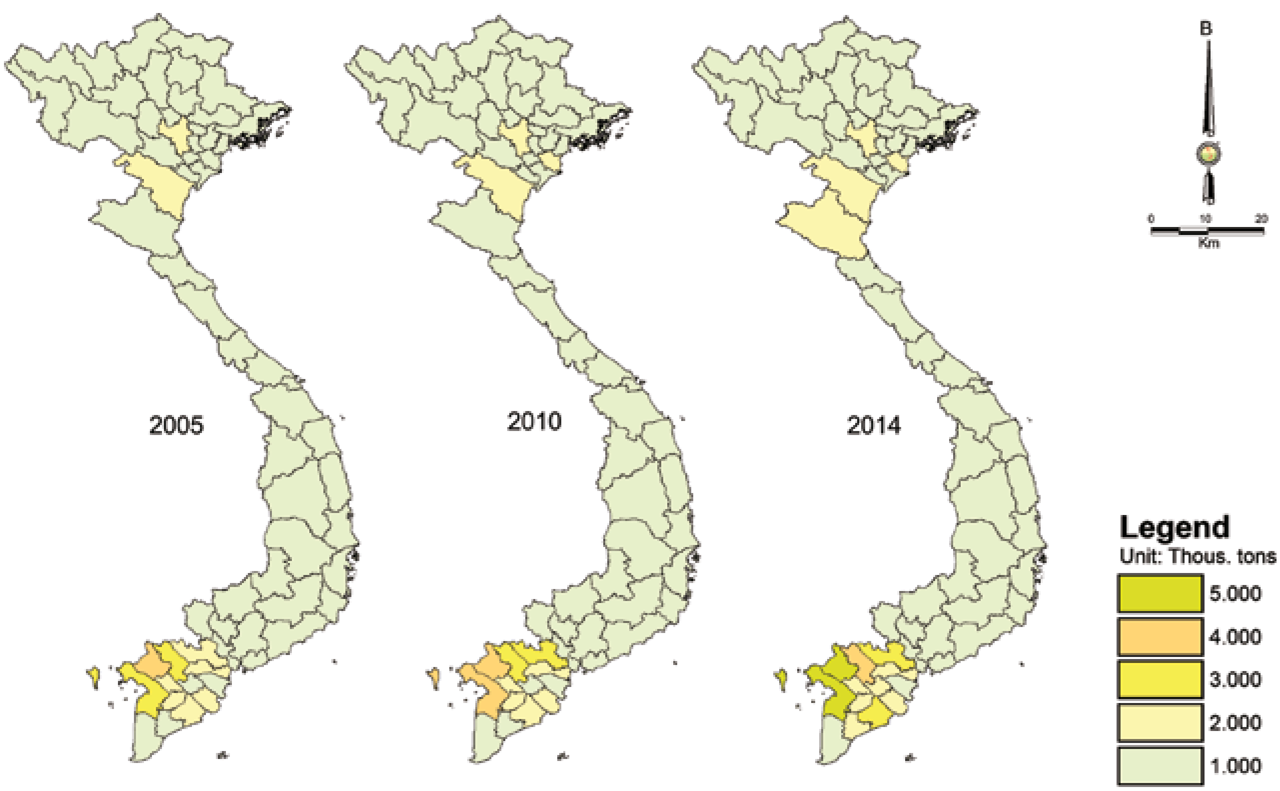
1 "Planted area" as used here is distinct from "harvested area," which counts the same plot of land twice if it has been used twice in a given year. Planted area does not factor in multiple harvests.

Figure 6. Rice harvested area and production, 2005–2014

Harvested area

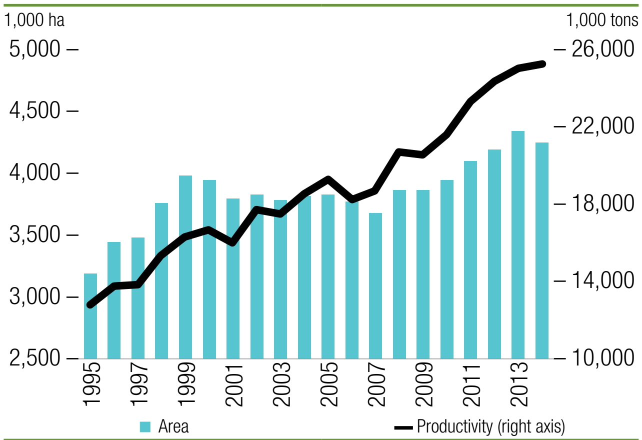


Production



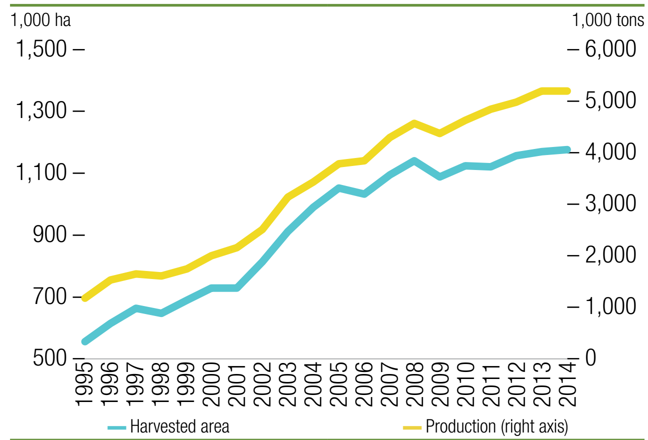
Source: Based on GSO data.

Figure 7. Rice harvested area and production in the Mekong Delta, 1995–2014



Source: Based on GSO data.

Figure 8. Maize harvested area and production, 1995–2014



Source: Based on GSO data.

Although maize production has been increasing rapidly, domestic supply does not meet domestic demand. Every year, Vietnam imports 2 million tons of maize (Hồ, Nhỏ, and Lê 2015). More than 80 percent of the maize is used as to make feed ingredients. Demand for maize is expected to continue rising in light of the livestock sector's rapid growth. To satisfy the rising demand for feed, it is estimated that domestic maize production will continue increasing in the next decade to reach up to 9 million tons in 2020, from a base of 5.2 million tons in 2014 (Viet 2015).

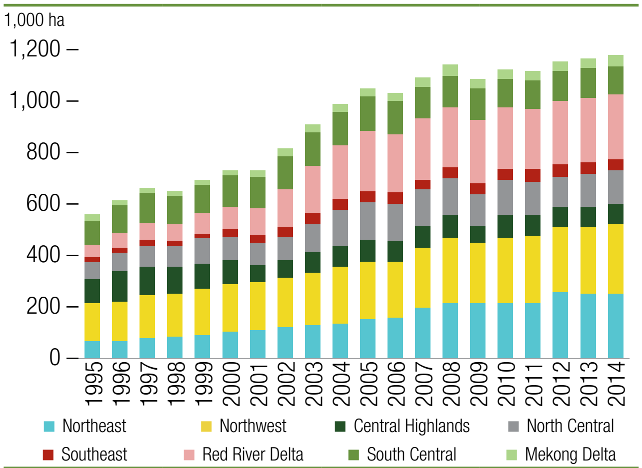
Table 3. Annual growth in maize area, production, and yield, 1990–2014

Items	1990	2014	Difference (time)	Annual growth rate (%)
Harvested area (1,000 ha)	432	1,178	2.73	4.36
Production (1,000 tons)	671	5,192	7.74	9.26
Yield (tons/ha)	1.55	4.41	2.84	4.60

Source: Based on GSO data.

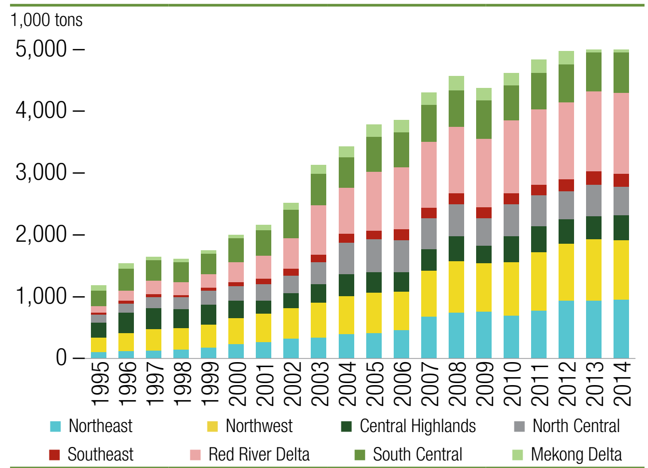
With regard to geographical distribution, maize is cultivated from the north to the south. Figure 9, Figure 10, and Figure 11 show maize area and production in eight AEZs across the country in 1995–2014. The North West, North East, and CH regions have the largest maize area and production, which account for nearly 60 percent total maize grown area and production of the nation (Figure 12). Maize

Figure 9. Maize harvested area by region, 1995–2014



Source: Based on GSO data.

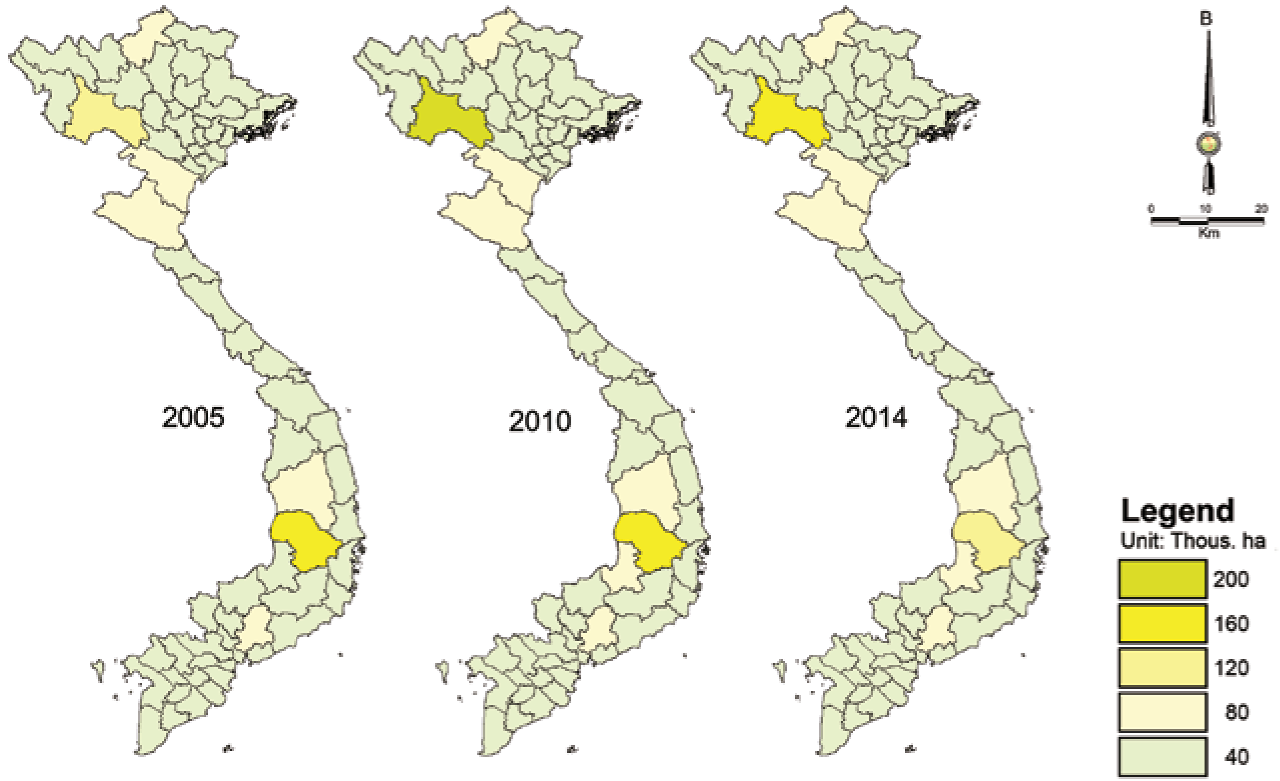
Figure 10. Maize production by region, 1995–2014



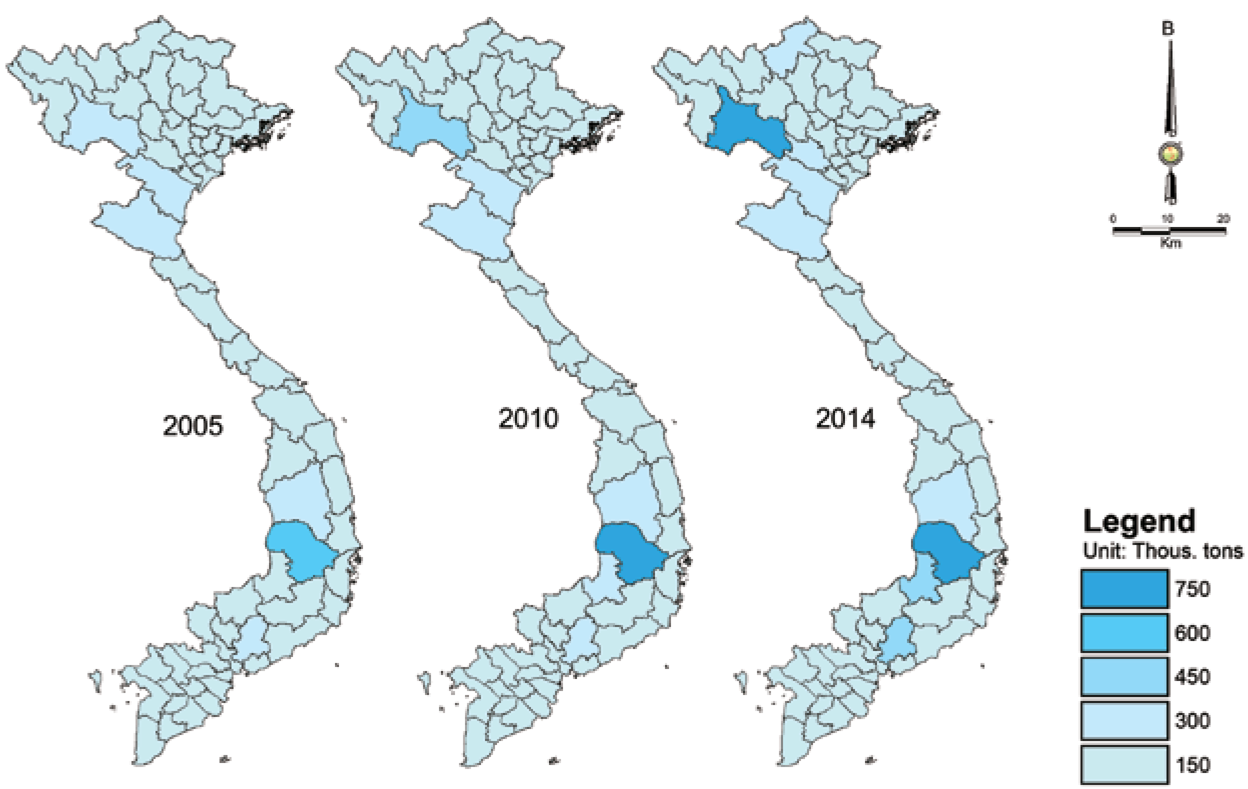
Source: Based on GSO data.

Figure 11. Maize harvested area and production, 2005–2014

Harvested area

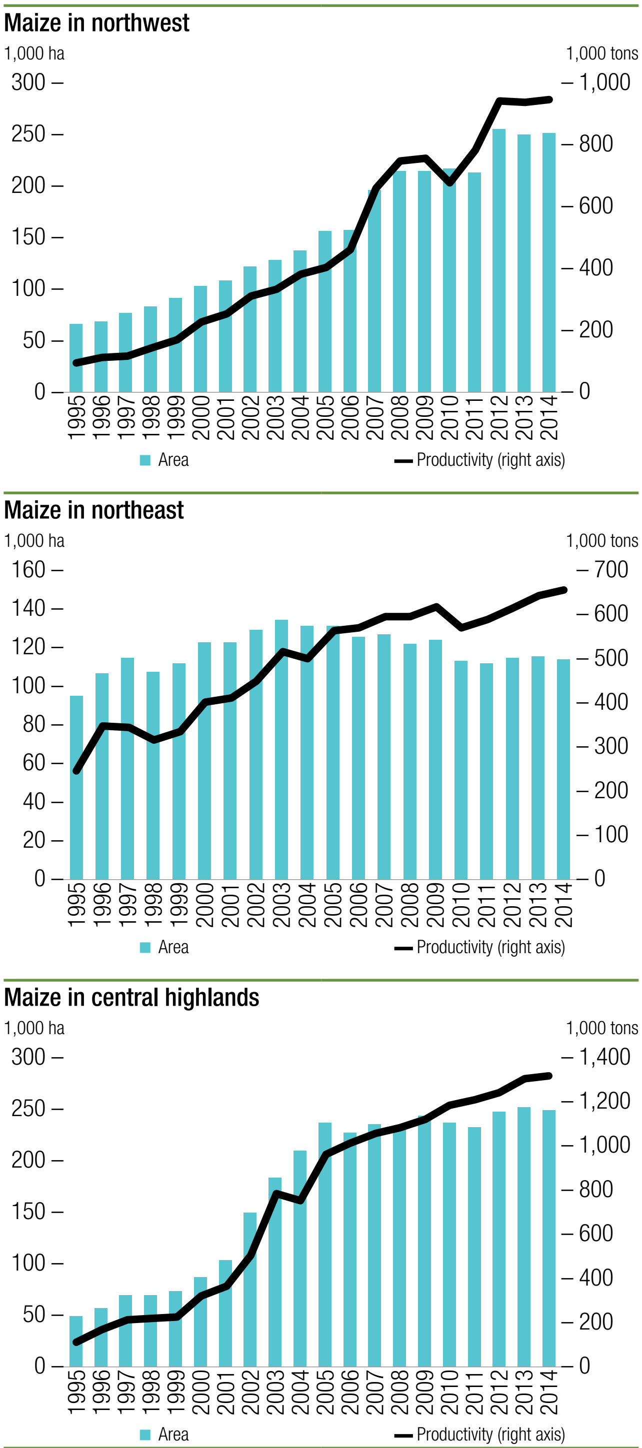


Production



Source: Based on GSO data.

Figure 12. Maize harvested area and production in three dominant regions, 1995–2014



Source: Based on GSO data.

grown area in the CH is smaller than that in the North West and North East regions, but yield in the former is higher than that in the latter because maize production in the CH is more intensive than that

Table 4. Top ten maize producing provinces, 2014

Rank	Harvested area		Production		Yield	
	Province	1,000 ha	Province	1,000 tons	Province	Ton/ ha
1	Son La	162.5	Dak Lak	664	An Giang	7.8
2	Dak Lak	121.1	Son La	659	Dong Thap	7.7
3	Nghe An	55.7	Dong Nai	353	Long An	7.0
4	Thanh Hoa	54.7	Dak Nong	333	Dong Nai	6.8
5	Ha Giang	54.2	Thanh Hoa	222	Dak Nong	6.4
6	Gia Lai	52.6	Gia Lai	217	Binh Thuan	6.2
7	Dak Nong	52.4	Nghe An	193	Hung Yen	5.6
8	Dong Nai	52.2	Ha Giang	179	Binh Dinh	5.6
9	Cao Bang	39.0	Hoa Binh	152	Dak Lak	5.5
10	Lao Cai	38.5	Cao Bang	128	Quang Ngai	5.5

Source: Based on GSO data.

in the North West and North East regions. Between 2005 and 2014, Son La and Dak Lak were the two most dominant provinces with regard to maize grown area and production.

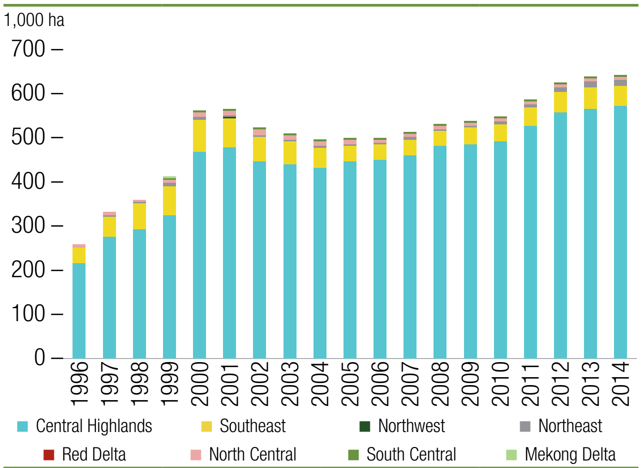
The top ten maize producing provinces are presented in Table 4. Among them, Son La Province in the northern midlands and mountain areas and Dak Lak Province in the CH have the largest harvested area as well as the biggest production volumes. With regard to yields, An Giang, Dong Thap, and Long An Provinces in the MKD ranked in the top three.

2.2.3 Coffee

In Vietnam, coffee was planted mostly in highland areas, the provinces of Dak Lak, Dak Nong, Lam Dong, and Gia Lai being the four leading coffee-producing areas. Figure 13 shows coffee-harvested area by region between 1996 and 2014. In 1996, the coffee area was around 408,000 ha. It increased significantly to around 565,000 ha in 2001, before declining slightly to 531,000 ha in 2008 and then climbing up again to 645,000 ha in 2014. The CH region (including Kon Tum, Gia Lai, Dak Lak, Dak Nong, and Lam Dong Provinces) accounted for approximately 85–95 percent of the total coffee area in 1996–2014.

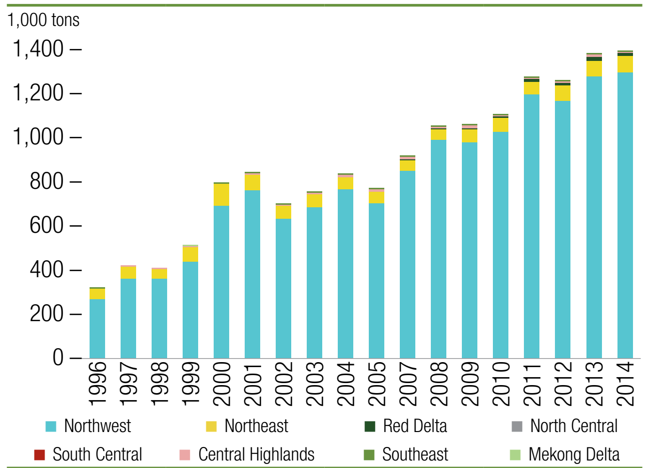
From 1996 to 2014, coffee production in Vietnam increased dramatically. According to the

Figure 13. Coffee harvested area by region, 1996–2014



Source: Based on GSO data.

Figure 14. Coffee production by region, 1996–2014

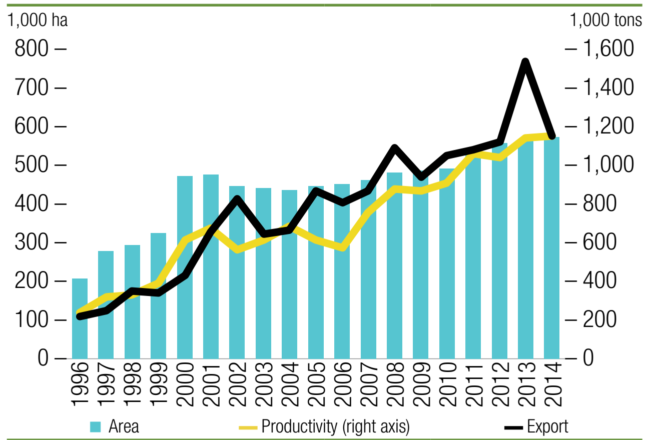


Source: Based on GSO data.

International Coffee Organization, in 2013, Vietnam became the second-largest coffee producer, accounting for about 19 percent of global volumes and 13 percent of the global market's value (FAOSTAT 2016). In 1996, Vietnam's coffee production was only around 320,000 tons, then increased steadily and reached about 1.4 million tons in 2014, most of it from the CH. The increased changes in coffee-harvested area and production in Vietnam were largely dependent on those in the CH (Figure 14, Figure 15, Figure 16, and Figure 17). In 2001–2014, the annual growth rates were 1 percent in area; 4 percent in production; 5 percent in export volume; and 19 percent in export value (GSO 2015; MARDc 2015; MOIT 2015). The growth rate between 1996 and 2014 of harvested area and coffee production in the CH was around 6 percent and 9 percent, respectively (Source: Based on GSO data. Figure 15). This contributed to the increase in coffee export volume of Vietnam to 10 percent per year in the same period.

In the same period, the yield of coffee plantations also increased considerably. In 1996, average yield was about 1.3 tons/ha/year, then increased to 2.3 tons/ha/year in 2014. This trend reflected the coffee subsector's gradual move toward intensification. The yield increase was attributed mainly to new technologies and intensification in coffee cultivation, especially the use of new and good-quality seed varieties, organic fertilizers application, timbering, and suitable pest management (Phạm et al. 2013).

Figure 15. Coffee harvested area and production in the Central Highlands, and national export volume, 1996–2014

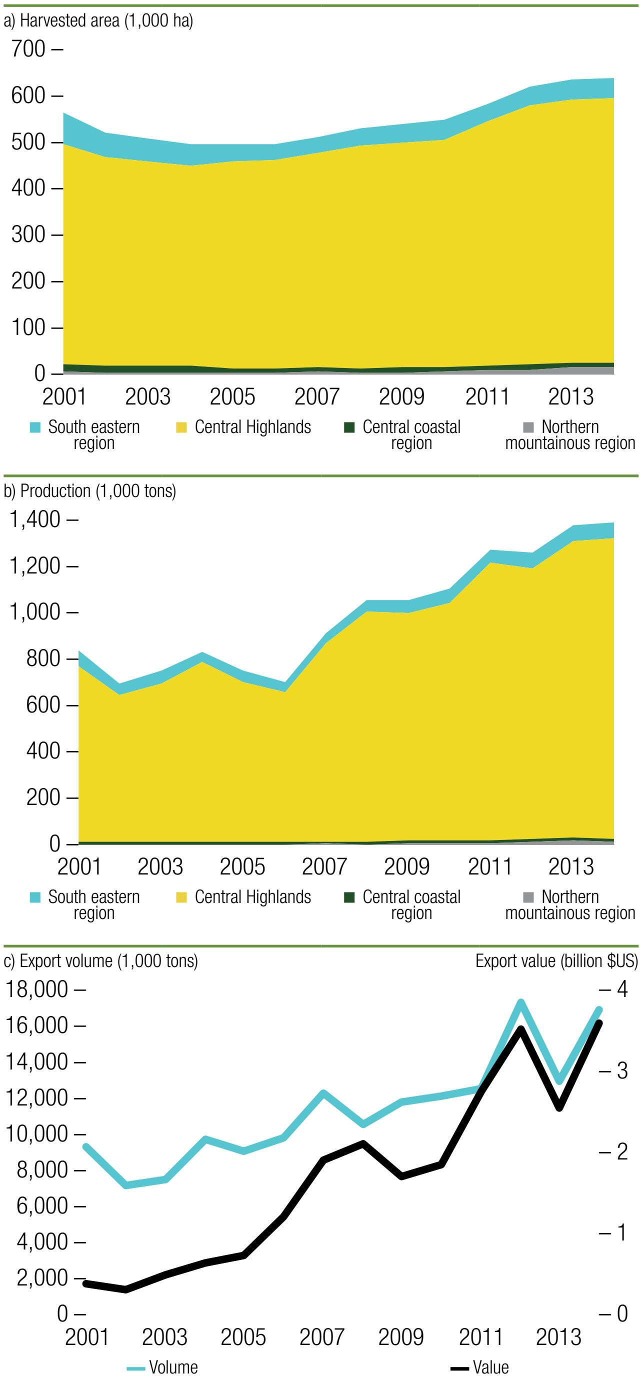


Source: Based on GSO data.

In Vietnam, about 95 percent of coffee plantations are owned by smallholders who have about 1 ha or less (IDH Vietnam 2013). Robusta coffee covers around 95 percent of the coffee area. Well-adapted to intensive farming and a wide range of agro-climatic conditions, Robusta yields around twice as much coffee as Robusta, but fetches only around half the market price (due to its lower quality). Nonetheless, Robusta is more profitable for farmers than Arabica (Marsh 2007).

Driven by small farmers, the expansion of coffee production in Vietnam occurred in a spontaneous and uncontrolled fasion, and at the expense of the

Figure 16. Coffee harvested area, production, and export volume and value, 2001–2014



Source: Based on GSO, MARD, and Ministry of Industry and Trade (MOIT) data.

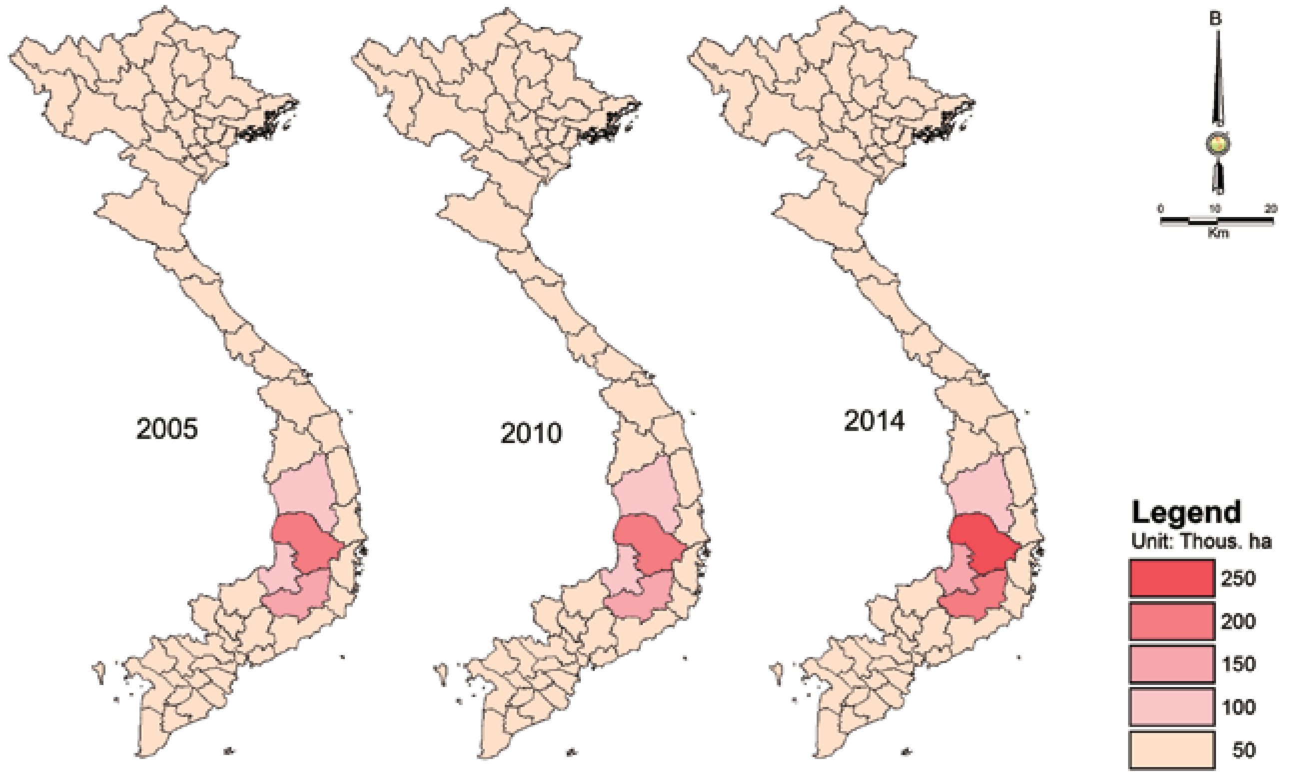
environment, since it has resulted in deforestation, land degradation, and the depletion of groundwater. In Lam Dong Province, a large forest area was converted to cultivate mulberries, tea, and coffee. In many areas in the CH, coffee expansion was associated with excessive deforestation, soil quality depletion, and degraded watershed functions. Every hectare of coffee requires 1,500–3,000 m^3 of water to maintain its yield. Irrigation water is taken from surface water stored in ponds and reservoirs (20.8 percent); from natural rivers, streams, and lakes (28.5 percent); and from groundwater (56.6 percent) extracted from about 2,500 wells in Dak Lak Province (that is, 1 well per 59 ha). According to local estimates, groundwater resources in Dak Lak Province have been exploited at over 71 percent of their total capacity. More than 95.5 percent of the extracted water is used for irrigating perennial industrial crops, particularly coffee, while only 4 percent is for urban use and 0.2 percent for the industrial sector (D'haeze 2008). An analysis of the logistic expansion of coffee in Vietnam indicates that in the next decade, Vietnam could reach the annual production peak of about 900,000 tons because of environmental and socioeconomic factors as a result of intensive agriculture (Giungato, Nardone, and Notarnicola 2008).

According to MARD's plans, Vietnam's coffee area will decrease to 550,000 ha by 2020 while maintaining a volume of 1.4–1.5 million tons (MARD 2014; MARD 2015b, 2015c). This implies greater intensification to increase coffee yields and compensate for the reduction in the harvested area. However, this will be a challenge for coffee producers and environmental management authorities because intensification means higher use of inputs and agrochemicals.

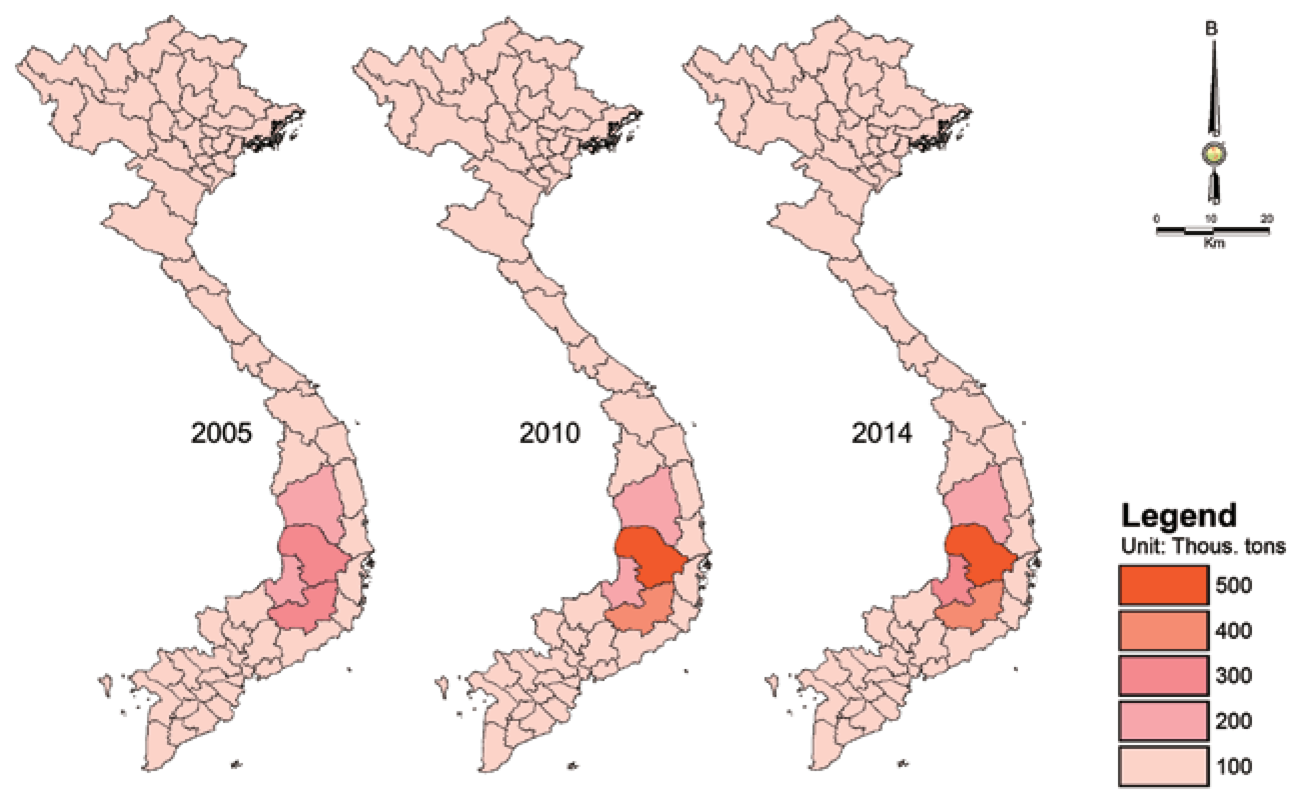
To sum up, in the past decades, crop production systems in Vietnam have expanded dramatically both with regards to harvested area and intensification. This has contributed to increases in crop yields, production, and farmer income. However, the intensification and expansion of crop systems has had significant environmental consequences. In particular, the expansion of farming into unused lands, the increase in the number of cropping seasons per year, and the extensive use of inputs such as pesticides and fertilizers have led to soil degradation and agricultural pollution.

Figure 17. Coffee harvested area and production, 2005–2014

Harvested area



Production



Source: Based on GSO data.

INPUT USES AND WASTE MANAGEMENT

3

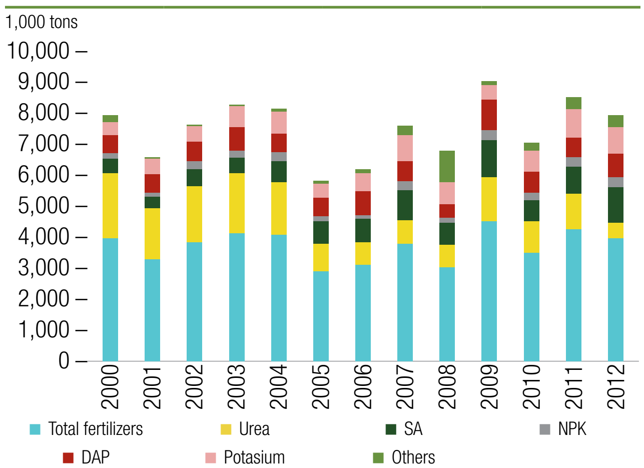
3.1 Fertilizers

3.1.1 Consumption trends

Vietnam is a net importer of inorganic fertilizers. The country has imported between 3.5 million and 4.5 million tons/year since 2000. Urea imports reached a peak in 2000–2004, before declining. In contrast, amounts of imported ammonium sulfate (SA) and potassium (K) have tended to increase since 2005 (Figure 18).

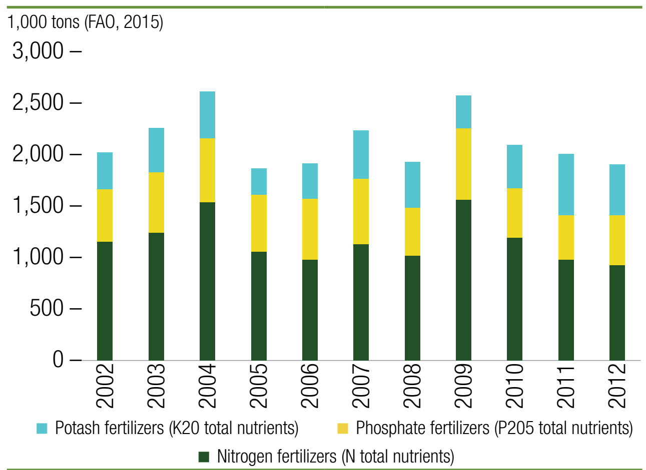
Together with the trend of agricultural intensification, the use of inputs, especially fertilizers and pesticides for crops, also increased very quickly in the past two decades. From 1985 to 2005, the rate of fertilizer consumption (nitrogen [N], phosphorous [P], and K) increased by about 10 percent per year, peaking at

Figure 18. Fertilizer imports into Vietnam, 2000–2012



Source: Based on FAOSAT and MOIT data.

Figure 19. Fertilizer consumption, 2002–2012



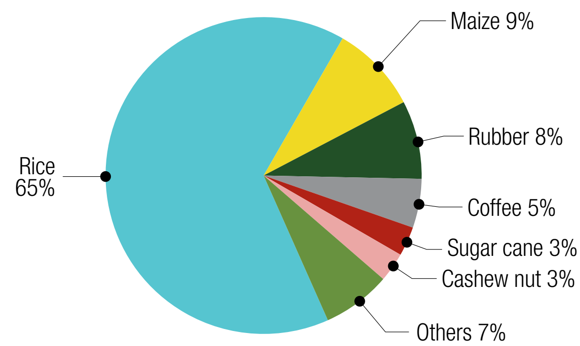
Source: Based on FAOSTAT and MOIT data.

Table 5. Fertilizer demand by key crop

Crop	Fertilizer demand (ton) N	P	K
Rice	1,485,864	1,598,105	219,739
Maize	342,255	160,702	55,241
Sugar cane	116,935	69,759	39,863
Coffee	260,461	400,000	170,000
Rubber	140,773	292,832	41,833
Cashew	51,647	233,898	97,458
Citrus tree	29,333	142,154	30,462
Longan, rambutan	50,704	30,000	20,000
Other fruit tree	43,902	40,000	20,000
Total	**2,521,875**	**2,967,450**	**694,596**

Source: Doan 2015 (based on GSO data for 2013).

Figure 20. Fertilizer use by crop



Source: Nguyen (ViettinBankSc) 2014.

25 million tons in 2004. After that, annual fertilizer consumption flattened out (Figure 19).

With regards to fertilizer consumption by crop, rice, coffee, and maize were the three main crops consuming the largest amount of fertilizers (Figure 20). In 2013, rice farming consumed around 1.5 million tons of N, 1.6 million tons of P, and 0.22 million tons of K. Coffee farming used around 0.26 million tons of N, 0.4 million tons of P, and 0.17 million tons of K (Table 5). Maize farming consumed around 0.34 million tons of N, 0.16 million tons of P, and 0.05 million tons of K.[2] Annually, Vietnam consumes approximately 11 million tons of fertilizer, of which inorganic fertilizers account for 90 percent. These include include 2.3 million tons of urea, 1.3 million tons of phosphate, and 4 million tons of NPK. Diammonium phosphate (DAP), K, and SA add to about 0.85–0.95 million tons.[3] The average amount of used fertilizers is 195–200 NPK kg/ha (Doan 2015; Nguyễn 2013).

3.1.2 Application rates

Fertilizer use for crops has varied among and within provinces, but generally increased in volume over time (Figure A9 in the Annex). Fertilizer application rates vary greatly, depending on the types of crops, varieties, cropping seasons, locations, soil types, and forms of application.

Overall, fertilizer use in rice, coffee, and maize cultivation has been increasing. This could be due to crop intensification (especially the growing of three rice crops per year) and soil degradation (especially the lack of alluvium caused by closed dyke systems built to allow three rice crops per year in the MKD).

Rice farming

Rice is the most important crop in Vietnam and rice production is mostly concentrated in the MKD. In the past decades, rice farming in the MKD has been greatly intensified. The area in which three rice crops are harvested per year increased from around 100,000 ha in 2000 to approximately 867,000 ha in 2015. To plant an additional crop during autumn-winter (the third crop), the government and farmers had to construct closed dyke systems to prevent rice fields from seasonal flooding. Natural flooding, however, replenishes rice fields with alluvia and flushes out acid sulfate and other toxic substances. In the closed dyke areas, natural flooding no longer occurs and the land is not given the time to recover its natural fertility. Riceland became degraded just a few years after closed dykes andn triple cropping was adopted. This has led farmers to increase their use of fertilizer to maintain rice yields. Table 6 shows that fertilizer use in MKD rice farming has increased considerably in the past 20 years.

2 http://www.mard.gov.vn/Pages/statistic_csdl.aspx?TabId=thongke. Those figures were calculated based on GSO data on crop production and fertilizer use.

3 http://www.moit.gov.vn/vn/tin-tuc/9122/moi-nam-viet-nam-tieu-thu-khoang-11-trieu-tan-phan-bon.aspx.

Table 6. Amount of fertilizer used in rice production in the Mekong Delta, 1991–2015

Year	Net used demand of fertilizers for rice in the MKD (1,000 tons)			Sources
	N	P_2O_5	K_2O	
1991	200	75	5	Vu 1995
2001	334	170	110	Pham 2001
2011	395	200	200	Chu 2012
2015	360	160	120	Author estimate 2015[a]

Note: a. Estimation is based on rice grown area in the MKD and fertilizer quantity proposed to be used for rice according to 1 Must and 5 Reductions (1M5R) (refer to Annex, item 6) technique in rice production.

Most rice farmers apply fertilizers well above recommended rates. For instance, in An Giang and Kien Giang provinces—the two largest rice producers in the MKD—rice farmers apply up to 20–30 percent more fertilizer than recommended (Table 7). In Kien Giang province, excessive fertilizer applications of up to 38 kg N, 24 kg phosphorus pentoxide (P_2O_5), and 14 kg potassium oxide (K_2O) per ha per crop have been reported. Similarly, in An Giang, the excess was 28 kg N, 15 kg P_2O_5, and 18 kg K_2O per ha per crop.

Improper use of fertilizer in rice production is common. Farmers tend to use more urea (N) while P and K are often ignored. This is because before 1995, farmers mostly planted traditional rice, so they did not use P and K. After 1995, high-yield varieties gradually replaced traditional varieties. However, fertilization regimes have remained based on farmers' experience and habits and not been updated to match the nutritional demands of plants and soil. Farmers continue to apply fertilizer above the dosage recommended by rice experts and extension workers. Another factor that contributes to fertilizer overuse is the poor quality of fertilizer products available in domestic markets. According to a recent report, about 54 percent of NPK fertilizers in the market did not meet quality standards (Phạm and Nguyễn 2013). Fertilizer use efficiency is also low at only about 60 percent for N, 40 percent for P, and 50 percent for K. Excess fertilizer is absorbed into the soil and water (percolation and runoff), causing air, water, and soil pollution (Nguyễn 2013).

It is estimated that every year, around 140,000 tons of N, 82,000 tons of P, and 66,000 tons of K are wasted due to overfertilization in rice farming in the MKD (see Table 8).[4] From an economic perspective, this is equivalent to US$150 million wasted per year from overfertilization in rice cultivation alone. In addition, overfertilization practices have high environmental costs, which in turn negatively affect the competitiveness of Vietnam's rice in the world market.

Rice farmers in the RRD use less inorganic fertilizer than those in the MKD. This is because farmers in the RRD use animal manure together with chemical fertilizers in rice production. In the MKD, by contrast, rice farmers mostly rely on chemical fertilizers. Rice in the RRD is generally transplanted, and produced less intensively. On average, fertilizer formulation for rice in the RRD was 100-60-90 (kg of N-P-K) for transplanting rice and 100-60-60 for sowing rice with four applications (that is, one time before transplanting or sowing, and three times after transplanting or sowing). That is why application rates of inorganic fertilizer in the MKD are much higher than those in the RRD.

Table 7. Farmer fertilization rates compared to rates recommended by 1M5R in Kien Giang and An Giang provinces, 2014

Unit: kg/ha/crop

Net items	Kien Giang				An Giang			
	1M5R	Farmers	Δ (%)[b]	T-test	1M5R	Farmers	Δ (%)[b]	T-test
N	95.98	134.21	39.83	a	150.55	178.15	18.33	a
P_2O_5	62.4	85.97	37.77	a	74.15	89.04	20.08	a
K_2O	45.44	59.18	30.24	a	44.28	61.79	39.54	a

Note: a. Difference through T-test at α=5%; b. Difference between 1M5R and farmers.

4 Assumption that 80 percent farmers overused fertilizers at the same level (quantity).

Table 8. Estimated excess fertilizer use in rice production in the Mekong Delta

Unit: ton/year

Provinces	N	P_2O_5	K_2O
An Giang	20,598	12,034	9,778
Bac Lieu	5,888	3,440	2,795
Ben Tre	2,192	1,281	1,041
Ca Mau	4,137	2,417	1,964
Can Tho	7,646	4,467	3,630
Đong Thap	17,402	10,167	8,261
Hau Giang	6,757	3,948	3,208
Kien Giang	24,805	14,492	11,775
Long An	17,089	9,984	8,113
Soc Trang	11,978	6,998	5,686
Tien Giang	7,590	4,434	3,603
Tra Vinh	7,761	4,534	3,684
Vinh Long	5,931	3,465	2,816
Total	**139,777**	**81,662**	**66,353**

Coffee farming

Coffee is one of the most important tree crops and its production is concentrated in the CH region. Recommended fertilization rates in coffee farming vary considerably, depending on the age of the trees and soil conditions (Table 9) (ASINCV 2012). During the harvest, coffee plants need more fertilizer. During the period of timbering and recovery (4–5 years after planting), coffee plants require more fertilizers than they do in earlier growth stages.

Like rice farmers, coffee farmers in the CH apply fertilizer at rates that are much higher than the recommended levels. Farmers apply N, P_2O_5, and K_2O at rates that are about 50 percent, 210 percent, and 30 percent higher than recommended levels, respectively (Table 10). It is estimated that, on average, farmers apply an excess of around 190 kg N, 232 kg P_2O_5, and 96 kg K_2O per hectare each year. With 670,000 ha of harvested coffee, of which 610,000 ha are at the harvest stage, and assuming 50 percent farmers overuse fertilizer in a given year, the coffee sector wastes an estimated US$110 million on excess fertilizer per year. Overfertilization not only favors coffee pests and increases production costs, but it also pollutes the environment.

Table 9. Fertilizer dosage recommended for coffee at various ages

Coffee age	N (kg)	P_2O_5 (kg)	K_2O (kg)
New planting	40	150	30
Caretaking in the first year	45	90	60
Caretaking in the second year	160	90	180
Harvesting time	280	120	300
Timbering and recovering	115	150	120

Source: ASINCV 2012.

Table 10. Actual fertilization rates compared to recommended rates in coffee production

Unit: kg/ha/year

	Actual farmers used			Recommended level	Difference[a]	
	Min	Max	Mean	Mean	(kg/ha)	(%)[b]
Gia Lai						
N	114	1,420	458	350	108	30.9
P_2O_5	0	960	276	85	191	224.7
K_2O	48	1,525	335	325	10	3.1
Dak Lak						
N	64	1,980	522	350	172	49.1
P_2O_5	0	1,504	263	85	178	209.4
K_2O	64	1,900	514	325	189	58.2
Lam Dong						
N	64	1,597	639	350	289	82.6
P_2O_5	0	1,549	489	163	326	200.0
K_2O	32	1,700	414	325	89	27.4
Mean						
N	64	1,980	540	350	190	54.3
P_2O_5	0	1,549	343	111	232	209.0
K_2O	32	1,900	421	325	96	29.5

Source: Adapted from Truong, Dinh, and Nguyen 2013.

Note: a. Difference between actual and recommended use; b. Percent of actual use increases in comparison to recommended level.

Certain farming practices contribute to excessive fertilization. Farmers often mix several types of fertilizer instead of calculating the amount of each fertilizer based on plant requirements at each stage (Phạm et al. 2013; Truong, Dinh, and Nguyen 2013; Nguyen, Le, and Nguyen 2013). Furthermore, farmers usually apply fertilizer manually, and on the soil surface around coffee trees. Under the sunlight and rainy conditions, some will be lost after a few days, and more fertilizer is needed to compensate those losses.

Maize farming

Maize is one of the most common crops across Vietnam's farming regions, and it is a crop of prime importance to ethnic minorities in midland and mountainous regions. Maize is a crop that can adapt well to different types of soil conditions. It can be grown on land with poor fertility that is unsuitable for growing rice. Maize can also be grown in rotation with rice and other upland crops. According to Mr. Nhan (Vice Director, Agricultural Extension Centre, Dong Thap Province), maize is often planted on lands that are not suitable for high-value crops. And the amounts of fertilizer applied by farmers are low compared to the biomass produced. So far, few studies and reports are available on farmers' fertilization rates in maize production compared to recommended levels. This could be because overfertilization in maize cultivation is less common and less serious than that in rice and coffee farming.

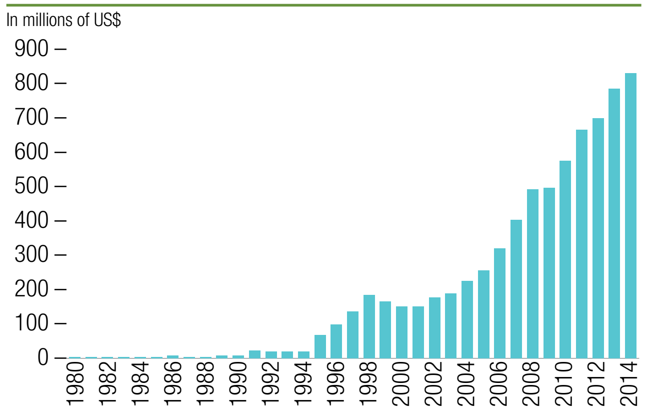
Application rates of inorganic fertilizer in maize farming in the MKD are generally higher than those in the northern regions. This is because farmers in the northern regions often use organic fertilizers (that is, manure) together with inorganic fertilizer while farmers in the MKD do not. According to the Crop Department of MARD, the recommended rates for the RRD, North West/East, and North Central regions are about 100–250 kg N, 40–70 kg P_2O_5, and 30–60 kg K_2O per hectare, depending on the soil type (Cục Trồng Trọt 2011). For local maize varieties, fertilization rates are proposed to be only about half (that is, 50–100 kg N). In the MKD, farmers normally applied 180-146-77 (N-P-K) kg/ha (Lam 2013).

3.2 Pesticides

3.2.1 Consumption trends

The consumption of pesticides in Vietnam, similar to fertilizers, has increased dramatically in the past decades together with the intensification of the agricultural sector. In 1981–1986, Vietnam imported around 6,500–9,000 tons of pesticide active ingredients (ai) (on average, 0.3 kg ai/ha); it then increased to 13,000–15,000 tons/year in 1986–1990 (on average, 0.4–0.5 kg ai/ha); to 20,000–30,000 tons/year (on average, 0.67–1.0 kg ai/ha) in 1991–2000; to 33,000–75,000 tons/year (on average, 2.54 kg ai/ha) in 2001–2010; and up to approximately 100,000 tons/year around 2015 (Lien 2015; Khanh and Thanh 2010; and Trương 2015). Along with that trend, the import value of pesticides increased quickly from around US$472 million in 2008 to US$537 million in 2010 and nearly US$700 million in recent years (Figure 21)(Lien 2015; FAOSAT 2015). These figures are reported excluding smuggling across the borders with China in the north.

Figure 21. Value of pesticide imports into Vietnam, 1980–2014



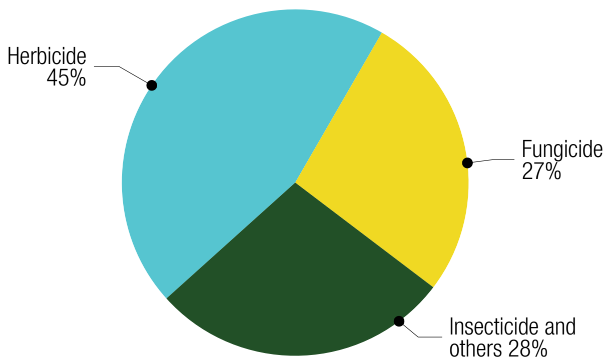
Source: Based on FAOSTAT data.

In 10 years (2000–2011), the number of pesticides registered and used in Vietnam has increased 10 times. Before 2000, the number of ai was around 77, corresponding to 96 trading products; in 2000, it increased to 197, corresponding to 722 trading products; and in 2011, it increased up to 1,202, corresponding to 3,108 trading products. Within the pesticides category, 45 percent was herbicides, 27 percent fungicides, and 28 percent insecticides and others (Figure 22)(Lien 2015).

The mix of pesticides that is currently in use is highly toxic. According to Pham et al. (2012), 31 percent of pesticides used by farmers in the RRD—Vietnam's second largest agricultural area after the MKD—belonged to the 'extremely or highly hazardous' Category I (under the World Health

Organization [WHO] system of classification), and 54 percent belonged to the 'moderately hazardous' Category II. In general, farmers have a tendency to use older, less expensive, non-patented pesticides that can be manufactured or blended domestically, and that happens to be more toxic and persistent than others (Pham et al. 2012). These include organophosphates, organocholrines, pyrethroids, and carbamates, among others. In addition, several banned pesticides (such as methyl parathion, methamidophos, and carbofuran) were found to be in use—though the percentage was declining (from 1.93 percent in 2009 to 0.89 percent in 2006).[5]

Figure 22. Pesticide imports by type



Source: Lien 2015.

Pesticide residues on agricultural products are still common and high. According to MARD's Department of Plant Protection (cited by Trương 2015), between 2000 and 2002, pesticide residues on cash crops were more than the maximum allowable level by 10–26 percent in Hanoi and 10–30 percent in Ho Chi Minh City (HCMC).[6] Pesticide residues higher than the maximum allowable level was 10.2 percent in 2010. In other studies, Khanh and Thanh (2010) reported that over 90 percent of pesticides sprayed on crops were insecticides. Within the pesticides used, nearly 20 percent are classified by the WHO as extremely hazardous. It is estimated that every year, about 69,238 kg and 43,574 L of pesticides and 69,640 kg of chemical packages (that is, paper and nylon bags) are released into the surrounding environment without proper treatment (Khanh and Thanh 2010). These are causing serious environmental concerns, especially soil, surface, and groundwater pollution (Toan et al. 2013).

It is still common among many farmers to completely ignore the risks, safety instructions, and protective guidance when applying pesticides. They are more concerned about the effectiveness of the pesticides in killing pests than paying attention to their health and the environment. The improper usage of pesticides and improper disposal of pesticide wastes, among others, are contributing to the increased pollution of groundwater, surface water, and soil and health problems for local communities.

Overuse of pesticides is also reported to cause resistance of pests to pesticides and disappearance of natural predators that help control pests naturally. Lê et al. (2013) conducted trials in 2009 and 2010. The results showed that brown plant hopper developed resistance to some pesticides, such as Fenobucarb, Fipronil, and Imidacloprid, in the Hanoi, Thai Binh, Bac Giang, Phu Tho, and Nam Dinh Provinces, with the resistance index (RI) varying from 13 to 33.[7] Other studies also showed that when Padan is applied on rice, it caused reduction in natural predators (who limit pests' population) of 13 times while it increased 25 times in the non-applied treatment (Pham Binh Quyen 2002, cited by Trương 2015).

Common problems in pesticides use in Vietnam are described below (Trương 2013, 2015; Khanh and Thanh 2010; Lien 2015; Toan et al. 2013).

- **Excessive use of pesticides and arbitrarily mixing of different types of pesticides.** In the southern provinces, about 38–70 percent farmers used pesticides higher than the recommended

5 Categories of pesticides were based on WHO classification of pesticides; banned pesticides were based on the Regulation of the Vietnam MARD.

6 Allowed level was set by the Ministry of Public Health (Decision No. 46/QĐ-BYT dated 19/12/2007). What, where, and how to apply the maximum level to control biological and chemical pollution in food was described clearly in this decision.

7 RI is based on LD50 (lethal dose 50), theamount of ingested substance that kills 50 percent of a test sample (expressed in mg/kg, or milligrams of substance per kilogram of body weight). Pests are classified as "resistant" when RI is greater than 10.

levels[8] (Tran Thi Ngoc Lan et al. 2014) and nearly 30 percent farmers mixed[9] many types of pesticides together when applying. In the RRD, farmers applied pesticides five times per rice crop and in the MKD up to six times per rice crop.

- **Use of pesticides that are banned or not in compliance with the government's regulations.** In 2010–2011, the Plan Protection Department (MARD) inspected 16,500 pesticide traders including companies, shops, retailers, and farmers. The results showed that 2,400 units (14.5 percent) and about 20 percent farmers violated, including trading and using banned pesticides or those that are not on the permitted list of MARD,[10] illegally imported pesticides, and fake pesticides and those that are not in compliance with Decision No. 46/QĐ-BYT.

- **Lack of knowledge of accurate pesticides use.** In 2002, only 52.2 percent local technicians had correct understanding about pesticide use, and this number was 33 percent and 49.6 percent for sellers and farmers, respectively.

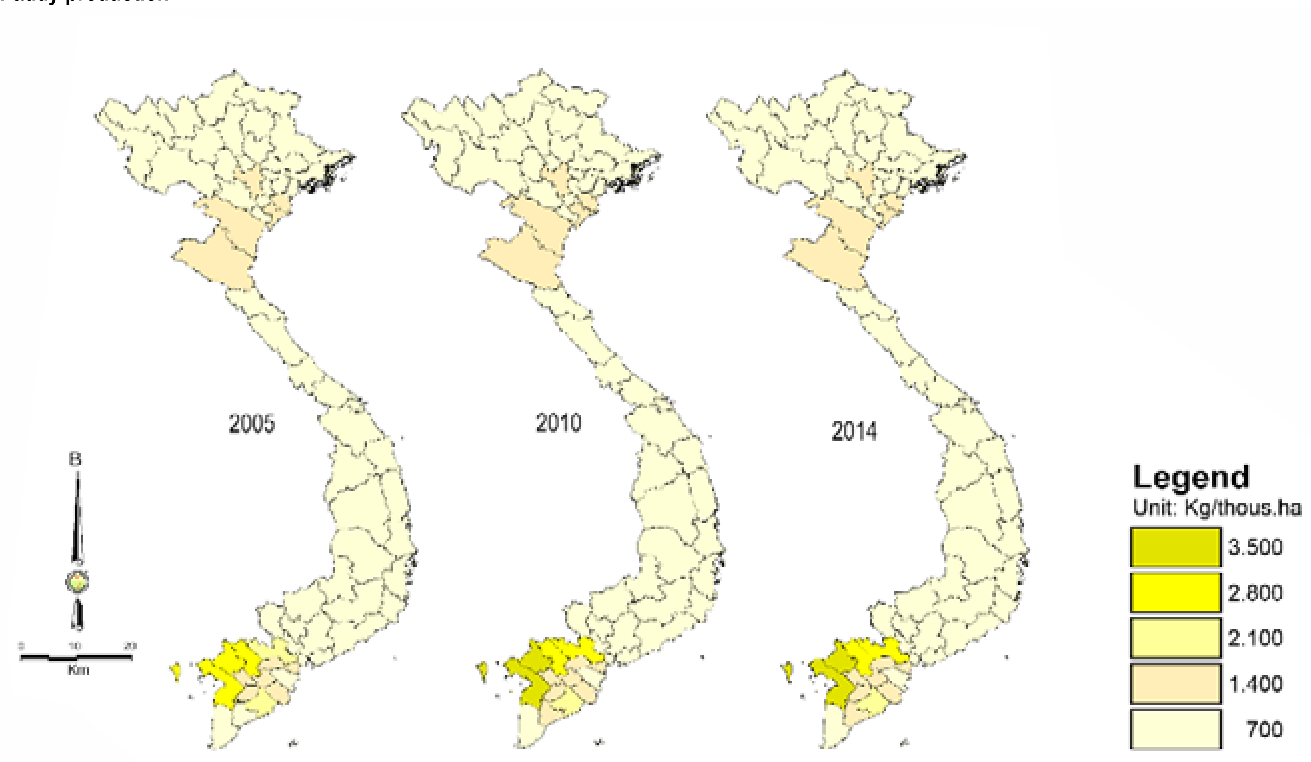
- **Harvesting of products right after spraying pesticides.** It is dangerous for consumers if pesticide residues still exist on the harvested products.

3.2.2 Pesticide uses in rice farming

In the MKD, farmers use more pesticides than those in the RRD (Figure 23) (MRC 2007). In the MKD, on average, pesticides were applied 5.3 times per crop. Rice farmers often make wrong decisions

Figure 23. Pesticides used for rice, maize, and coffee production in Vietnam, 2005–2014

Paddy production



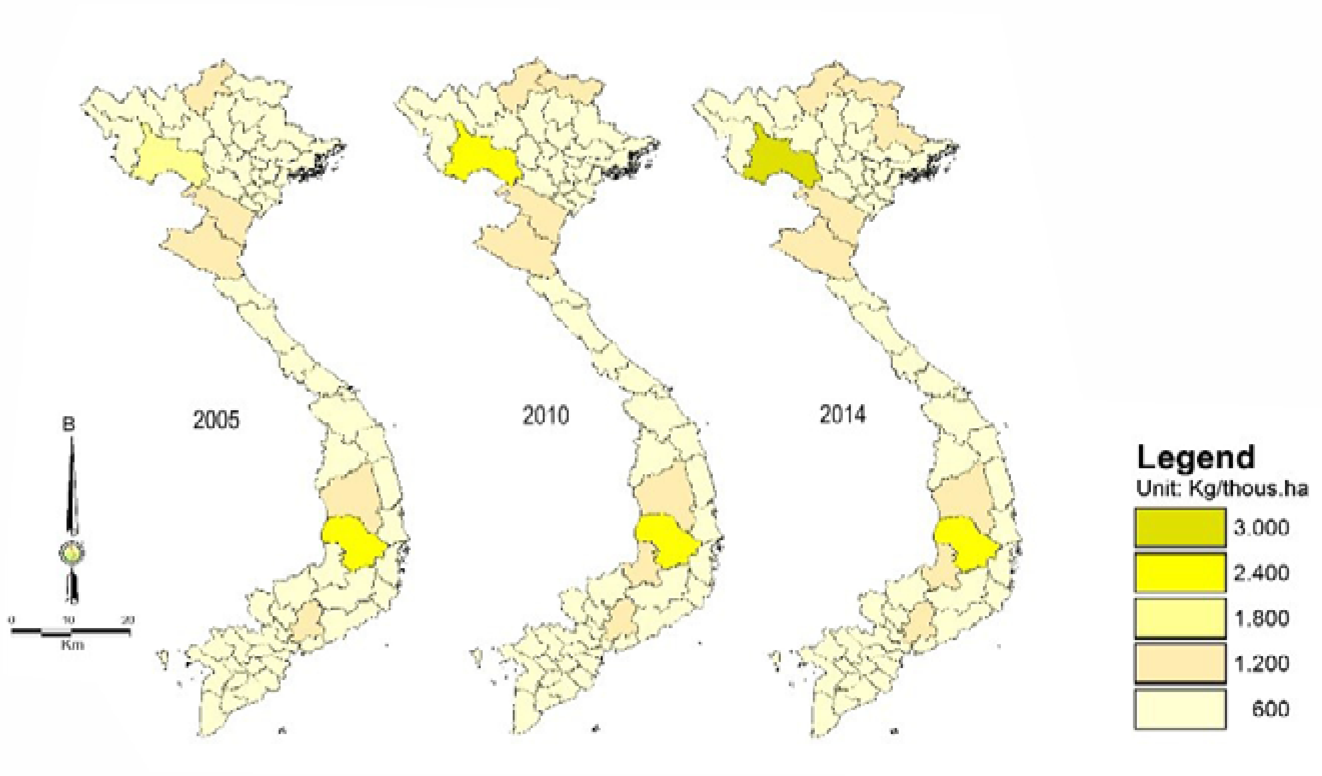
8 By DARDs, Agricultural Extension Centers, Division of Plant Protection, and other research institutes and universities. These were based on local trials, which have proven to be the most effective.

9 This will reduce the effectiveness of pesticides because different types of pesticides may have similar functions.

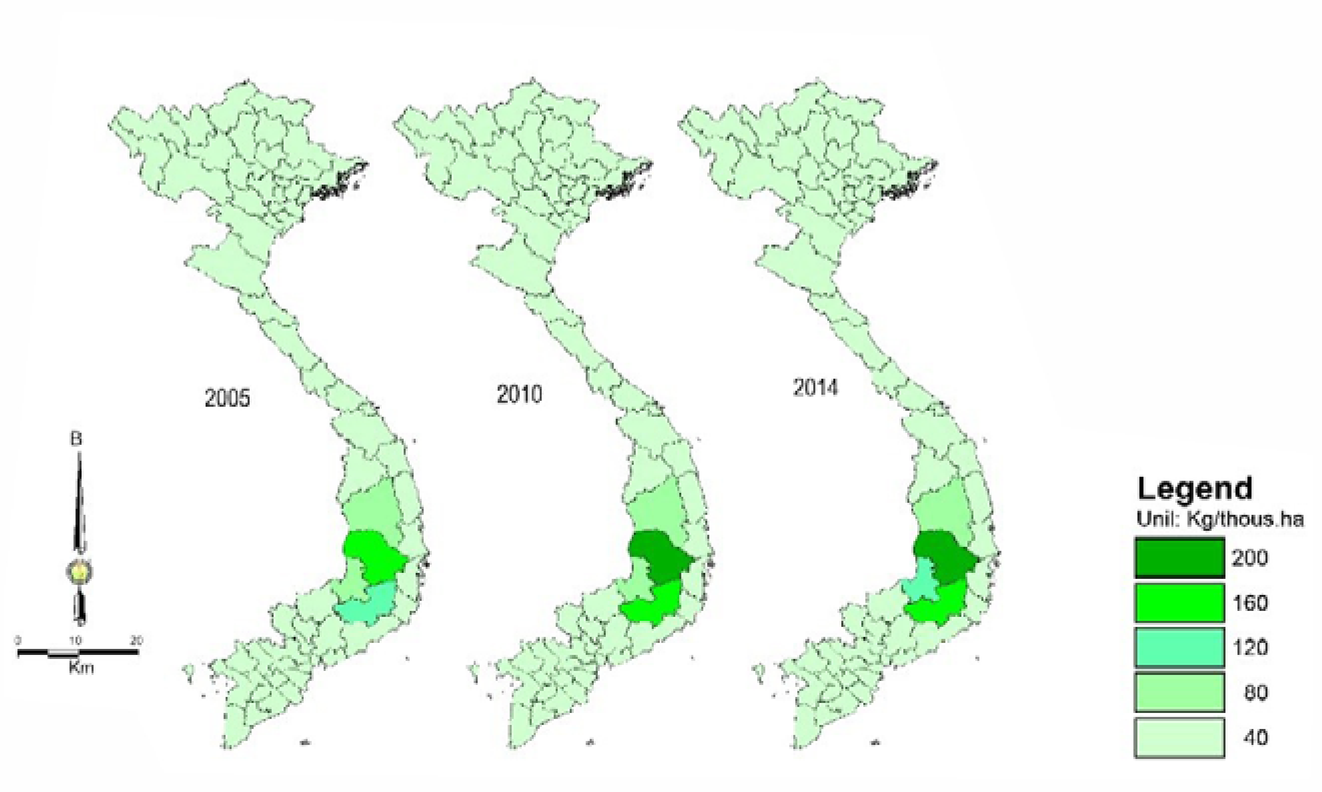
10 Refer to Circular No. 03/2015/TT-BNNPTNT on pesticides that are allowed and banned in Vietnam.

Figure 23. Pesticides used for rice, maize, and coffee production in Vietnam, 2005–2014

Maize production



Coffee production



Source: Based on GSO data.

Note: These figures were mapped based on grown area, yield, production, and pesticides used for each crop.

on the need to use pesticides (that is, misunderstand symbols of damage and get confused about the damages caused by insects and fungi, between insects and natural predators, between lack of nutrients and diseases, and so on). In many cases, pesticides are used as a preventive measure, and as the first line of defense (Phạm 2013).

Rice farmers still used organophosphate and organochlorine insecticides, and the trend to use pyrethroids was rapidly increasing in the MKD (Nguyen et al. 1999). Berg et al. (2001) reported that 64 different ai were used in rice cultivation in Can Tho and Tien Giang Provinces. These included banned pesticides, including methyl parathion and methamidophos (organophosphate compounds), which belong to WHO's Category Ia and Ib (extremely and highly hazardous), respectively; and endosulfan (organochlorine compound), which belongs to Category II (moderately hazardous) (Nguyen and Tran 1999; Dasgupta et al. 2007). The continued use of banned pesticides is partly due to their relatively low prices but also due to their broad spectrum of pest toxicity. In addition, the enforcement and control of hazardous chemical use is generally weak (Toan et al. 2013).

Farmers sometimes apply pesticides in the early stages of the rice crop's development to prevent leaf-feeding insect damage (especially leaf folder and leaf blast). Many believe that these pests affect rice yields. In rice production, 50–80 percent farmers used pesticides higher than the recommended levels (Bui, Vo, and Nguyen 2013) because they thought that a higher dosage is more effective against pests; no farmer used less than the recommended level. Farmers' overreaction with regard to pesticide use led to the outbreak of secondary pests such as the brown plant hopper, with negative economic and health consequences (Nguyen et al. 1999).

The use of pesticides is mostly determined by farmers' knowledge, practices, and economic conditions. Farmers obtain information about pesticide use and dosing from diverse sources. A survey in the MKD showed that approximately 28 percent of the respondents received assistance from agricultural extension officials regarding pesticide uses (Nguyen and Tran 1999). These often were the farmers who followed integrated pest management (IPM). The majority of farmers obtained information from other means, such as television, newspapers, pesticide retailers, and radio. A study conducted by Berg et al. (2001) and Nguyen and Tran (1999) showed that the farmers practicing IPM used less amounts of pesticides than non-IPM farmers (that is, application frequency and amount of ai used by non-IPM farmers were 2–3 times higher than those of IPM farmers on a crop basis). In general, the majority of farmers did not have a good understanding of pesticide uses. They often mixed 2–5 types of pesticides together in one spraying, seldom followed the guidance and instructions on the product labels, rarely respected the recommended preharvest intervals, and seldom used protective clothing/equipment (Toan et al. 2013; Phạm et al. 2013).

Although IPM has shown good results in pest management, its scale-up in the MKD has faced constraints related to the small scale of farms and complicated planting calendars. For instance, some farmers wanted to plant their rice during the off-season to fetch high selling prices and others did not care about rice farming because their rice fields are very small. Under those circumstances, IPM was less effective and farmers returned to their habits of relying on pesticides to control pests.

To address the constraints faced by IPM programs, in the past ten years, the government initiated the 3 Must and 3 Reduction (3R3G) and later the 1 Must and 5 Reduction (1M5R)[11] programs, and has promoted a "large field" model in which farmers voluntarily join together to form farmer organizations (FOs) or cooperatives. A recent study was conducted by the MDI (2015) to compare pesticides use in rice production in Kien Giang and An Giang Provinces between 1M5R farmers and a

11 The 3R3G package calls for farmers to reduce their use of seed, fertilizer, and pesticides to increase productivity, quality, and profitability. The 1M5R package calls for the use of certified seed and adds new requirements for reducing water and postharvest losses.

Table 11. Pesticide use in rice production in the Mekong Delta, 2014

Respondents (%)	Control	1M5R	T-test
According to farmers' habits	16.22	2.86	*
Farmers observed rice field	81.08	48.57	*
Farmers applied based on recommendation	2.70	48.57	*
Pesticides application times/crop			
Winter-spring	7.97 ± 0.29	5.2 ± 0.14	*
Summer-autumn	7.38 ± 0.27	6.25 ± 0.40	*
Autumn-winter	7.11 ± 0.24	4.3 ± 0.12	*
Annual average	**7.49**	**5.25**	*

Source: MDI surveys in Kien Giang and An Giang Provinces, 2015.
Note: * Difference at statistical significance α=5 percent.

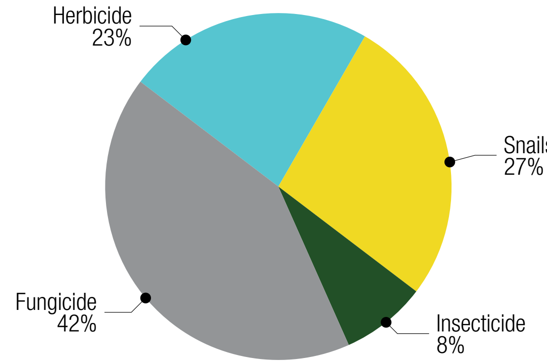
Table 12. Pesticides used in rice production in the Mekong Delta, 2014

Cropping seasons	Control		1M5R	
	Trade names	Active ingredients	Trade names	Active ingredients
Winter-spring	83	66	73	56
Summer-autumn	54	47	40	33
Autumn-winter	69	53	68	51
Annual average	**68.67**	**55.33**	**60.33**	**46.67**

Source: MDI surveys in Kien Giang and An Giang Provinces, 2015.

control group. It found that the number of sprayings per crop in all groups was still high (more than five times). However, the 1M5R farmers used significantly less pesticides than the control group (5.25 times per crop compared to 7.5 times per crop). In addition, the control farmers used pesticides mainly based on their habits and field observations (97.3 percent of respondents), and only 2.7 percent of them applied pesticides following the technical recommendations

Figure 24. Pesticides used in rice production by type



Source: MDI 2015.

(Table 11). In contrast, around 50 percent of the 1M5R farmers followed technical recommendations when using pesticides. The control group farmers used more than 55 ais of pesticides with nearly 70 trading products per crop (including snails, herbicides, insecticides, and fungicides; Table 12 and Figure 24), and the quantity of ai was more than 7 kg/ha/year (three rice cropping seasons, Table 13), whereas the 1M5R farmers used only 45 ais of pesticides with 60 trading products per crop, and the quantity of ai was more than 5.2 kg/ha/year. Regarding types of pesticides used, the use of fungicides and herbicides was more than the others (Table 13, Figure 24), and the winter-spring planting season used the highest amounts of pesticides compared to the summer-autumn and autumn-winter seasons. Compared to a previous study, the findings from this study showed that farmers have used new generation pesticides in

Table 13. Quantity of pesticides used in rice production in the Mekong Delta, 2014

Control (gram.ai/ha)	Summer-Autumn	Autumn-Winter	Winter-Spring	Whole Year
Control farmers (gram.ai/ha)				
Molluscicides	583.63	321.33	421.74	1,326.7
Herbicides	664.53	570.43	500.83	1,735.79
Insecticides	325.91	334.33	597.87	1,258.11
Fungicides	830.16	838.25	1,034.53	2,702.94
Total	**2,404.23**	**2,064.35**	**2,554.96**	**7,023.54**
Farmers who applied 1M5R (gram.ai/ha)				
Molluscicides	235.2	377.50	292.41	905.11
Herbicides	702.31	480.87	503.18	1,686.36
Insecticides	350.69	242.71	376.47	969.87
Fungicides	406.7	734.63	561.88	1,703.21
Total	**1,694.91**	**1,835.71**	**1,733.94**	**5,264.56**

Source: MDI surveys in Kien Giang and An Giang provinces, 2015.

Table 14. Chemicals used by rice farmers in the Mekong Delta

No	Groups of chemical	Proportion (%)
1	Conazoles	11.8
2	Pyrethroids	9.8
3	Biopesticides	8.8
4	Carbamates	6.9
5	Chlorinate phenoxy	6.9
6	Organophosphates	5.9
7	Chitin synthesis inhibitor	5.9
8	Amide	3.9
9	Molluscicide	3.9
10	Nicotinoid	3.9
11	Phosphorothiolate	3.9
12	Pyrazole	2.9
13	Sulfonylure	2.9
14	Nereistoxin	2
15	Organochlorines	1
16	Bipyridylim	1
17	Nitroguanidine	1
18	Anilide	1
19	Quinolinecarboxylic acid	1
20	Others	15.6

Source: Toan et al. 2013.

recent years, which more easily and quickly decompose in soil and water environment (Table 14). However, the groups of Pyrethoide and Carbamate still were used, which could threaten fisheries and other aquatic animals living at the bottom.

Based on the above review of farmers' practices and the recommended standards of the 1M5R package, an attempt has been made to estimate the wasted amounts of pesticides resulting from excessive use of pesticides. According to our calculations, every year about 1,790 ai tons of molluscicides, 210 ai tons of herbicides, 1,224 ai tons of insecticides, and 4,245 ai tons of fungicides are wasted from excessive/ unnecessary use in rice production in the MKD (Table 15). These chemicals are directly and indirectly causing air, water, and soil pollution and human health problems. These also increase production costs and reduce the quality of products from Vietnam.

Table 15. Estimated pesticides waste in Mekong Delta rice production

Unit: kg ai

Provinces	Snails	Herbicides	Insecticides	Fungicides
An Giang	263,831	30,933	180,381	625,631
Bac Lieu	75,422	8,843	51,566	178,852
Ben Tre	28,078	3,292	19,197	66,582
Ca Mau	52,994	6,213	36,232	125,666
Can Tho	97,935	11,483	66,958	232,237
Đong Thap	222,895	26,134	152,392	528,557
Hau Giang	86,552	10,148	59,176	205,245
Kien Giang	317,710	37,250	217,218	753,397
Long An	218,890	25,664	149,654	519,060
Soc Trang	153,417	17,988	104,891	363,802
Tien Giang	97,219	11,399	66,468	230,538
Tra Vinh	99,411	11,656	67,967	235,736
Vinh Long	75,971	8,907	51,941	180,151
Total	**1,790,324**	**209,909**	**1,224,040**	**4,245,453**

3.2.3 Pesticides used in maize and coffee production

There are few studies and reports available on farmers' use of pesticides in maize and coffee production in Vietnam. Through the key informant panel interviews and focus group discussion with advanced farmers, pesticide use in maize and coffee production was reported to vary from location to location and largely based on farmers' habits. In some cases, farmers actively apply them to treat the soil before planting to prevent pests. Integrated crop management (ICM) and IPM associated with integrated nutrient management (INM) are proposed for maize and coffee production. These tools are a broad-based approach rather than a package of farming techniques. Therefore, it is difficult to compare the actual use of pesticides and the recommended levels for these crops.

Maize is a crop resistant to pests and resilient to different soil conditions. Pesticides used in maize production are mainly to treat leaf diseases and worms on stems and fruits. Liquid pesticides are often used to treat diseases, while grain and powder pesticides are used to treat insects. Little information and few reports are currently available on the excessive use of pesticides in maize production.

In coffee farming, farmers often treat the soil before planting coffee, then pesticides are applied when pests are found on trees. The frequency of pesticides application is about 1–4 times a year and about 4 L/ha/year. Pesticides are used when insects, fungi, and nematode attack leaves, stems, root systems, and other parts of trees. The main types of insects include *Coccus viridis, Saissetia hemisphaerica, Pseudococcus* sp, *Stepphanoderes hampei, Xyleborus morstatti, Xylotrechus quadripes Chevrolat*, and diseases such as *Hemileia vastatrix, Corticicum salmonicolor, Zhizoctonia solani, Pratylenchus coffea, nấm Fusarium* spp., and *Rhizoctonia* spp. Little information and few reports are available on the excessive use of pesticides in coffee production.

3.3 Waste management

3.3.1 Wastes from farming inputs

Solid wastes generated from agricultural production activities are one of the big emerging problems in the rural areas of Vietnam (Chi 2011; MONRE 2014; Trương 2015). Toxic solid wastes from farming activities include residues of pesticides, fertilizers, and packaging materials (that is, bottles and bags). In 2008, around 11,000 tons of pesticide packaging materials and 240,000 tons of fertilizer packaging materials were generated (Khanh and Thanh 2010). On average, the volume of packaging materials accounted for about 10 percent of the total volume of pesticides/fertilizers. These wastes increased together with the increased use of pesticides and fertilizers in recent years. The problem is getting worse because those wastes were not handled and treated properly. The present most common ways are burning and burying them. Smoke released from burning causes air pollution and affects public health. Residues of pesticides and fertilizers from packaging bags and bottles could follow rainwater and irrigated water going to rivers and canals, which will then cause soil and water pollution killing fisheries and other aquatic animals.

In rice production, on average, 1 ha of rice farming will produce 12.8 kg of solid waste, including plastic (75.8 percent), glass and metal (21.9 percent), nylon (1.7 percent), and paper (0.6 percent) (Bui, Vo, and Nguyen 2013). Packaging materials of fertilizers and pesticides are major sources contributing to this waste.

Most farmers did not practice safe handling and storage of pesticides and fertilizers, and wastes generated from packaging materials at present are poorly managed. More than 70 percent farmers in the MKD, after using pesticides, dumped the bottles, bags, and so on into canals or in the rice fields. Only 17 percent farmers were reported to collect the wastes and treat them by burying or selling them for recycling. Approximately 90 percent farmers said that

Figure 25. Pesticide packaging waste collection bin, and pesticide packaging waste

they washed their sprayers right away at the rice fields, canals, ponds, or rivers. These practices would cause water pollution with impacts on fishery resources and biodiversity (Toan et al. 2013). With regard to storing pesticides and fertilizers, most farmers stored pesticides right in their houses, kitchens, or storages next to their houses. Only some farmers who registered to be certified for GAP (MARD 2010 Decision No. 2998/QĐ-BNN-TT dated 9/11/2010 on VietGAP implementation process for rice) or the 1M5R standards collected packaging materials and stored them properly in suitable places (Figure 25).

In short, rice farming activities, particularly in the MKD, generate a huge amount of solid waste, particularly from packaging materials of pesticides and fertilizers. This is one of the challenges faced by the rural environment, including increasing water and soil pollution. This problem needs to be addressed urgently. Rice producers themselves have to find suitable waste management solutions to reduce and stop it. At present, the government's monitoring and enforcement on agricultural waste handling and treatment is inadequate and not effective (MONRE 2014) as local authorities only encourage awareness of farmers on protecting the environment rather than making it a compulsory requirement. In addition, waste treatment technologies and facilities in rural areas are not available, so farmers have to do it in their own ways.

3.3.2 Wastes from crop outputs

Wastes generated from crop outputs include rice straw, rice husk, coffee husk, and other agricultural by-products. For instance, in 2010, these generated wastes included 61.9 million tons of paddy straw, 5.6 million tons of rice husk, 4.8 million tons of maize by-products, and 0.3 million tons of coffee husk. During 2013–2015, these generated wastes were 67.6 million tons of paddy straw, 11 million tons of rice husk, 4.4 million tons of maize by-products, and 0.7 million tons of coffee husk each year. (Table 16)

Paddy straw is generally considered a form of waste, and most is been burned after rice harvest. Up to 98.2 percent of farmers in the MKD burn straw after the winter-spring season, 89.7 percent burned them after the summer-autumn season, and 54.1 percent burned them after the autumn-winter season (Trần et al. 2014). Burning of crop residues has been a common practice to eliminate wastes after harvesting because it was a cheap and quick way to prepare land for the next crop. This practice directly contributes to air pollution and human health problems. Burning of these residues emits gases such as sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), black carbon (BC), organic carbon (OC), methane (CH_4), volatile organic compounds (VOC), non-methane hydrocarbons (NMHCs), ozone (O_3), aerosols, and so on, which affect the global atmospheric chemistry and climate (Tripathi, Singh, and Sharma 2013). On average, 1 kg of rice straw burnt directly on the field will emit 1.46 kg CO_2, 34.7 gm CO, and 56 gm of dust (flying and ash) (Gadde et al. 2009). CH4 emission from rice straw burning is around 2,200 g CH_4 per ton of rice straw (Yevich and Logan 2003). CH_4 emission factor from using rice straw for cattle feeding is around 15,000 g (10,000–20,000 g) CH_4 per ton of rice straw (Singhal et al. 2005). If we assume 50 percent of rice straw is burnt in Vietnam, it would emit around 100 million tons of CO_2 per year (Phạm and Yoshiro 2015). Burning is particularly popular among farmers who want to reduce the rest time between two rice crops, and who do not have uses for straw as livestock feed.

Some farmers have turned to alternative uses of rice straw in recent years. Instead of burning, some farmers reportedly collect and recycle rice straw on farms. For instance, paddy straw is sometimes used for vegetable cultivation, mushroom production, and animal feeding; rice husk and coffee husk are sometimes used for producing black coal in industries and for domestic use; and maize by-products are sometimes used for producing animal feed (fermented and fresh feeds). Some reports suggest that alternative uses of straw increased after 2015, helped by increases in the selling price of rice straw and the availability of equipment to collect and roll it. However, no official data or statistics have been reported on this. Currently (2017), from observations in actual rice farming in the

Table 16. Rice production and estimated rice straw generation

No.	Region	Rice production (dry 1,000 ton)	Rice straw quantity (dry 1,000 ton)	Rice straw density (dry ton/km^2)
1	RRD	6,698.0	10,273	487.8
2	Northern Midlands and mountain areas	3,275.8	5,024	52.73
3	Northern Central and Central Coastal areas	6,600.7	10,123	105.63
4	CH	1,162.8	1,783	32.64
5	South East	1,345.8	2,064	87.49
6	Mekong River Delta	24,993.0	38,331	944.77
7	**Total**	**44,076.1**	**67,599**	**204.24**

Source: Based on GSO 2013 data and estimation based on correlation between rice yield and straw.

MKD, burning rice straw in winter-spring and early spring-autumn seasons is still the preferred means of disposal.

PHYSICAL IMPACTS

4

Agricultural pollution exists in various forms, which can be classified into water pollution (that is, surface water and groundwater), soil pollution, and air pollution. They will be reviewed and discussed in the following sections.

4.1 Surface water pollution

The overuse of pesticides is one of the most important causes of water pollution as relates to crop farming activities. In past decades, the application of pesticides in Vietnam, especially in the MKD, was higher than in some other countries in Asia, including India, the Philippines, and Indonesia (Nguyen and Tran 1999). As such, adverse impacts of pesticide residues on surface water systems, especially on nontarget organisms, are inevitable (Sebesvari et al. 2012). Unsafe pesticide handling, improper labor protection, and poor awareness of pesticide toxicology were also reported to have negative consequences on human health (Berg et al. 2001; Toan et al. 2013).

Concerning levels of pesticides have been found in water, soil, and sediments in the past decade. Maximum concentrations recorded were up to 11.24 µg/L in water for isoprothiolane and up to 521 µg/kg of dry matter in sediment for buprofezin (Toan et al. 2013). Residues of several organochlorine and organophosphate pesticides (diazinon, fenitrothion, and endosulfan sulfate cyclic) in water bodies of the MKD were also reported, ranging from 3.5 to 42.8 µg/L (Carvalho et al. 2008). Endosulfan was detected in 2.6 percent and 17.4 percent of the samples in some places of the MKD (Ba Lang and An Long, respectively). In 9.2 percent (An Long) and 1.3 percent (Ba Lang) of the samples, concentration exceeded the B1 quality guideline of this regulation (0.01 µg/L), meaning that the water is not suitable for irrigation purposes (Sebesvari et al. 2012). These findings suggest that surface water is so polluted that it is not suitable for farming activities. Even in rainwater or purchased bottled water, up to 12 different pesticides were detected at concentrations exceeding the European Commission's parametric guideline values for individual or total pesticides in drinking water (Nguyen, C. G. D. 2015). Occurrence of pesticides in the environment throughout the year and co-occurrence of several pesticides indicated a considerable chronic exposure of biota and humans to pesticides.

Pollution of drinking water sources with agrochemicals is a major threat to human health in the MKD. This is a serious problem because most rural people in the MKD use surface water from rivers as their main source of drinking water. Normally, after getting water from the river, rural villagers keep it in jars for a few days to let solid particles settle down before boiling it for drinking. Such simple treatments are not sufficient to remove dissolved and nonvolatile chemical pollutants that are present in the water.

In summary, the use of pesticides and fertilizer has agriculture has intensified over the past decades, and this has seriously impacted surface water and drinking water quality (Propsom 2010; Pham et al. 2012; Toan et al. 2013; Nguyen, C. G. D. et al. 2015). Agrochemical residues are causing various degrees of pollution in rivers and canals in rural areas (Truyet and Quang 2003). However, so far, the study of surface water pollution has focused mostly on pesticides and not much on fertilizers. There are still big knowledge gaps in these areas, and more comprehensive work on water pollution is needed.

4.2 Groundwater pollution

Residues of pesticides and fertilizers used in farming activities are among the main contributors to groundwater pollution. In rural areas of Vietnam, groundwater is extracted and used for domestic, agricultural, and industrial purposes. Nitrate, phosphate, and pesticide residues are the key pollutants that result from the excessive and improper use and low efficiency of fertilizers and pesticides available in the market. Pollution is mainly concentrated in and around intensively farmed areas, especially intensive rice-growing areas.

Pesticides used in rice fields pose a serious problem for groundwater extracted from wells (Lamers et al. 2011). In 2010, during two rice cropping seasons, Schumacher et al. (2011) monitored five commonly applied pesticides (that is, imidacloprid, fenitrothion, fenobucarb, trichlorfon, and dichlorvos) in 16 wells and one natural spring. The wells and the spring were serving domestic and drinking water to local populations. In addition, an extensive field survey of rice farmers was conducted to gain an understanding of current pesticide uses and application practices, and water consumption habits. The study detected all of the monitored pesticides in the groundwater. More specifically, 27 percent (spring season, n = 97) and 35 percent (summer season, n = 105) of the analyzed water samples[12] showed pesticide concentrations above the detection limit. Pesticide concentrations in 22 percent and 31 percent of samples exceeded 0.1 µg/L, the threshold for drinking water in Europe (European Commission). Peak concentrations of 2.1 µg/L and 4.0 µg/L were detected for imidacloprid during the spring and summer seasons, respectively.

To date, studies on groundwater pollution in Vietnam caused by pesticide and fertilizer residues are limited. Most pollution studies still focus on heavy metals such as arsenic (As), pH, calcium carbonate ($CaCO_3$), *E. Coli*, and chlorine (Cl) contents (especially dissolved iron (II), As, and manganese), N compounds (nitrate and ammonium) (Berg et al. 2001; Buschmann et al. 2008; Erban et al. 2013; IGES 2007; IUCN 2011; Merola et al. 2015; Nguyen, N. V. 2006; Takizawa 2008).

4.3 Soil pollution

Soil pollution is defined as the buildup in soil of persistent toxic compounds, chemicals, salts, and radioactive materials, which have adverse effects on plant growth and animal health. There are different ways in which soils can be polluted, including percolation of contaminated water into soil and excess application of pesticides and fertilizers. In

12 Samples taken during the spring and summer seasons, but at the same place.

rural farming areas, soil pollution is often associated with the indiscriminate use of fertilizers and pesticides (USAGIC 2008).

The overuse and low efficiency of fertilizers are the main causes of soil fertility loss (Phạm 2006). Plant growth needs soil nutrients, and farmers supply necessary nutrients like N, P, K, calcium, magnesium, and sulphur into the soil to feed the plants, in addition to carbon, hydrogen, and oxygen available in air and water. Fertilizers can contaminate the soil with their impurities which come from the raw materials used in manufacture. Mixed fertilizers often contain ammonium nitrate (NH_4NO_3), P as P_2O_5, and K as K_2O, that is, macronutrients. Micronutrients such as As, Pb, and Cd, present in traces in rock phosphate, and other minerals are also added to superphosphate fertilizer. Because metals are not degradable, their accumulation in the soil above toxic levels due to excessive use of phosphate fertilizers becomes an indestructible poison for crops. The overuse of NPK fertilizers can ultimately reduce the quantity of vegetables and other crops that can be grown in a soil. It can also affect the protein content and carbohydrate quality of crops grown in that soil. Excess potassium content in soil decreases Vitamin C and carotene contents in vegetables and fruits. Vegetables and fruits grown on overfertilized soil are also more prone to attacks by insects and diseases.

Fertilizers' degrading effects on soils can be imperceptible, but cumulatively, fertilizers can seriously pollute receiving water bodies, soils, and the environment unless preventive measures are taken. In developed countries, levels of fertilizer application are based on regular soil analyses to prevent negative effects. Generally speaking, this is not often done in developing countries like Vietnam, where farmers apply excessive quantities of fertilizers based on the erroneous belief that more fertilizer will always result in higher crop yields and increased profits (MRCs 2001). In fact, overuse of NPK fertilizers in crops could lead to imbalance of micronutrients in soils and accumulation of toxic substances in crop root systems (Tran, Đức, and Quý 2013).

High rates of N fertilization can lead to soil acidification. This process occurs when ammonium in N fertilizers undergoes nitrification to form nitrate, and that nitrate leaches into the soil. However, ammonium-based fertilizers can also contribute directly to acidification in the absence of nitrate leaching (Crews and Peoples 2004). Soil acidification is a problem in East Asian countries (FAO 2003). For example, a recent survey on major crop production areas found significant acidification of all top soils primarily due to high N fertilizer inputs. Long-term water saturation and continuous monoculture can also affect soil conditions by causing micronutrient deficiencies, particularly of zinc, and increased soil toxicities, especially due to iron buildup (Pingali and Rosegrant 1994). Over time, excessive applications of N lead to soil acidification. Highly acidic soils are inefficient at transferring nutrients from the soil to the plants, causing crop yields to remain below their potential (IDH Vietnam 2013).

The excessive and indiscriminate use of pesticides are two of the most direct causes of soil pollution. Plants are susceptive to attack from insects, fungi, bacteria, viruses, rodents, and other animals, and they must also compete with weeds for nutrients. To protect crops, farmers use pesticides (such as dichloro-diphenyl-trichloroethane [DDT], benzene hexachloride [BHC], aldrin, malathion, dieldrin, furodan, chlorinated hydrocarbons, organophosphates, and others). Pesticide remnants get adsorbed by soil particles, which then contaminate crops through their roots. The consumption of such crops causes the pesticide remnants to enter humans' and animals' biological systems, with potential adverse effects. Pesticides not only have a toxic effect on humans and animals but also decrease soil fertility. This is because some pesticides are quite stable and their biodegradation may take weeks and even months.

While the excessive use of pesticides and fertilizers on crops have been widely reported, their environmental and socioeconomic impacts have not been studied systematically. Few studies on Vietnam analyze and evaluate the impacts of pollution or seek to valuate these in economic terms. The information,

Table 17. GHG emissions by sector, 1994–2010

Unit: 1,000 tons

Sectors	1994		2000		2010	
	CO_2e	(%)	CO_2e	(%)	CO_2e	(%)
Energy	25,637.1	24.7	52,773.5	35.0	141,170.8	53.1
Industrial process	3,807.2	3.7	10,005.7	6.6	21,172.0	7.9
Agriculture	52,450.0	50.5	65,090.7	43.1	88,354.8	33.2
LULUCF[a]	19,380.0	18.7	15,104.7	10.0	–19,218.6	—
Wastes	2,565.0	2.5	7,925.2	5.3	15,351.7	5.8
Total	**103,839.3**	**100.0**	**150,899.7**	**100.0**	**246,830.7**	**100.0**

Source: MONRE 2014. *Note:* a. Land use, land-use change, and forestry.

knowledge, and available data on impacts in Vietnam are very limited and scattered.

4.4 Air pollution

Various farming and agricultural waste-handling practices give rise to different forms of air pollution. One critical group of air pollutants is GHGs. Together, wheat, maize, and rice consume 45–50 percent of all N fertilizers produced around the world (Heffer 2009; 2013). However, only half the amount of N in the applied fertilizers is recovered in the crops or soil (Matson et al. 1997). The remaining N exists in various forms, causing impacts on ecosystems and public health before it is ultimately denitrified (conversion of inorganic N forms to N_2). One of the forms of N that is lost to the atmosphere is N_2O, and it is closely associated with N fertilized agriculture (Ortiz-Monasterio et al. 2010). In addition, rice production is a significant emitter of CH_4 because the warm and waterlogged soils in rice paddies are an ideal habitat for CH_4-producing microbes. Globally, rice systems account for 11 percent of agricultural GHG emissions, with South Asia and East Asia responsible for 82 percent of the total CH_4 emissions from rice (IPCC 2007). Continuously flooded and irrigated rice fields produce more CH_4 than rain-fed systems that are drained for short periods (Wassmann et al. 1995; Yan, Ohara, and Akimoto 2003).

In Vietnam, the agricultural sector is the second-largest contributor to Vietnam's total GHG emissions. In 1994, GHG emissions from agriculture were around 52.5 million tons of CO_2e[13] (50.5 percent of Vietnam's total GHG emissions). They increased to 65.1 million tons in 2000 (43.1 percent), and up to 88.4 million tons in 2010 (33.2 percent) (Table 17)(MONRE 2014). Agricultural sources of GHG emissions include livestock (feed digestion) (10.7 percent), organic fertilizer management (9.7 percent), agricultural land (27 percent), and the burning of byproducts (2.1 percent) (Table 18). Rice production accounts for more than 50 percent of agricultural GHG emissions, or 44.6 million tons of CO_2e (MONRE 2014). GHG emissions in rice production are predicted to reach around 39.4 million tons of CO_2e (39 percent) in 2020 and 40 million tons of CO_2e (36.5 percent) in 2030 (Table 19). The

Table 18. Agricultural GHG emissions, 2010

Unit: 1,000 tons

Emission sources	CH_4	N_2O	CO_2e	Share (%)
A. Livestock (feed digestion)	9,467.5	0.0	9,467.5	10.7
B. Organic fertilizer management	2,319.5	6,240.5	8,560.0	9.7
C. Rice cultivation	44,614.2	0.0	44,614.2	50.5
Irrigation	41,310.3	—	41,310.3	—
Rain-fed	3,304.0	—	3,304.0	—
D. Agricultural lands	0.0	23,812.0	23,812.0	27.0
E. Savana burning (grazing)	1.4	0.3	1.7	—
F. Agricultural by-products burning	1,506.3	393.0	1,899.3	2.1
Cereals	1,431.4	348.0	1,779.4	—
Legumes	23.0	15.0	38.0	—
Others	51.9	30.0	81.9	—
Total	**57,909.0**	**30,445.8**	**88,354.8**	**100.0**

Source: MONRE 2014.

13 Carbon dioxide equivalent (CO_2 equivalent).

Table 19. Projected agricultural GHG emissions, 2020–2030

Unit: 1,000 ton CO_2e

Emission sources	2010		2020		2030	
	Emission	(%)	Emission	(%)	Emission	(%)
Livestock	18,030.0	20.4	24,948.0	24.8	29,322.0	26.8
Rice cultivation	44,614.0	50.5	39,360.0	39.1	39,949.0	36.5
Agricultural lands	23,812.0	27.0	33,947.0	33.7	37,397.0	34.2
Agricultural by-products burning	1,899.0	2.1	2,504.0	2.5	2,673.0	2.4
Total	**88,355.0**	**100.0**	**100,759.0**	**100.0**	**109,341.0**	**100.0**

Source: MONRE 2014.

Table 20. Methane emissions from rice production in An Giang Province

kg CH_4/ha/crop

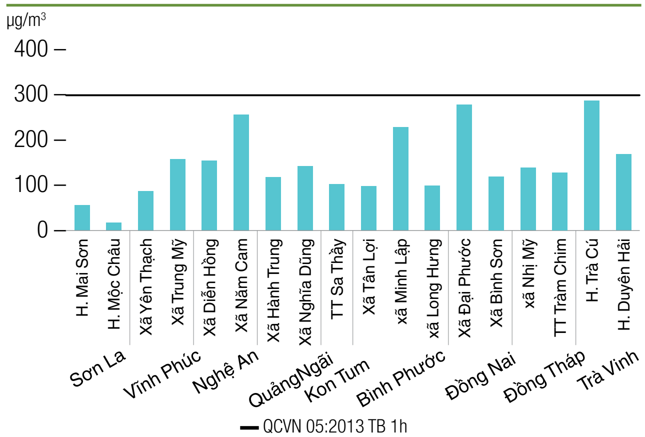
Cropping season	Control treatment	1M5R treatment	Variation
1	151	n.a.	n.a.
2	132	39	93*
3	82	58	24
4	217	92	125*
5	370	165	205*

Source: VLCRP (2013–2014).
Note: n.a. = not available. * Difference at statistical significance α=5 percent.

magnitude and pattern of GHG emissions from rice fields are largely determined by water regimes and organic inputs, and to a lesser extent by soil-type, weather, tillage, residue management, fertilizer use, and rice cultivars. Flooding of the soil is a prerequisite for sustained emissions of CH_4 (Reynolds 2010).

The 1M5R technical package, which is being promoted in the MKD, has shown promising results in reducing GHG emissions in rice production in recent years. The principles of this technique include regulating water levels in rice fields and reducing N fertilizer use. The Vietnam Low Carbon Rice Project (VLCRP) (2013–2014) reported that the amount of CH_4 emitted in the experimental 1M5R pilot was significantly lower than that of the control (traditional farming) in three out of four crop seasons (Table 20). The average annual GHG reduction in the 1M5R pilot was 7.7 metric tons CO_2eq/ha, though it varied considerably between seasons. Nguyen et al. (2016) showed that alternate wetting and drying (AWD) together with organic fertilizer use (combining biochar and compost) in rice production helped reduce CH_4 and N_2O emissions up to 53.4 percent in comparison to the traditional farming.

Figure 26. Total suspended particles in different rural areas



Source: Department of Natural Resources and Environment of Son La, Vinh Phuc, Nghe An, Quang Ngai, Kon Tum, Binh Phuoc, Dong Nai, Dong Thap and Tra Vinh Provinces, cited by MONRE 2014.

The practice of burning rice straw and other agricultural waste also contributes to emissions of GHGs, dust, and other solid particles. Figure 26 shows that the contents of total suspended particles (TSP) in the air in some rural areas of Vietnam have now nearly reached the maximum limit of the national standard (MONRE 2014).

4.5 Wildlife health and biodiversity losses

4.5.1 Fertilizers use

The leaching of N and other fertilizer nutrients into fresh and saltwater environments can lead to a state of eutrophication, resulting in algae blooms and dissolved oxygen depletion. "Dead zones" may develop in areas where the dissolved oxygen contents of water dramatically drop. Eutrophication also reduces the diversity of aquatic resources, including fish populations.

High fertilizer and pesticide use is often found in intensive rice farming systems. About 10 percent of global N fertilizer is dedicated to rice production. When applied during flooding, fertilizers can lose N compounds through leaching, denitrification, volatilization, and runoff. Urea, which provides about 80 percent of N supplied to rice, is highly water soluble and particularly susceptible to losses. Escaped N from rice systems causes air and water pollution and may be especially lethal to fish in downstream ecosystems.

4.5.2 Pesticides use

Leaching of pesticides into water systems can also lead to negative impacts on human health and on the quantity and diversity of insects and wildlife near rice paddies (Ghosh and Bhat 1998). While pesticide filtration into soil and water harms animal and human health, it also causes loss of fisheries resources and biodiversity in terrestrial and aquatic ecosystems (Cagauan 1995; Leonard 2010; Nguyễn, Nguyễn, and Bayley 2008). Efficiency rates of pesticide applications are even lower than those of fertilizers. Some studies have estimated that less than 0.1 percent of the pesticide amount applied to crops actually reaches the intended pests (not Vietnam specific, Arias-Estevez et al. 2008). The remainder accumulates in soils where it may filter into groundwater or surface water and prove toxic to microorganisms, aquatic animals, and humans. The accumulation of pesticides in soils can harm arthropods, earthworms, fungi, bacteria, protozoa, and other organisms that contribute to the functions and structure of soils. Exposure of birds to pesticides can cause reproductive failure, or even kill them directly at high enough doses. Domesticated livestock may also be affected by exposure to pesticides (Wilson and Tisdell 2001).

Pesticide use in rice production has been associated with negative effects on fish populations in Vietnam's rice-fish production systems (Kleimick and Lichtenberg 2008). Studies on physiological changes in fish revealed long-lasting effects of organophosphate pesticides on the fish population health in Vietnam (Nguyễn, Nguyễn, and Bayley 2008). In another study, a representative farming system based on a paddy field connected to a fish pond was chosen in 2008 to examine the environmental fate of agrochemicals. A mixture of two pesticides (dimethoate and fenitrothion) was applied in two consecutive rice growing seasons. Under the study conditions, both pesticides dissipated rapidly from paddy water. A significant fraction of dimethoate was transported with the outflow while the losses of denitrothion were lower during both seasons. The simultaneous appearance of both pesticides in soil water at two depths indicated the potential for disruption to microorganism systems in soils (Anyusheva et al. 2008). When pesticides are used in rice fields, their residues are not just confined to those rice fields. The water discharged and overflows from the rice fields will also contaminate the surrounding soil and water. Prolonged misuse of pesticides, herbicides, and fertilizers over the years has shown much reduction of inland fisheries in the MKD in the past decades.[14]

Pesticide pollution can have direct negative effects on local aquatic environments, preventing the growth of or destroying the structures of aquatic ecosystems (Margni et al. 2002). Indirectly, it also affects organisms that reach these polluted water sources such as migratory fish and aquatic birds, and beneficial soil microorganisms that support insects and plants (Agrawal et al. 2010). These negative effects not only exist where pesticides are applied, but also in downstream areas. Pesticide contamination can cause a loss in the value of water resources, particularly surface water in rural areas (Dang and Gopalakrishnan 2003) where surface water is used for irrigation, personal hygiene, washing, and especially drinking and cooking in the dry season.

14 www.servenet/agriculture/fish/forestry.

4.6 Other environmental concerns

Below are some other environment concerns relating to farming activities:

Farming practices

- Overirrigation and poor drainage can cause waterlogging and soil salinization, which can decrease soil productivity and lead to a decline in crop yields.
- Runoff from irrigation and high extraction rates can damage downstream natural ecosystems.
- Land preparation and multi-cropping can cause a self-accelerating process of land degradation leading to more reliance on fertilizer.

Continuous cropping

- Consecutive crop cycles mine nutrients from the soil, encouraging more fertilizer use.
- Continuous cropping can lead to higher pesticide use by disrupting farmers' ability to take advantage of natural pest balances.

New seed varieties introduction

- Many new seed varieties require high inputs (fertilizer, pesticides, and water), which negatively impact soil conditions, water quality and quantity, and biodiversity.
- Improved seeds can threaten natural genetic diversity of crops.

Intensive rice production

- Inadequate drainage and continuous flooding can cause waterlogging, soil salinization, nutrient deficiencies, and increased soil toxicity.
- Irrigation for intensive rice production requires large volumes of water and can leach chemicals into downstream ecosystems.

Table 21. Overview of agricultural technologies and impacts on ecosystem services

Technology	Impacts on soil	Impacts on water	Impact on biodiversity	Impacts on air/climate
Chemical fertilizers	Increased soil acidification due to nitrate leaching	Reduced dissolved oxygen levels due to runoff, harming aquatic ecosystems, reducing water quality for human uses	—	Contributing to smog, ozone, acid rain, and N_2O emissions
Pesticides	—	—	Harming animal and human health by accumulating in soils and leaching into water bodies	—
Intensive rice production	Inadequate drainage and continuous flooding causes waterlogging, salinization, and nutrient problems	Degraded downstream ecosystems due to polluted runoff and overextraction of water	—	Contributing to CH_4 emissions due to anaerobic conditions in paddy fields

Source: Killebrew and Wolff 2010.

- Low-oxygen conditions of flooded rice paddies support CH4-producing organisms.

In summary, while they can help protect plants and enhance crop yields when judiciously used, pesticides and fertilizers can also have negative impacts (Table 21). The improper use of pesticides can cause water and soil pollution, animal deaths, biodiversity losses, and human health problems. The excessive and improper use of fertilizer can cause environmental problems that include the following (Killebrew and Wolff 2010; MRCs 2001; Rudek and Tinh 2015).

- N and P residues follow the runoff and water flows contributing to eutrophication in receiving waters, risking depletion of dissolved oxygen and die-off of fish and aquatic organisms.

- NH_3 gas can cause haze and contribute to the acidification of soils; nitric gas contributes to smog, ozone, and acid rains.
- NO_x can contribute to acid rain at the regional level and local air quality impairment.
- SO_2 combines with other gases and contributes to haze formation and also acid rain at the regional level.
- Dust can be a local nuisance and contribute to visible haze.
- Fluoride (F), in high concentrations, is dangerous to plants and animals.
- Nitrogen overuse and improper water management in rice production can affect N_2O and CH_4 emissions.
- Nitrate leaching and ammonium-based fertilizers contribute to soil acidification.
- Inefficient fertilization is a major source of N_2O.

SOCIOECONOMIC IMPACTS

5

The multiplication of cropping seasons per year, the improper use of chemical fertilizer and pesticides, and less use of organic fertilizer can cause soil degradation, fertility loss, and erosion. These in turn can affect crop and farm productivity. To maintain rice yields, farmers have to increase fertilizer and pesticide use, leading to higher production costs, lower net revenues, environmental costs, and negative impacts on public health (Vo, Trần, and Châu 2010).

5.1 Social impacts

Nitrate, pesticide residues, and other toxic chemicals in foods and drinking water can cause serious health problems if people are exposed to them for a long period. According to the national media, one of the main causes of cancer in Vietnam is related to food safety issues including the presence of toxic chemical residues in foods, drinking water, and the air. Rural populations may be particularly at risk as they are exposed to agricultural chemicals every day. Pesticides and other agrochemicals are also destructive to fisheries and other aquatic resources on which low-income rural populations tend to rely on as a food source to a large extent.

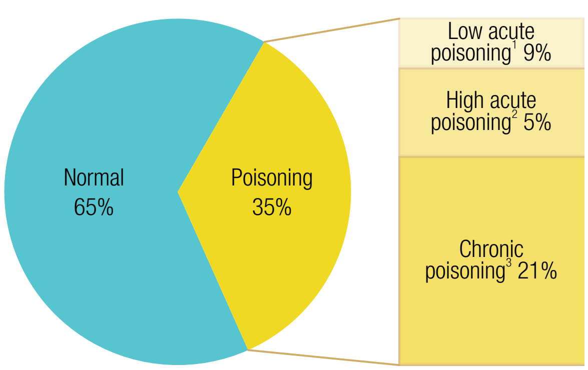
Health and other social impacts of pollution not only vary by pollutant, but also according to the intensity and duration of exposure—and these can be influenced by socioeconomic conditions (Ngan and Thang 2006). Humans may be directly exposed to pesticides through breathing and touching chemicals while spraying or indirectly by drinking contaminated water and consuming food products, such as rice, vegetables, and fish containing pesticide residues (Özdemir et al. 2011; Toan et al. 2013; Wilbers et al. 2013, 2014). Contamination can cause headaches, irritation, breathlessness, vomiting, and so on, and even cancer or other forms of tumors in serious cases (Dasgupta et al. 2007). In addition, farmers and agricultural workers face chronic health effects with eye, dermal, pulmonary, and kidney problems due to prolonged exposure to pesticides (MRCs 2001). The most vulnerable groups are youth and people who are poor and have limited education because they are often in charge of pesticide application services (through so-called agricultural service groups).

Unsafe applications of pesticides are the cause of accidents for workers and food poisoning for consumers (Propsom 2010; Hoi, Mol, and Oosterveer 2013). In 2005, the Viet Nam Food Administration reported 133 cases of food poisoning and 4,000 injuries. In 2007, the Ministry of Health (MOH) reported that 7,329 people were injured by chemical residues on produce and that 55 cases were fatal (Hoi, Mol, and Oosterveer 2009). Chemical agents were responsible for 25 percent of food poisoning cases (Propsom 2010; World Bank 2006). Pesticide poisoning often caused serious cases. Poisoned patients had to be admitted to hospitals for treatment; so, functional offices could collect reliable data on those cases. However, there were also many minor poisoning cases that were treated at community health centers, so they were not reported.

A study conducted in the MKD in 2015 showed frightening results, with pesticide residues detected in the blood of farmers (Dasgupta et al. 2007). Blood cholinesterase tests suggested that the incidence of poisoning from exposure to organophosphates and carbamates was quite high. In the blood tests regression analysis (Figure 27), it revealed a lower incidence of poisoning among farmers who avoided the most toxic pesticides and used protective gear. The most commonly reported symptoms were dermal (skin irritation: 63 percent), neurological (headache: 60 percent; dizziness: 53 percent), ocular (eye irritation: 55 percent), and respiratory (shortness of breath: 45 percent). Most (88 percent) of the surveyed farmers reported multiple symptoms, with an average of four and a maximum of nine. Among farmers reporting symptoms, 82 percent attributed them to pesticide use (Figure 28). A survey conducted by MDI in 2013–2014 in An Giang province also showed that women suffered from more skin problems and headaches during retransplanting and weeding, right after pesticide spraying.

Data and studies on the social impacts of agricultural pollution are fragmented and limited. There are no comprehensive studies on impacts and no regular statistical reports at the regional and country levels. It is therefore difficult to quantify the full social costs of health impacts of agricultural pollution.

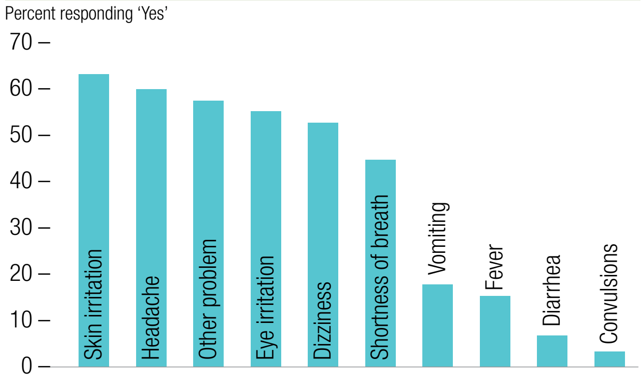
Figure 27. Medical blood test results for the detection of acute and chronic pesticide poisoning



Source: Dasgupta et al. 2007.

Note: 1. Reduction of numerical value of AchE red cells and in plasma >25%; 2. Reduction of numerical value of AchE red cells and in plasma >33%; 3. Reduction of numerical value of AchE red cells >66%.

Figure 28. Self-reported health impairments after using pesticides



Source: Dasgupta et al. 2007.

5.2 Economic impacts

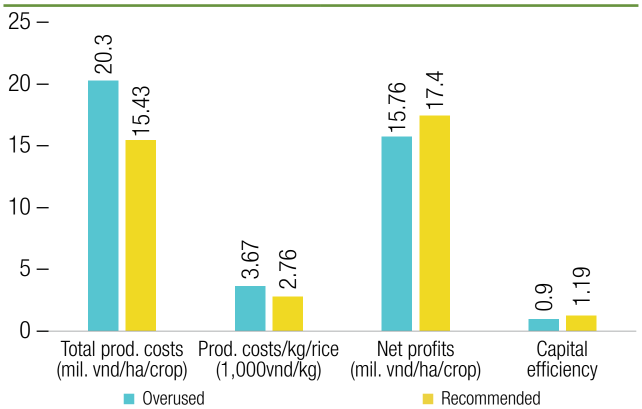
Economic impacts of excessive and improper uses of fertilizer, pesticides, and other inputs include increased production costs and reduced competitiveness of agricultural products, and lower financial returns to farmers. They also include higher risk in business transactions and product rejections due to nitrate and pesticide contamination.

A study to compare technical and economic efficiencies between farms applying the 1M5R package and a control group (overapplying fertilizer and pesticides) was undertaken through nine rice cropping seasons in the Kien Giang and An Giang provinces from 2012 to 2014. Control group farms had higher total costs and production costs per kilogram of rice than 1M5R farms. Correspondingly, the net profits and investment efficiency of the control groupwere lower than those of 1M5R farms (Nguyen, T. H. et al. 2015). The production costs of the "overuse farms" were around VND 20–22 million/ha/crop while they were only VND 15–18 million/ha/crop for the 1M5R farms (18–25 percent reduction). Respectively, production costs per kilogram of rice decreased from VND 3,500–3,700/kg in the control group to VND 2,760/kg in the 1M5R farms (Figure 29 and Figure 30). If production costs per hectare of rice farming were reduced by VND 4–5 million per crop, with each rice crop covering a planted area of approximately 4 million ha, Vietnamese farmers could save about VND 16,000 billion (equivalent to US$720 million) per crop or VND 32,000 billion (US$1.4 billion) each year (assuming two crops per year).

A statistical comparison between 1M5R and control group farms in Kien Giang and An Giang Provinces is presented in Table 22 and Table 23. The difference in total revenue between the two groups was not statistically significant (T-test at α=5 percent). However, the input factors, such as costs of seeds, fertilizers, and pesticides were significantly different. As a result, the gross margin, capital efficiency, and rate of return to input investment of the 1M5R farms were significantly higher than the control group. Table 22 and Table 23. Women farmers overapplying pesticides and fertilizer were reported to spend more time on rice farming than women farmers who adopted the 1M5R package (Nguyen, T. H. et al. 2015). Furthermore, economic returns to the former were lower than that of the latter (Table 24).

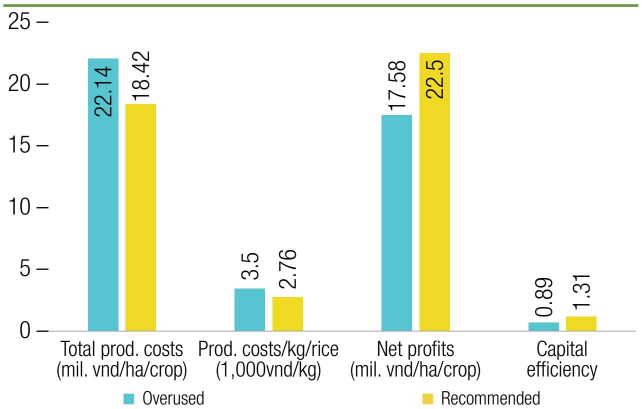
Nguyen and Tran (1999) also found that the quantity of pesticides applied was far higher than the optimal level for profit maximization. Insecticides negatively and significantly affected farmers' health through the number of contacts rather than the total dose. The higher the number of the doses and the number of applications of herbicides and fungicides, the bigger the health cost due to exposure. Nguyen and Tran (1999) revealed that

Figure 29. Economic comparison between 1M5R and control group farms in Kien Giang



Source: Nguyen, T. H. et al. 2015.

Figure 30. Economic comparison between 1M5R and control group farms in An Giang



Source: Nguyen, T. H. et al. 2015.

Table 22. Economic comparison between 1M5R and control group farms in Kien Giang

Unit: million VND/ha/crop

Parameters	1M5R	Overused	T-test
1. Costs			
Seed cost	1.73	2.21	*
Fertilizer cost	3.95	5.55	*
Pesticide cost	2.73	3.69	*
Pumping cost	0.62	0.71	*
Harvest cost	1.85	2.32	*
2. Total costs	14.59	19.32	*
3. Total revenue	33.88	32.87	ns
4. Gross margin	19.29	13.56	*
5. Returns to capital investmenta	1.38	0.75	*
6. Inputs' investment efficiency	3.40	2.51	*
7. Production costs (VND/kg)	2,607.30	3,506.98	*

Note: a. Net profit earned per VND 1 investment in rice production.
* Significant level at α= 5%, ns = non-significant.

Table 23. Economic comparison between 1M5R and control group farms in An Giang

Unit: million VND/ha

Parameters	1M5R	Overused	T-test
1. Costs			
Seed cost	1.77	1.84	ns
Fertilizer cost	5.34	7.09	*
Pesticide cost	3.20	4.11	*
Pumping cost	1.17	1.04	*
Harvest cost	2.46	2.61	*
2. Total costs	17.92	21.94	*
3. Total return	36.24	35.60	ns
4. Profits	18.32	13.65	*
5. Returns to capital investment	1.07	0.71	*
6. Inputs' investment efficiency	3.26	2.14	*
7. Production costs (VND/kg)	2,695.78	3,401.69	*

Note: * Significant level at α = 5%, ns = non-significant.

farmers overused pesticides by 274.4 ai grams per ha in rice production in the MKD and caused much impact by decreasing farm income and increasing health and environment costs. Recent surveys carried out in the MKD by Tin at el. (2015) and MDI (2013–2014) showed that, normally, pesticides and fertilizer costs account for approximately 50 percent of total rice production costs, so overuse of fertilizer and pesticides could increase rice production costs up to VND 4–5 million/ha/crop. These are all the more significant for poor farmers who have more constraints on capital investments. Meanwhile, Vietnamese food exports, including those of rice, suffer from pesticide-related trade rejections.[15] The lowering effect of such food safety issues on the price commanded by Vietnamese exports has not been studied empirically.

As in rice farming, the heavy use of chemical fertilizer and pesticides in coffee production has also led to higher production costs. In Vietnam, Robusta is grown on more than 90 percent of coffee plantations. Vietnam's coffee industry has taken the view that even for a lower-value commodity, it can be profitable if grown intensively. At present, chemical fertilizer and pesticide inputs account for about 25–50 percent and 3–8 percent of total production costs, respectively (Amarasinghe et al. 2013; Trương 2013). Among fertilizer input costs, N fertilizer accounts for an average of about 50 percent, P, 31 percent, and K, 19 percent. As noted, farmers have applied excessive chemical fertilizers compared to the levels recommended by specialists. It is estimated that if farmers followed the recommended levels for fertilization, they would save about 30 percent of chemical fertilizer (equivalent to US$17 million for the CH) (Truong 2015). Over the last two decades, the rising price of fertilizers has prevented coffee farmers from benefitting from the rising price of coffee beans in international markets, though the rising price of fuel and labor have also factored in (Truong 2015). In the CH region, income and livelihoods of coffee farmers are totally dependent on the profitability of

Table 24. Economic efficiency of women rice farming groups in the Mekong Delta

Items	An Giang		Kien Giang	
	Overused	1M5R	Overused	1M5R
Total costs	21.28	18.42	18.20	16.65
Total returns	35.67	38.18	36.20	36.24
Margin	14.40	19.76	17.99	19.58
Returns to capital investment	0.69	1.10	0.99	1.18
Yield (ton/ha/crop)	6.55	7.08	6.84	8.15

15 http://www.vinacert.vn/bai-hoc-tu-viec-nong-san-xuat-khau-bi-tra-ve_info.html.
http://nld.com.vn/kinh-te/nguy-co-my-cam-cua-gao-viet-la-lon-20161001073450761.htm.
http://www.baomoi.com/canh-bao-doanh-nghiep-can-trong-khi-xuat-khau-gao-sang-my/c/20456552.epi.

coffee-growing. Therefore, reducing production costs while maintaining or improving yields or market value are of great importance. In addition, improved income from coffee production would allow households to spend more on nutritious food and education.

Another problem in coffee production is overwatering, since it increases input losses, raises energy costs (linked to water pumping), and sometimes creates social conflict. On average, watering costs account for about 15–20 percent of total production costs, which amount to US$300–1,000/ha/year. The watering costs would be higher if farmers had to pay water fees. Because water fees do not apply, farmers lack a financial incentive to save water. Resulting competition for water has led to conflict within local communities (IDH Vietnam 2013).

There are few data on the socioeconomic impacts of excessive fertilizer and pesticide use in maize production. As mentioned in previous sections, few studies and reports are available on farmers' fertilization rates in maize production compared to recommended levels. This could be because overfertilization in maize cultivation is less common and less serious than that it is in rice and coffee farming.

DRIVERS AND RESPONSES TO POLLUTION

6

6.1 Factors contributing to agricultural pollution

6.1.1 Crop intensification, soil degradation, climate change, and weather extremes

Crop intensification is one of the most direct causes of agricultural pollution. In the past three decades, as a result of agricultural reforms, intensification has taken place in most agricultural crops, including rice, coffee, maize, fruit trees, and vegetables. This trend will continue, at least in the upcoming decade, as food demand continues to grow. In MARD's land-use plan to 2020, the harvested area for rice, coffee, and maize is relatively flat, but yields and production volumes are expected to increase further. This means greater intensification is expected for the main food crops. It also implies that more fertilizer, pesticides, and other inputs will be used to sustain yields and production volumes. If there is no effective solution to address fertilizer and pesticide residues as well as agricultural waste, the problems of agricultural pollution will continue to worsen.

Soil degradation due to consecutive cropping seasons and decreased use of organic fertilizer is also contributing to increased use of inorganic fertilizer. Owing to high intensification levels, soil fertility in those areas has decreased. In case of rice in the MKD, construction of closed dyke systems to prevent seasonal flooding for planting the third rice crop has reduced fertile alluvium from the Mekong River coming to replenish rice fields. In the CH and mountainous regions, forest clearance and soil erosion have contributed to soil degradation. To maintain and improve yields, farmers have had to use more fertilizer to compensate for the losses. A similar pattern has followed the loss of natural defenses against pests in intensified cropping systems.

Climate change impacts and quick pest evolution have imposed greater pressures on crop yields in recent years. Climate change impacts and extreme weather events (including changes in air temperature, rainfall regimes, long droughts, and so on) have pushed farmers to increase fertilizer applications. The excessive use of pesticides for prolonged periods kills most natural predators; so, pests evolve faster and put greater pressure on crops. Farmers have had no choice but to increase pesticide applications to kill pests. For example, in the winter-spring cropping season in An Giang province in 2014, extreme weather events led to increased applications of agrochemicals. As a result, production costs in that cropping season increased by 10 percent compared to those of the previous year.[16]

Environmental impacts of crop intensification have not been clearly understood especially at the ecological and landscape levels. So far, most attention has focused on the impacts at the farm level while wider, ecosystem- and landscape-level impacts have received limited attention, particularly in relation to coffee and maize.

6.1.2 Market forces, incentives, and farming practices

Most farmers have been more driven to increase short-term yields than to mazimize total net profits. This explains why the rice, maize, and coffee volumes have continued to increase steadily over time, even as profits have started to fall. In rural areas, achieving high crop yields is a source of pride (more so than high net profits), and it is common for farmers to compete on higher yields (more so than on profits).

Farmers' perceptions and misunderstandings about the relationship between input use and crop yields. The majority of farmers believe that higher inputs always result in higher yields and that the early application of pesticides helps prevent pests better. Such perceptions lead farmers to routinely overapply chemicals, as their financial means permit, rather than on the basis of soil and crop needs. Furthermore, the abuse of pesticides leads to pest resistance, and farmers respond by applying even higher amounts (more frequent or higher doses) and shifting to different pesticides. This leads to a neverending cycle of pest development and pesticide use.

There have been few incentives for farmers to produce safe, clean, or organic products. Despite the government trying to promote high-quality and safe products through the application of the GlobalG.A.P. and VietGAP criteria in the past decade, efforts to date still remain at a pilot and demonstration scale. Many farmers have adopted improved farming techniques and received certification, only to go back to their less-sustainable farming practices for lack of access to premium prices for higher-quality products. This is because value chains of major agricultural commodities are still largely underdeveloped and there are inadequate linkages between producers (farmers), traders (agribusinesses), and markets (consumers).

6.1.3 Oversupply of agricultural inputs and advertisements on mass media

The removal of import restrictions in 1991 allowed prices of chemical fertilizers, pesticides, and other inputs to drop by 50 percent in the following few years. This resulted in farmers moving from traditional organic and farm manure fertilizers to the imported chemical fertilizers to increase yields (World Bank 2004). Through the 1990s, the government created incentives for farmers to move to export crops. Cheaper inputs encouraged and allowed most farmers to use more of these in farming to achieve short-term gains in yields.

The availability of cheap fertilizers and pesticides in local markets and their advertisement in local mass media are encouraging farmers to use more of these. In the past decades, fertilizer and pesticide product companies, wholesalers, and retailers have spread and thriven across all farming areas in Vietnam. In 2010, there were some 200 companies involved in importing, processing, packing, and trading

16 Based on author interviews with DARD staff in 2015.

pesticides; 93 factories; and a network to supply and distribute pesticides to 28,750 wholesalers and shops (Truong 2015). In addition, there were numerous retailers at district and commune levels. Fertilizer and pesticide companies (such as Syngenta, Bayer, Loc Troi Cooperation, and others) have spent a lot to advertise and sponsor public activities and programs in rural areas (for example, Farmers' Bridge on TV, festivals, and so on). Such public relations activities made them well-known and appreciated by farmers and local authorities, so eventually, they were convinced and willing to try them. On the supply side, huge amounts of pesticides and chemicals are imported and/or smuggled from China across the border every year (Dieu 2014). According to Circular No. 03/2015/TT-BNNPTNT (2015), which was updated from Circular No. 21/2013/TT-BNNPTNT, presently, over 1,500 pesticides (ai names) are permitted for use in Vietnam (Table 25). This has created opportunities for pesticide companies to market and sell their products freely, and made it easy for farmers to access a large variety of chemicals. Things were getting worse when monitoring and control of pesticide use and trading in rural areas did not exist. Everyone could buy pesticides easily from wholesalers or retailers at low prices for all kinds of purposes.

Table 25. Number of pesticides permitted for use in Vietnam, 2013, 2015

	Active ingredient names	Trade names
Circular No. 21/2013/TT-BNNPTNT		
Insecticides	745	662
Fungicides	552	1229
Herbicides	217	664
Rats	10	22
Hormones	52	139
Insect attraction	8	9
Snails	25	134
Others	5	6
Circular No. 03/2015/TT-BNNPTNT (2015)		
Insecticide	769	Many
Fungicide	607	Huge amount
Herbicide	223	
Rat, hormone, snails, and others	>2,013	

The low and unreliable quality of many pesticides and fertilizers also leads farmers to apply more to ensure that they take effect. Quality assurance in production, trading, and marketing of agricultural inputs including pesticide and fertilizer production in general is weak. According to Phạm and Nguyễn (2013), nearly 54 percent of NPK fertilizers in the market were of low quality. In 2013, 1,483 violation cases were reported relating to distributing low-quality pesticides and fertilizers.[17]

6.1.4 Inadequate government monitoring, control and enforcement, and public pressure

Over much of the past three decades, the government has focused mostly on production volumes and export value while paying less attention to quality and sustainability. As a result, farming intensification has taken place based on higher inputs and agrochemicals. The input-based growth has resulted in high social and environmental costs, which are unsustainable in the long-run. In international markets, the quality and price of Vietnamese rice and coffee are generally lower than those of other major exporting countries in Asia and South America.

Enforcement in monitoring of the use of fertilizers, pesticides, agrochemicals, and agricultural pollution, in general, is weak. At present, farmers' compliance with GAP standards is still optional and not compulsory. In addition, the roles and responsibilities of different government agencies (that is, MARD/DARDs, MONRE/DONREs, MOIT/Departments of Industry and Trade [DOITs], and MOH/Departments of Health [DOHs]) are not clearly defined. The requirements and GAP standards presented in Circular No. 59/2009/TT-BNN, Decision No. 379/2008/QĐ-BNN-KHCN, Decision No. 2998/2014/QĐ-BNN-TT, Decision No. 2999/2010/QĐ-BNN-TT, Decision No. 84/2008/QĐ-BNN, and Circular 1311/CT-BNN-TT dated 4/5/2012 are not suitable for smallholders' farming conditions. Hence, GlobalG.A.P. and VietGAP programs to date are still at a pilot and demonstration stage and could

17 Nongnghiep.vn accessed dated July 30, 2014.

not be scaled up because the majority of farmers could not apply them in their farm conditions.

6.2 Responses to agricultural pollution

6.2.1 Government's agricultural restructuring plan

Considering the problems and constraints facing the agricultura sector, in June 2013, the Prime Minister formally approved the national ARP, prepared and submitted by MARD. The aims of this plan are to improve the quality, competitive advantage, efficiency, and sustainability of the agricultural sector and its products through increasing value addition to commodities, improving value chains, and protecting the environment (Nguyễn 2014; Vietnamese Prime Minister QĐ 899/QĐ-TTg 2013). Accordingly, the rice area in 2020 will be maintained at 3.8 million ha to ensure national food security. Rice value chains will be improved by encouraging farmers to adopt the 1M5R techniques (that is, reducing the use of seeds, fertilizer, pesticides, and water, and postharvest losses), establishing more FOs, and linking them to markets through contract farming with agribusinesses. The maize area will be increased to produce about 8.5 million tons. For the coffee sector, key priorities include (a) engaging the private sector to establish public-private partnerships (PPPs); (b) encouraging farmers and the private sector in coffee replanting and rejuvenation to replace old plantations (that is, about 140,000–160,000 ha to be replaced in the next 5–10 years); (c) encouraging farmers to adopt sustainable coffee production and management practices (such as those defined by the Common Code for the Coffee Community [4C], Rainforest Alliance certification, UTZ and others); and (d) developing domestic markets.

6.2.2 Laws, regulations, and policies

A series of laws, regulations, and policies aiming at improving the performance and sustainability of the agricultural sector have been issued in the past decade. They includeg the following:

- **Law on food safety No. 55/2010/QH12, effective on July 1, 2011.** This law developed a framework on standards and processes to apply Good Manufacturing Practices (GMP) and GAPs in agricultural production. In Chapter 3, Article 10 regulates allowed levels of pesticide residue, wastes, and other chemicals in foods as well as conditions for agricultural production and waste treatment.

- **Law on environment protection No. 55/2014/QH13, effective on January 1, 2015.** This law prohibited untreated wastes and toxic chemicals discharged into soils, water bodies, and air. The roles and responsibilities of individuals and organizations producing, importing, and trading pesticides were set in this law. This law also provided guidance on the treatment of farming tools, packaging materials, and expired fertilizers and pesticides.

- **Law on protecting people's health No. 21-LCT/HDNN8, effective on June 30, 1989.** This law regulated the requirements on producing, storing, and transporting fertilizers, pesticides, and other chemicals to ensure human health and safety.

- **Order on plant protection and quarantine No. 36/2001/PL-UBTVQH10 dated 25/07/2001.** In this order, pesticides are considered restricted trading goods. Activities like producing, using, and trading pesticides have to follow the guidance on objects, types, dosages, ai, timing, safe time, and so on, to safeguard humans, plants, animals, foods, and environment. According to this order, biopesticides are encouraged to be produced and applied.

- **Circular on pesticides management No. 21/2015/TT-BNNPTNT dated June 8, 2015 and Circular on pesticides allowed to be used in Vietnam No. 03/2015/TT-BNNPTNT dated January 29, 2015.** In these circulars, prohibited and permitted pesticides in Vietnam are presented.

6.2.3 Good agricultural practice programs

In the past decades, a number of government programs have been implemented to promote sustainable farming and GAPs, including the following.

- **The national IPM program.** This program was introduced in 1992 based on the IPM program of the Food and Agriculture Organization (FAO). At first, the program targeted rice to address the brown plant hopper problem, and it later expanded to other crops, including vegetables and fruit trees. The IPM program helped farmers select healthy plants, protect natural enemies (predators), and restrict the use of pesticides and chemicals. Particularly in rice production, the IPM program advised farmers not to apply pesticides in the first 40 days after planting. Through this IPM program, local extension workers, farmers, and other stakeholders have been trained on plant protection based on natural ecological balance, using natural predators to control pests. Farmers' field schools have also been offered in over 90 percent of farming communes in Vietnam. Recently, this program was modified to become the "ecological technologies" (ET) program. Similar to IPM, the ET approach uses colorful flowers to attract natural predators to control pests in fields. IPM and ET programs have achieved positive results in terms of enhancing farmers' awareness and improving their practices.

- **The integrated crop management (ICM) and integrated nutrient management (INM) programs for coffee.** The ICM and INM techniques were designed for coffee plantations in the CH Province. These techniques allow farmers to balance and leverage interactions between and within input groups, such as fertilizers, water, and pesticides. Biological measures to control pests are used to produce safe and clean products.

- **The GlobalG.A.P. and VietGAP programs.** These programs encourage farmers to produce clean and safe agricultural products. Fertilizer and pesticides management (including packaging, trademarks, storage, use, transportation, agricultural waste treatment, and so on) were clearly given in these programs. The programs' goals were to help farmers control and use pesticides and fertilizers effectively to produce clean and safe products, which would add more value to the products to improve farmers' income. Policies and documents promoting the GlobalG.A.P. and VietGAP included Circular No. 59/2009/TT-BNN, Decision No. 379/2008/QĐ-BNN-KHCN, Decision No. 2998/2014/QĐ-BNN-TT, Decision No. 2999/2010/QĐ-BNN-TT, Decision No. 84/2008/QĐ-BNN, and Circular 1311/CT-BNN-TT dated 4/5/2012.

- **3 Reductions 3 Gains (3R3G) Program for rice.** The aims of this program were to reduce seeds, fertilizer, and pesticide application in rice production to increase yields, rice quality, and profits for rice farmers. This program was assessed to be one of the most successful technical innovations in rice production in the south (Decision No. 1579/2005/BNN-KHCN). In the past decade, this program was recommended to be scaled up throughout the country and DARDs were assigned to establish a leading panel to support the adoption of this program in their provinces. Policies promoting this program included Directive No. 24/2006/CT-NN, Decision No. 2575 QĐ/BNN-TCCB dated 06/9/2006, and Decision 3073/QĐ-BNNKHCN dated 28/10/2009.

- **The 1 Must and 5 Reductions (1M5R) Program for rice production in the south and the system of rice intensification (SRI) program in the north.** These programs were introduced more recently. Pest management is based on the resistance of crops (on healthy crops and seed varieties) and on cultivation techniques that use natural predators or enemies to control pests together with effective water management to optimize available nutrients in the soil. Pesticides are only used when rice yields are under threat. Fertilizer use is based on the nutritional demands of rice plants. The alternate wetting and drying (AWD) method of water management also significantly reduces GHG emissions from rice paddies. Policies promoting this program include Decision No. 3062/QĐ-BNN-KHCN dated 15/10/2007 and Decision No. 3073/QĐ-BNN-KHCN dated 28/10/2009.

- **The large field program for rice.** This program was introduced in the south in 2011 and in the north in 2012 (Đỗ 2012). Under this program, small individual farms are encouraged to come together to form large-scale rice fields. Pest management and pesticide and fertilizer applications are consequently planned and carried out at a larger scale, an approach that has multiple advantages and can be more effective.

6.2.4 Private sector responses

Value chain actors are increasingly working together to improve quality, add more value to products, reduce production costs, and reduce environmental impacts. The private sector (agribusinesses) has started to work more proactively with farmers, collectors, wholesalers, and processors in value chains to improve efficiency at every step of production. It has become more common to see agribusinesses organize farming contracts with farmer groups and cooperatives, in which they supply inputs (seeds, fertilizer, pesticides) to FOs, and later buy / collect agricultural products from FOs. During farming processes, agribusinesses also send their technicians and experts to work with farmers to help them improve their farming practices to meet the market requirements. In contract farming models, farmers usually have to follow the guidance or instructions of agribusinesses, especially on the use of inputs. Horizontal linkages between farmers within the FO are strengthened, and that can help improve a broader set of farmers improve product quality and environmental performance.

In response to market demand, more and more farmers have been diversifying their crops and farming systems in recent years. Integrated farming systems such as rice-fish, rice-shrimp, intercropping, crop rotation, and other agroforestry systems are developing. In some of these farming systems, the use of pesticides and chemical fertilizers is strictly controlled and monitored.

POTENTIAL SOLUTIONS AND KNOWLEDGE GAPS

7

7.1 Potential solutions

7.1.1 National level

Monitoring and enforcement of existing policies and regulations. Recent government policies have set priorities with respect to protecting the environment and addressing environmental pollution. In 2012, the government approved the National Sustainable Development Strategies and the National Green Growth Development to 2020 and vision to 2030, which focused on (a) improving reproductive health and health of women and children, (b) increasing productivity of land ecosystems and agriculture production, (c) protecting water environment and sustaining water resource use, (d) managing solid and toxic wastes, and (e) reducing GHG emissions through the development of sustainable organic agriculture, improved competitiveness of agricultural production, and sustainable forest management. In 2013, the government approved the ARP, in which rice and coffee are the two most important subsectors to be improved. That said, although there may still be inconsistencies among existing policies and regulations, they are quite sufficient and available for implementation to address pollution in the agricultural sector. The most important thing now is monitoring and enforcement of policy implementation.

Value chain approach. In recent years, programs that support linkages between farmers within an FO, and between FOs and agribusinesses, have been widely piloted and relatively successful at improving farming practices and value chain efficiency while reducing the environmental impacts of farming. For instance, in the MKD, GlobalG.A.P., VietGAP, and the large field model have been successfully tested with the active engagement of private sector companies (such as Loc Troi Company and others). Similar experiences exist in coffee production in the CH (such as with

Nescafé, the Rainforest Alliance,[18] and others). Good examples exist at the local level. The key challenge now is to create an enabling legal environment and incentives to scale it up.

Public-private partnerships. In recent years, the government has paid special attention to promoting PPPs in which the government provides public goods to leverage private sector investments to improve commodity value chains. For example, the Loc Troi Group has applied the Sustainable Rice Platform (SRP) standards within the context of applying the "large field" model in the MKD. Similarly, the Rainforest Alliance worked alongside Nestlé, the Sustainable Agriculture Network (SAN), and 4C to assist farmers in adopting sustainable coffee farming practices. To support these partnerships, the government has also financed public infrastructure to improve production efficiency and market access for FOs and agribusinesses. There have been several good PPP models in the agricultural sector. The key constraint in scaling them up is the availability of public funds to meet demand.

Ecological and landscape approaches. These approaches have been increasingly recognized in recent years as effective ways of improving the sustainability of agricultural production systems, especially in cropping systems on sloping lands. IPM techniques in rice are in fact based on the principles of ecological balance to control pests. However, these measures are only effective when small farms are able to cooperate with one another to protect the whole ecosystem rather than focus on spraying to protect their crops alone. The landscape approach, applied to coffee, helps reduce deforestation and protect soil from erosion, which in turn reduces the need for fertilizer and other inputs. The challenge of this approach is that it not only rests on comprehensive spatial planning with the participation of different actors in the value chain as well as with other concerned sectors operating in the same area. It is technically complex but doable, provided the strong commitment of local government authorities and local communities. Perhaps it is the best approach to achieve the dual goal of ensuring the long-term sustainability of the agricultural sector while effectively protecting the natural environment.

Enhanced extension networks at the grassroots level. Regardless of the approach, farmers' awareness and know-how are preconditions for successful implementation and adoption. Therefore, establishing and maintaining a strong and capable extension force at local levels (in hamlets and communes) is critical. In Vietnam, local extension networks already exist and they have contributed to the success of the agricultural reforms of the past decades. They can again be the pioneers in helping and working with farmers to change unsustainable farming practices. The government and MARD / DARDs should recognize the important role of grassroots extension and provide these networks with adequate training as well as financial resources in this new period of reform.

7.1.2 Farm level

On-farm technical packages of locally-adapted sustainable farming practices are available for farmers to adopt. Packages designed for rice farming (3R3G, 1M5R, VietGAP, GlobalG.A.P., SRP, and so on) have been piloted extensively in the MKD over the past decade. Farmers adopting 1M5R techniques were able to not only obtain higher yields and better quality rice, but also save around 30 percent on input costs (by reducing fertilizer, pesticides, and water use), and cut GHG emissions by 60 percent. Sustainable farming techniques have also been developed for coffee production in the CH region (IPM, water-saving techniques, soil fertility and nutrient management, increased use of organic fertilizers, and so on). However, to accelerate farmer adoption of these improved technologies, the government needs to pay greater attention to enhancing farmers' awareness, facilitating the establishment of FOs, and attracting and engaging the private sector through contract farming with FOs.

To reduce disease and pest risks resulting from monoculture, integrated farming systems have

18 Rainforest Alliance. "A Sustainable Future for Vietnam." http://thefrogblog.org/2012/10/04/a-sustainable-future-for-vietnam.

been widely developed and spontaneously adopted by farmers in many places. Examples include crop rotation and agroforestry systems in uplands, and rice-fish farming systems in low land areas. A benefit of such systems is that they help diversify income sources and reduce pesticide needs. From a technical perspective, no major issues are foreseen. However, to help them become more sustainable in the long term, coordinated planning, improved public services, and market development to support efficient and sustainable diversification are needed.

The burning of rice straw and agricultural wastes after harvest could be significantly reduced if financial assistance were available to farmers to access agricultural machines to collect on-farm wastes more easily. These byproducts have recycling value. Farmers may sell them to buyers or recycle them for vegetable cultivation, mushroom production, and animal feeding. There are no technical issues, but the constraints are the capital investments for farm machinery and the markets for the new products produced from the recycled agricultural byproducts.

7.2 Knowledge gaps

7.2.1 Knowledge gaps

Based on the findings from the present review, the following knowledge gaps have been identified with regards to pollution related to crop development.

Technical

1. Systematic studies on social and environmental impacts of different crop farming systems, including scales and geographical distribution of major commodities (vegetables, fruit trees, maize, and so on).

2. Systematic studies to quantify concentrations of pollutants discharged from different crop farming systems into soils, water bodies, groundwater, and air and their impacts on environmental health, public health, and population quality.

Economic

1. Cost-benefit analysis of intensification for different crops, including impacts on local livelihoods at household and community levels, especially on vulnerable groups (ethnic minorities, women and children, and so on).

Policy

1. Policies to ensure that producers comply with the minimum requirements of environmental protection, especially with respect to the contamination of surface water, groundwater, and soil.

7.2.2 Data gaps

1. Regularly updated data on the amount of pollutants discharged into environment broken down by commodity, level of intensification, and region.

2. Updated quantitative data on levels of water pollution, air pollution, soil pollution, and product contamination caused by different crop systems.

3. Updated quantitative data on socioeconomic impacts of agricultural crop pollution (disability and disease, premature death, product rejections, revenue losses of producers, and so on).

4. Updated statistical data on the level of intensification observed within major crop systems and regions.

5. Systematically updated data linking environmental data to crop systems at the province and regional levels.

Fundamental studies and systematic and serial data on pollution are not available. So far, studies on agro-pollution have been carried out with funding from NGOs, development organizations, and donors rather than by or with funding from the government.

Ministries (MARD, MONRE, and others) do not have dedicated research programs on agricultural pollution. Therefore, the data on agricultural pollution is ridden with gaps and discontinuous. Moreover, studies on pollution conducted so far have mainly focused on observations and description instead of looking into principles and relationships between pollution, its causes and impacts, and farming practices. In recent years, concerned ministries have issued many regulations and policies on food safety, pesticides and fertilizer management, environmental protection, and so on; however, little effort has been made to monitor, enforce, and implement those policies.

With regard to access to information, data on pollution have not been published, shared, and used effectively. Due to some politically sensitive reasons, data and information on pollution are often kept within the organizations that collected the data and not shared widely with other data users. This not only contributes to gaps and overlaps in research and wasted time and funding, but also leads to missed opportunities to improve public awareness, especially that of policy makers, local authorities, and farmers, about agricultural pollution. Advertisements of pesticides and agrochemicals continue to appear everywhere and every day on mass media while the same media are nearly completely silent on the pollution problems caused by the overuse of those chemicals.

CONCLUSIONS AND RECOMMENDATIONS

8

8.1 Conclusions

1. The agricultural sector plays an important role in Vietnam's economy. In Vietnam, there are eight main different AEZs spreading from the north to the south, including the North East, North West, RRD, North Central Coast, South Central Coast, CH, South East, and the MKD. Of these, the MKD and the CH are the most important regions with regard to agricultural land, production volumes, and export value. In the agricultural sector, rice, coffee, and maize are among the most important crops with respect to rural incomes, employment, and social and environmental impacts. Commercial rice production is mainly concentrated in the MKD region, maize in the northern mountainous region, and coffee in the CH region.

2. In the past two decades, the harvested area for rice, maize, and coffee have fluctuated slightly; however, their intensification, yields, and production volumes have increased steadily. These trends are likely to continue into the next decades because the government has set increasingly high production targets for the key commodities while harvested areas have reached the maximum levels and started stabilizing.

3. Together with the trend of agricultural intensification, the use of inputs, especially fertilizer and pesticides, for crops has also increased very quickly in the past two decades. From 1985 to 2005, the rate of fertilizer consumption (N, P, and K) in the country increased about 10 percent per year reaching a peak of 25 million tons in 2004. After 2005, annual fertilizer consumption flattened out, with rice and maize production using more than 70 percent of the total. Similarly, the amount of pesticides used in Vietnam was only around 6,500–9,000 tons of trading products in 1981–1986, then increased more than 10 times to approximately 100,000 tons/year in 2015. Compared to other crops, rice is the crop consuming the most pesticides.

4. In rice farming, most farmers applied around 20–30 percent more fertilizer than what is recommended. Fertilization regimes are largely based on farmers' experience and habits and less so on the nutritional needs of plants and soils. The low quality of fertilizers available in domestic markets is another issue which contributes to fertilizer overuse. It is estimated that every year, rice farmers are wasting about US$150 million on overfertilization in rice farming. Similar practices also exist in coffee farming. It is estimated that every year, coffee farmers are wasting about US$110 million due to overfertilization. Little information about overfertilization in maize production has been reported probably because it is less common and less serious than it is in rice and coffee. Regarding pesticides application rates, the number of sprayings per rice crop is quite high (5–7 times per crop). Fewer studies and reports are available on farmers' pesticide applications in maize and coffee production. The most common problems include the use of banned pesticides (that is, highly toxic, illegally imported, fake products, and so on), the overuse of pesticides, the improper combination of pesticides in one spray, the lack of basic understanding of proper pesticide use, and improper practices (for example, not following the instructions on product labels, not respecting recommended time intervals between spraying and harvest, and not using personal protective clothing or equipment).

5. Agricultural pollution normally comes from two sources: wastes from farming inputs and the wastes from crop outputs. The former includes residues of pesticides, fertilizers, and their packaging materials (that is, bottles, bags, and so on). It is estimated that every year, some 140,000 tons of N, 82,000 tons of P, and 66,000 tons of K are directly released into nearby water and soil environments from overfertilization practices in rice farming in the MKD. Similarly, some 127,000 tons of N, 155,000 tons of P, and 64,000 tons of K are released annually from overfertilization in coffee production. Data on the amounts of pesticide released into the environment due to overapplication are not available, but it is probably less than 30,000 tons out of 100,000 tons annually consumed. However, regardless of these estimated figures, these highly toxic chemicals (many of which have been banned) when accumulating over years in soils and water bodies (which would penetrate into groundwater) will severely affect biodiversity and human health. The poor handling of solid wastes from packaging materials is another concern. One study estimated that on average, 1 ha of rice farming will generate 12.8 kg solid wastes, including plastic (75.8 percent), glass and metal (21.9 percent), nylon (1.7 percent), and paper (0.6 percent) per year. With the current 4 million ha of rice farming in the country, the amount of these solid wastes generated would be considerable. Less than 20 percent of farmers report that they collect and treat these solid wastes (burying them or selling them for recycling); the majority simply dump them somewhere on their land or in nearby canals. Agricultural residues including rice straw, rice husks, coffee husks, and others are also a problem as most farmers burned them as a quick way to prepare their land for farming. Data in 2010 showed that these solid wastes were huge, including 61.9 million tons of paddy straw, 5.6 million tons of rice husks, 4.8 million tons of maize by-products, and 0.3 million tons of coffee husks. In recent years, the burning practices may have lessened due to the wider availability of equipment that helps farmers collect and recycle residues on the farm, such as for the production of mushrooms, organic fertilizer, and more. However, this is not backed by strong evidence.

6. The physical impacts of agricultural pollution include the pollution of surface water, groundwater, soil, and the air. Although systematic and comprehensive studies are lacking on these, various reports and available information show that concentrations of several pesticides present in surface water in canals and the Mekong River exceed the permitted levels for human use and farming activities. Similar results have been found for groundwater. Regarding impacts on

soils, the overuse of NPK fertilizer on cropland is known to potentially lead to micronutrient imbalances in soils and to the accumulation of toxic substances in crops' root systems; over time, excessive N can also lead to soil acidification. For pesticides, their remnants get adsorbed by soil particles, which in turn contaminate crop roots. The consumption of such crops can be harmful to humans and animals. The overuse of pesticides can also harm soil fertility, especially in the presence of pesticides that take long to break down in the environemnt. GHG emissions are another important problem. GHG emissions from agriculture rose from 52.5 million tons of CO_2e in 1994 to 88.4 million tons in 2010, with rice production accounting for more than 50 percent of the total. The magnitude and pattern of GHG emissions from rice fields are largely determined by the water regime and organic inputs, and to a lesser extent by soil type, weather, tillage, the management of residues and fertilizer, and rice cultivars. Flooding of the soil is a prerequisite for sustained emissions of CH_4. In the past few years, a technical package known as 1M5R that was introduced and successfully piloted in the MKD showed that AWD water management in rice production can help reduce CH_4 and N_2O emissions by up to 53.4 percent in comparison to traditional farming.

7. With regard to socioeconomic impacts, it is difficult to quantify impacts on fisheries, aquatic and terrestrial biodiversity, ecosystem services, and public health. Nitrate content, pesticide residues, and other toxic chemicals in food and drinking water can cause serious health problems if people are exposed long enough. In 2007, the MOH reported 7,329 people injured by chemical residues on the produce and 55 fatal cases. These figures exclude the minor cases which were treated at community health centers and not reported. One study showed that pesticide residues were detected in the blood of farmers in the MKD. From an economic perspecitve, the review found that if rice farmers in the MKD adopted GAPs recommended in the 1M5R package, they could save around US$1.4 billion in agrochemical savings. If other regions and crops (coffee, vegetables, fruit trees, and so on) were included in this estimate, the savings would be much higher.

8. Factors contributing to agricultural pollution in Vietnam include (a) crop intensification, soil degradation, climate change, and weather extremes; (b) short-term market forces, a lack of incentives, and farmers' perceptions and practices; (c) oversupply of cheap and low-quality agricultural inputs and their excessive advertisement in mass media; and (d) low public pressure and inadequate government monitoring, control, and enforcement. Factors mitigating agricultural pollution include (a) the recent ARP;[19] (b) laws, regulations, policies, programs, and projects on environmental protection, pesticides management, GAPs, and food safety; and (c) private sector engagement to improve value chain efficiency and commodity quality in response to the demands of high-value markets.

9. To mitigate agricultural pollution in Vietnam, potential solutions include (a) at the national level: (i) monitoring and enforcement of existing policies and regulations; (ii) pursuit of PPPs and adoption of value chain, agro-ecological, and landscape approaches; (iii) enhancement of extension networks at the grassroots level and (b) at the farm level: (i) adoption of sustainable farming practices touted by 3R3G, 1M5R, VietGAP, GlobalG.A.P., and so on which are locally and readily available and (ii) integrated farming systems. These technical solutions are now available, but there are constraints to overcome to scale them up.

10. This study revealed a lot of data and knowledge gaps in agricultural pollution, which include technical, socioeconomic, and policy aspects. The most important ones include the lack of (a) regularly updated data on the amounts of

19 http://www.vnep.org.vn/Upload/So%207%202014%20Chuyen%20dich%20co%20cau%20nong%20nghiep.pdf.

pollutants broken down by commodity, farming system, and region; (b) updated quantitative data on levels of water pollution, air pollution, soil pollution, and food contamination caused by different crop systems; (c) updated quantitative data and studies on socioeconomic impacts of agricultural pollution (including on disability and disease, premature death, product rejections, revenue losses of producers, and so on); and (d) systematic data linking environmental data to crop systems at the province and regional levels. The fundamental causes of this include (a) the concerned ministries (MARD and MONRE) not having a systematic program to finance the research and data collection, and (b) limited sharing of and access to data among agencies.

8.2 Recommendations

Based on the findings of the present study, it is suggested that

1. MARD and MONRE coordinate their research institutes and technical departments to carry out additional studies to fill in the knowledge and data gaps identified above.

2. MARD coordinate with MONRE to review and clarify responsibilities of all agencies responsible for environmental monitoring and enforcement at all levels. For this, they need adequate manpower and financial resources to effectively implement their functions. Greater attention should be placed on enforcement, and it should be an integral part of all government incentive programs; and

3. To address agricultural pollution in the crops subsector, technical solutions are available and ready for scale-up. The government can prioritize and implement them in a phased approach. To do so sucessfully, it is critical to have strong political commitment, adequate technical capacity, and financial resources. The active engagement of the private sector and strong participation of small household producers are critical in this quality transformation process.

ANNEX

The Annex includes five sections, which clarify and contribute to the body of the report.

Section 1 *is an introduction to agricultural land and agroecological zones (AEZs) in Vietnam to provide readers an overall understanding of crop production in Vietnam. The information covers the country's eight AEZs: North East, North West, RRD, North Central Coast, South Central Coast, CH, South East, and MKD.*

Section 2 *summarizes the history of agricultural changes and crop systems development in Vietnam between the 1980s and the present. This provides an overview of intensification and expansion of crop systems in Vietnam to give evidence for selecting key crops causing pollution as the scope of the study.*

Section 3 *provides information on major crops in Vietnam and hotspots, which help explain reason why rice, maize, and coffee were selected.*

Section 4 *describes characteristics of rice, maize, and coffee production systems in different AEZs of Vietnam. This gives evidence and principles on how and why production of crops causes pollution.*

Section 5 *illustrates the quantity of chemical fertilizers used in the production of seleted crops, to complement the discussion in section 3.1 (on fertilizer consumption).*

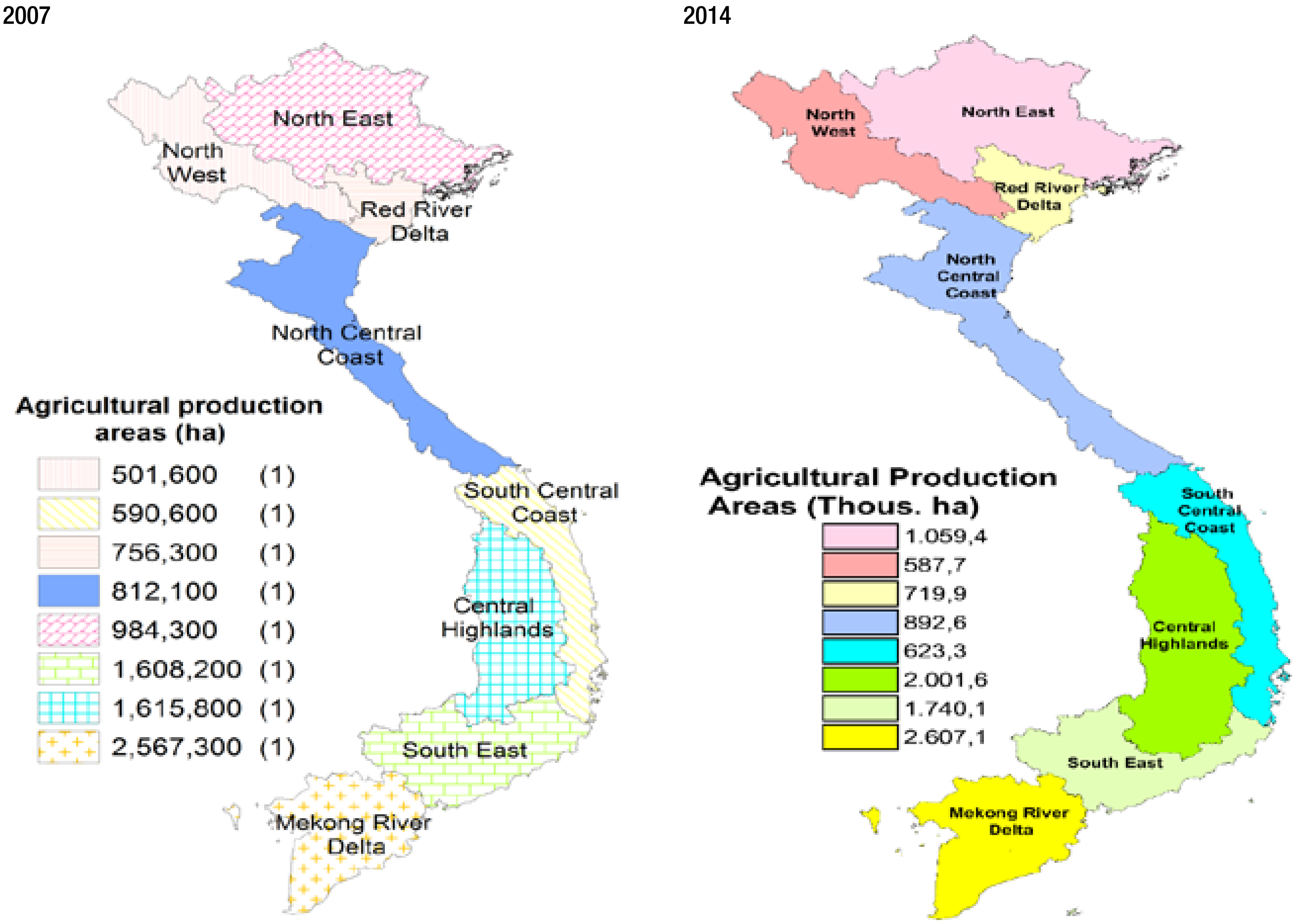
Section 6 *provides details on the 1M5R package. This section provides technical standards such as recommended levels of fertilizer and pesticides use in rice production.*

1 Agriculture land area and zones

In Vietnam, agriculture plays an important role in socioeconomic development. In recent years, the agricultural sector (including forestry and fishery) has contributed to total national GDP 23 percent, 20 percent, and 18 percent in 2008, 2010–2012, and 2013–2014, respectively. Agricultural production activities are a key source of livelihood for more than 70 percent of the rural population. In addition, agriculture also creates job opportunities for many agricultural value chain actors.

Vietnam has eight typical AEZs (Figure A1), spreading from the North to the South: the North East, North West, RRD, North Central Coast, South Central

Figure A1. Vietnam's agroecological zones



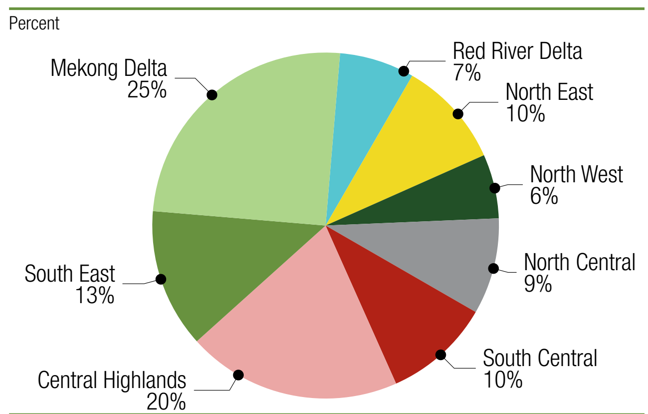
Source: Based on GSO 2007, 2014.

Coast, CH, South East, and the MKD (Table A1). Of these zones, the MKD and CH are two dominants in terms of agricultural land (Figure A2). The weather, land conditions, number of administrative units, population, natural and agricultural land areas, and method of cultivation vary between these zones.

Particularly, Vietnam's agricultural land areas account for about 28 percent of the total natural land areas. The Northern Mountainous and Mid-land zone located in the north of the country (zones North East and North West) is the largest area having 10.1 million ha of mountains and hills corresponding to 13 percent of the agricultural land. The zone is dominated by sloping and upland farming agriculture.

The MKD and the RRD are the two main agricultural and aquaculture regions of the nation, where rice is a permanent crop (Figure A3). The agricultural strength of the North East and the North West is in tea cultivation. The zones of the CH and the South East have comparative advantages in terms of cultivating coffee, tea, and rubber, with intensive farming of vegetables in the CH.

Figure A2. Agricultural land structure



Source: Based on GSO data and author calculations.

Figure A3. Farmers transplanting rice in the Mekong Delta

Source: Author.

The RRD is the most populated and agriculturally intensive area of the country. The majority of the land area (more than 58 percent) is allocated for agriculture. The Northern and Southern Central Coasts (as presented in Table 1), with the Truong Son mountain ranges as the backbone, are the narrowest and longest AEZs of Vietnam. Only 14 percent to 16 percent, respectively, of the natural land, consisting of sandy and degraded soils, are used for agricultural development.

The Western Highland zone is a large plateau with a cool climate and red grey basaltic, humid, and sandy soils. Of this land, 23 percent is allocated for agricultural activities. This area is suitable for perennial industrial crops such as coffee, tea, and rubber. Moreover, this region has the highest percentage of forest coverage for the country (55.2 percent of the natural land).

The Southeast zone is the transition area between the highlands of the middle region and the flat land of the MKD; it is where the elevation ranges from 0.5 m to about 100 m above sea level. This area is characterized by sandy loam soil underlain with old alluvial soils and mixed grey podsolic and red basaltic soils. The land-use pattern in this region varies with approximately 49 percent being for agriculture, 30 percent for forest, and the rest for other land-use types.

Table A1. Major characteristics of Vietnam's eight agroecological zones

AEZs	No. of provinces/ cities	Population (Persons in thousands)	Natural land (km^2)	Agricultural land (ha in thousands)
North East	11	9,544	64,025	984
North West	4	2,650	37,534	502
RRD	11	18,401	14,862	756
North Central Coast	6	10,723	51,552	812
South Central Coast	6	7,185	33,166	591
CH	5	4,935	54,660	1,616
South East	8	14,193	34,808	1,608
MKD	13	17,524	40,605	2,567
Whole country	**64**	**85,155**	**331,212**	**9,436**

Source: Based on GSO 2007 data.
Note: Data are subject to rounding.

In agricultural land-use, rice harvested area was about 7.8 million ha (45 million tons) in 2014 and planned 7.0 million ha in 2020 (41.3 million tons). This makes

Vietnam one of the top rice export countries in the world.

2 Main agriculture changes in Vietnam

For Vietnam, agriculture has been the main sector in the national economy for many decades. The impressive milestone for agriculture in Vietnam could be highlighted by the sixth Party Congress of the Communist Party in 1986, which designed an economic redirection, announcing its program of innovation (*Doi Moi*), first in agriculture. A range of agricultural policies have been launched such as the upgraded Contract 100 to complete contract to household (HH),[20] accelerating the first Foreign Investment Law Open-door policy; enacting Land Law, which established agricultural land-use rights; and introducing a more market-determined exchange rate in 1987. It identified that the responsibility of Vietnamese agriculture between 1986 and 1988 was "overcoming poverty."

On April 5, 1998, Resolution 10, with the content of reforming the management of Vietnam's agricultural economy, was promulgated launching the *Doi Moi* reform process, a breakthrough in economic development thinking; promoting a multisector economy with the leading role of the state sector; and starting the transition to a market economy with state management (De 2005).

These initiatives had a distinct impact on agriculture by encouraging farmers to take more control in decisionmaking relating to their farm production and main inputs as well. As a result, agricultural productivity improved markedly. Yields and crop output increased and the number of animals also increased. Local inhabitants prospered with more food being available and with increased incomes.

Unfortunately, unfavorable weather in 1987 brought about huge harvest losses; food output was 1 million tons lower than in 1986. Vietnam suffered an ongoing food shortage, borrowing around 800,000 tons of food and importing 322,500 tons of rice (Son et al. 2006).

Later, in 1989–2000, agricultural production become increasingly commercially- and export-oriented. Agriculture had been influenced by the open economic policy through the liberalization of domestic and foreign trade of agricultural products in general and rice in particular.

Subsequently, the gap between international and domestic prices narrowed significantly, and this led to the improvement of farmers' income. In 1989, food output increased dramatically to more than 21 million tons, food output per capita recovered to 300 kg, and this year was the first year that Vietnam exported rice after a long time of being a net rice importer.

From this time, agricultural output increased 1 million tons annually and the rice export volume kept increasing. In three years, from 1988 to 1991, the rice harvested area expanded by nearly 10 percent, from 5,726,400 ha to 6,302,700 ha; rice output climbed up from 17 million tons to 19.6 million tons. In 1990, Vietnam became the world's third largest rice exporter, with an export volume of 1.5 million tons (GSO 2001; Son et al. 2006).

During this early phase of development, the agricultural sector faced new opportunities. The fact that farmers could make their own plan for using their land, and other inputs in production together with trade liberalization, created favorable conditions for commercial agricultural production, to meet both domestic and export demand.

Government investment in the agricultural sector accelerated, the investment amount was increased from VND 3,495 billion to VND 3,712 billion and then VND 4,591 billion in 1995, 1997, and 1998.

20 Under 'contract 100', farmers were entitled to be master of three production stages (planting, caring, and harvesting); others stages (land use, crop choice, land preparation, irrigation, and input supply) were still under the cooperative's control; the contract level was not stable and subject adjustment every crop and year (individual household got only 20 percent of contracted output) (De 2005).

Investment in agriculture and rural development was 25 percent of the state budget in 2000, at more than VND 10,000 billion.

The 1990s were a critical period for agricultural development in Vietnam, as the sector switched from self-sufficiency to commercial production. In 10 consecutive years following 1989, the annual agricultural growth rate was 4.3 percent on average.

Productivity of many crops and animal husbandry increased: that of rice went up 33 percent, coffee 6–7 times, rubber 2 times, and pig 27 percent. Food had been secured. Before 1989, Vietnam had to import 0.6–1 million tons of food annually. Since 1989, Vietnam has been a rice exporter with exports reaching a high of 4.5 million tons in 1999. In 2000, total food output was 35.64 million tons of rice-equivalent (Son et al. 2006; GSO 2003).

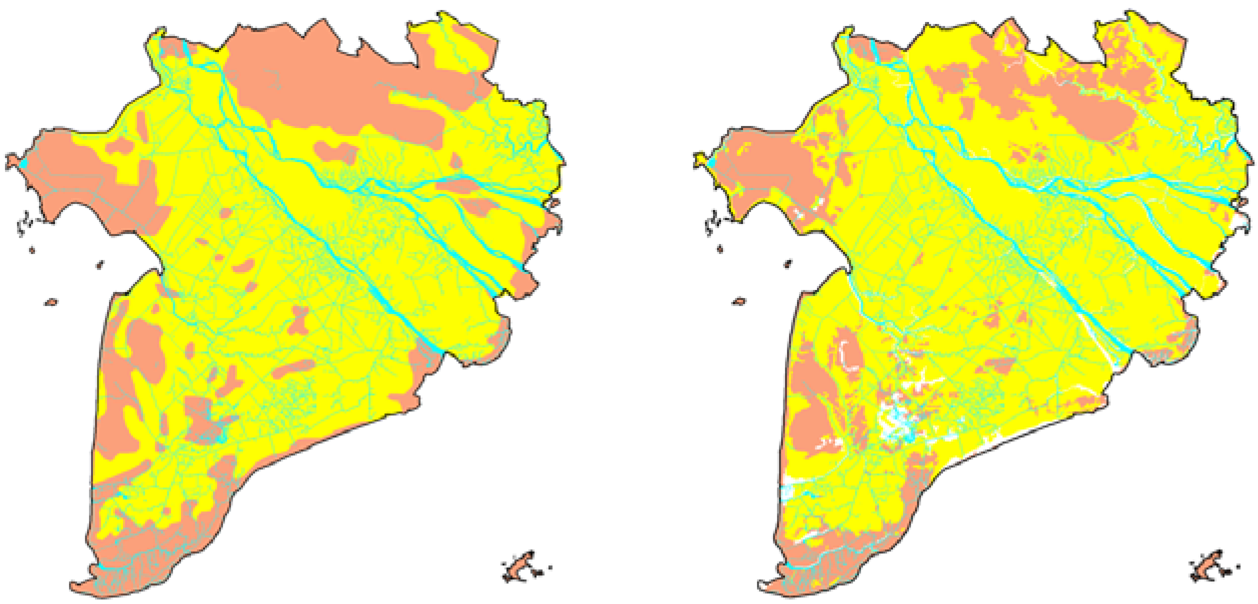
As agriculture became more commercial, many specialized production zones developed such as intensive rice areas in the MKD and the RRD; coffee areas in the CH and South East; tea areas in the North East and North West; rubber areas in the South East; fruit areas in the South East, MKD, and some provinces in the North; vegetable areas in the Lam Dong Province and RRD; and sugarcane areas in the CH area and the South. Many commodities had a high rate of export, for example, coffee 95 percent, cashew nut 100 percent, rubber 80–85 percent, pepper 90 percent, and tea 50 percent. In 1999, the share of commercial products in total agricultural output reached over 40 percent. Agricultural export value accounted for 38–40 percent of the national annual export turnover (Son et al. 2006).

The stage of intensive development from 2000 to the present has meant that agriculture in Vietnam has shifted to intensive production with the goal of higher productivity and quality, focusing on effectiveness, job generation, and income improvement. Reduced production costs, upgrading of the quality of products, and production at an industrial scale to compete were the trends for agricultural development in this period. Today, the current responsibility of Vietnamese agriculture is to help farmers in the environment of the World Trade Organization (WTO).

3 Major crop systems in Vietnam

Figure A4. Rice planted area changed between 1972 and 2010 in the MKD

2005 **1995**



Source: Based on GSO data and author calculations. Note: Yellow in years 1972, 1995, and 2005 and green in year 2010 indicate rice grown area.

According to GSO (2014), the MKD, CH, and South East are three dominant AEZs with the largest crop land areas in Vietnam (Figure A5). In each region, crop land areas vary between provinces (Figure A6). In different crop land areas, rice, maize, rubber, fruit, coffee, cassava, sugarcane, peanut, sweet potato, and soybean are the top 10 crops that have the biggest harvested area (Figure A7). Of this, the rice-harvested area occupied more than 7.8 million ha distributed across most provinces of Vietnam, and particularly concentrated in the MKD and RRD. Second is maize, which had a harvested area of 1.2 million ha, much of which was located in the North East, North West, and CH. Remaining crops have smaller harvested areas compared to rice and maize, and they are scattered across Vietnam.

Figure A5. Cropland area by agroecological zone

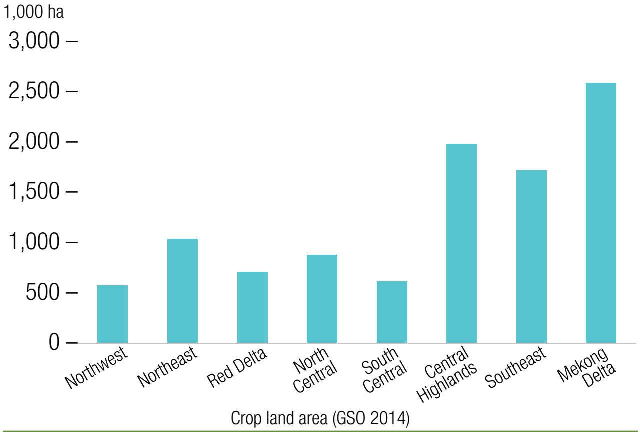
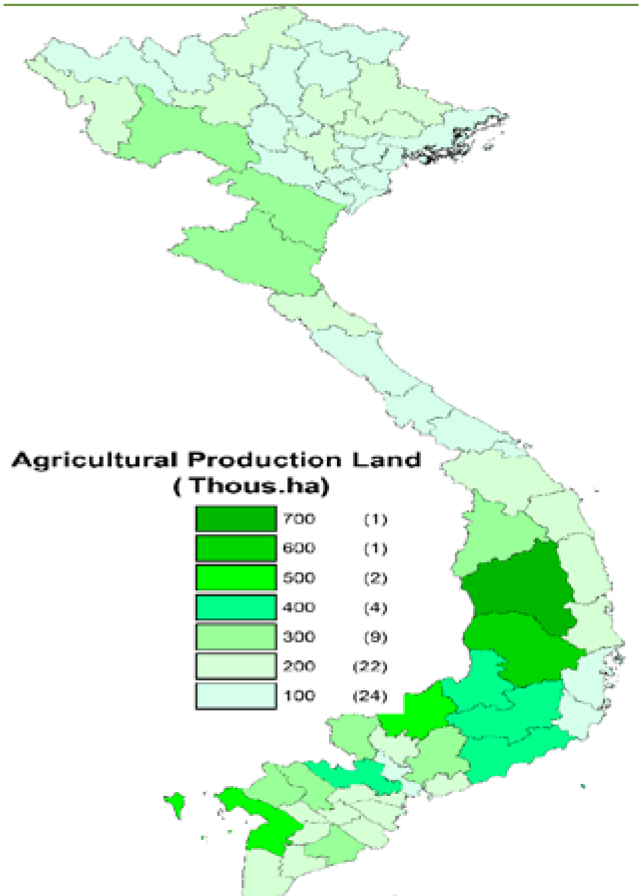


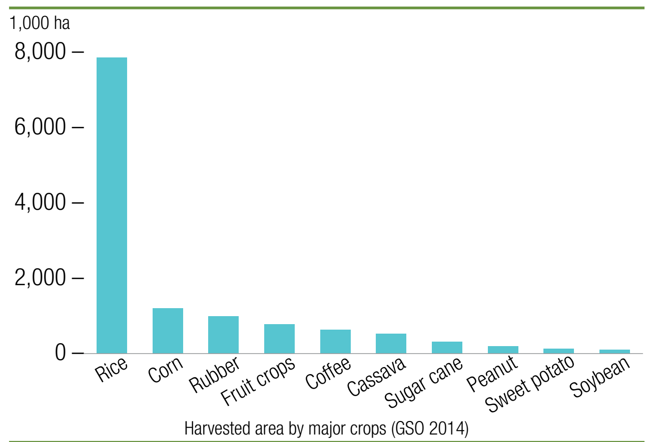
Figure A6. Cropland area by province



Data from GSO (2005, 2010, and 2015) and the Vietnamese government (2015) indicate that harvested area for the top 10 crops among AEZs in Vietnam changed over time. However, the change was not significant because land-use changes have to follow the government's land-use plans. Similarly, according to land-use planning for 2016 to 2020 and vision to 2030 by the Vietnamese government and MARD in 2015, harvested areas for the top 10 crops will change slightly. Specifically, total rice area will be decreased from 7.8 million ha in 2014 to 7 million ha in 2020, maize will be increased from 1.17 million ha in 2014 to 1.2 million ha in 2020, coffee will be stabilized about 550 million ha, and fruit trees will be increased from 840 million ha in 2014 to 1,000 million ha in 2020. Other remaining crops will fluctuate marginally; some will be increased while some decreased.

In this study, rice, maize, and coffee are selected to analyze pollution because they are the main crops in

Figure A7. Top 10 crops by harvested area, 2014



terms of harvested area, export value earnings, and livelihood opportunities for farmers in the two biggest deltas of Vietnam, in the CH, and the mountainous areas. Fruit crops, upland crops, vegetables, and several others are also key groups that need to be considered from a pollution perspective. However, due to limited resources, these crops are excluded from this study.

4 Characteristics of rice, maize, and coffee production systems

In Vietnam, agricultural HHs were dominant (>90 percent) among total HHs (including both rural and urban HHs). Rural HHs included agricultural, forestry, and fishing HHs, of which the number of HHs engaged in crop systems production were accounted for about 60 percent, and they were distributed mostly in the north central and central coastal areas, RRD, and MKD zones (Table 2). In general, HHs that worked in crop systems declined around 9 percent between 2006 and 2011; the RRD and South East were the two most declining zones. For farm size per HH, about 70 percent and 85 percent HHs have less than 0.5 ha/HH of agricultural land area and rice land area, respectively (Table A3 and Table A4). The CH zone has the largest agricultural land area per HH and the MKD zone has largest rice land area per HH. Similarly, maize farmers in North West have 0.5–1.0 ha per HH on average (Đỗ Văn Ngọc and Trần Đình Thao 2014). These figures show that agricultural production and crop systems production in Vietnam are dominated by smallholders, resulting in weak links between producers and enterprises (and other actors) in the value chain.

Rice system practices

MARD developed a program for shifting from rice to other cash crops; priorities include maize and soybean. The third year of the program is 2016. There is a plan that 100,000–110,000 ha of riceland will be converted to maize and soybean each, that is, 200,000 ha in two years. In reality, the harvested area from 2014 to 2015 shrunk from 7.86 million ha to 7.70 million ha (about

Table A2. Number of rural households growing crops

Region	HHs engaged in crop systems production		Share (%)		Change (2006–2011, %)
	2006	2011	2006	2011	
RRD	2,053,400	1,749,654	58.48	45.54	–12.94
Northern midlands and mountain areas	1,720,330	1,788,546	86.36	80.39	–5.97
North central and central coastal areas	2,302,937	2,215,308	68.22	60.58	–7.64
CH	651,357	742,854	88.67	86.10	–2.57
South East	551,109	536,716	48.78	37.53	–11.25
MKD	1,869,985	1,833,432	61.81	55.09	–6.72
Vietnam	**9,149,118**	**8,866,510**	**66.45**	**57.79**	**–8.66**

Source: GSO 2012.

Table A3. Farm size by agricultural land-use in Vietnam

Total HHs		HH structure by size of agricultural production land-used (%)			
	Total HHs	≤0.2 ha	0.2 to ≤0.5 ha	0.5 to ≤2 ha	≥2 ha
RRD	3,136,734	59.51	37.23	3.18	0.08
Northern midlands and mountain areas	2,142,383	28.24	37.50	29.56	4.70
North central and central coastal areas	3,006,663	36.27	41.74	19.12	2.87
CH	904,645	6.49	14.87	55.40	23.24
South East	624,618	18.77	19.19	42.22	19.82
MKD	2,133,218	18.97	29.10	41.84	10.09
Vietnam	**11,948,261**	**34.67**	**34.33**	**24.82**	**6.18**

Source: GSO 2012.

Table A4. Farm size by region

Total rice HHs	Total HHs	Structure of HHs by size of paddy land-used (%) ≤0.2 ha	0.2 to ≤0.5 ha	0.5 to ≤2 ha	≥2 ha
RRD	2,896,436	64.84	33.19	1.94	0.03
Northern midlands and mountain areas	1,913,797	58.12	33.48	7.94	0.46
North Central and Central coastal areas	2,561,883	53.43	39	7.36	0.21
CH	385,935	37.83	40.68	20.39	1.1
South East	147,817	12.37	40.06	42.01	5.56
MKD	1,365,326	8.49	29.87	48.2	13.44
Vietnam	**9,271,194**	**50.04**	**34.79**	**12.9**	**2.27**

Source: GSO 2012.

160,000 ha in those two years); the program is not considered as successful as expected (Tran 2015).

In Vietnam, rice has three cropping systems including winter-spring, summer-autumn, and autumn-winter. In reality, to ensure rice stocks, many localities have established a seasonal calendar of rice that lasts the whole year.

The large-scale rice farm was started in 2008 (at the beginning it was called large sample rice farm). The total area of large-scale rice farms in the MKD (all 13 provinces) reached over 200,000 ha in 2013. A large-scale rice farm can cover 50–100 ha of suitable land. A few farms reach to 400–500 ha. A common large-scale rice farm in the MKD ranges between 100–150 ha. MARD expected fully 300,000–500,000 ha of large-scale rice farms in 2015.

MARD continues encouraging farmers to implement the large-scale rice farm model, where farmers gather their individual small farms to form a larger-scale farm in which farmers can realize economies of scale in such activities as land preparation, seeding, chemical fertilizer application, irrigation, and harvesting (by saving production costs and better using mechanical tools). Most of the production input (fertilizer, pesticides, and machinery) is supported by a trading company. In return, the company will directly purchase most of the rice output from farmers, without going through middle men. This is what is called a closed rice value chain (for example, in Loc Troi Cooperation in An Giang Province).

In the past few years, many provinces in the MKD have set up large-scale rice farms, attracting the participation of plant protection companies, trading companies, and local farmers (vertical and horizontal links). Companies provide farmers with rice seed and pesticides and, in turn, they get to buy rice from farmers immediately after harvesting. Companies provide rice experts to help farmers in rice production practices. The model allows more effective use of machinery and pesticides so as to gain higher yield. The model to grow large-scale rice farms has helped farmers reduce production costs. However, numerous farmers have complained that plant protection companies take nearly all the profits from these projects, consequently leaving farmers taking part in the model with little benefits. Particularly, participating farmers are buying rice seed and pesticides from these companies at prices higher than the market prices while the companies buy harvested rice at a price equal to that set by the Vietnam Food Association. Meanwhile, Vietnam's MARD considers this model as the modern scheme of rice growing and is now planning to expand the model from a few hundred hectares to 1 million hectares nationwide. However, rice farmers are still facing hardships because rice exporters and intermediary traders often gain the most in the rice industry (Tran 2015).

According to the 2015 MDI survey (Can Tho University), the large-scale model faces many difficulties in terms of links and agreements between farmers and trading companies. On top of that, rice selling price, forms of rice buying, kinds of inputs allocated and proposed by trading companies, and standards of rice products were problems that are very difficult to agree between farmers and trading companies, while there are no legislative frameworks and referees to help solving those issues.

Table A5. Comparison of input use in Mekong Delta rice production by 1M5R and control group farms over 11 cropping seasons

Inputs and farming techniques	An Giang			Kien Giang		
	1M5R	CON	Change	1M5R	CON	Change
Ratio of farmers that used certified seeds (%)	100	25.4	▲	100	38.3	▲
Sowing density (kg/ha/crop)	149.7	202.5	▼	150.5	218.8	▼
Net N used (kg/ha/crop)	142.2	149.9	▼	94.2	103.8	▼
Pesticides application (times/crop)	5.3	6.5	▼	5.8	7	▼
Water management style (irrigation times/crop)	AWD	10	▼	AWD	5–7	▲
Yield (ton/ha/crop)	6.8	6.5	▲	5.9	5.8	▲

Source: Nguyen, T. H. et al. 2015.

Note: 1M5R = Farmers applying certified seed; using reduced amounts of seed, water, pesticides, and chemical fertilizer; and following local extension worker and rice expert recommendations for reducing postharvest losses. CON = Control group farmers using traditional or habitual practices. Change = Comparison between 1M5R and CON. AWD technique means water is used based on rice demand. Data are from 2012.

In rice production (particularly in the MKD), most farmers overuse inputs such as seeds, pesticides, and chemical fertilizers, and this causes increased production costs and less efficiency in rice production.[21] Nguyen et al. (2015) carried out a study over 11 cropping seasons on rice in An Giang and Kien Giang Provinces. The results indicated that more than 90 percent of surveyed farmers used seeds, fertilizers, and pesticides higher than the quantity recommended by rice scientists and local extension workers (Table 4) (that is, the 1M5R recommendations).

Maize system practices

Maize planted in Vietnam was mostly hybrid maize (shared 90 percent in 2010, Cục Trồng Troọt 2011). There were many maize varieties with high yield and good quality introduced to farmers in the north between 2005 and 2010 including early, medium-term, and long-term varieties. Maize production area is located only where other better cash crops cannot be grown (such as in the mountainous regions with poor soil fertility) or where there is lack of water for other better cash crops, intercropped after a better cash crop (such as soybeans in the upland area or rice in the lowland area when water supply is short for rice). Because it is primarily being grown in unfavorable conditions, Vietnam's maize crop is usually yield diminished or damaged by insects and weed (Tran 2015).

Maize is one of several local crops such as cassava and rice which are used to supply the quickly-growing feed industry. Domestic maize production has been not able to satisfy the demand in recent years and may be later years. Imported maize is brought in with the volume of about 2 million tons each year. Maize producers are under pressure to quickly increase their productivity to satisfy increasing demand. Significantly improving average yields by using high-yielding varieties seems the most likely way to achieve the government's objectives of increasing maize production for supplying the feed sector. In March 2015, MARD signed Decision 69/QD-CTCLT, which recognized three genetically modified (GM) maize varieties of Syngenta Co. This has officially allowed the production of GM maize for commercialization.

In Vietnam, maize is the main ingredient and source of energy in animal feed. It is also consumed in the form of starch and has other limited uses in the beer, textile, and pharmaceutical industries. However, more than 80 percent of maize is used as feed ingredients. Maize is used in both commercial and home-made feed, mainly for hogs and poultry. Maize-use is expected to increase to accompany the livestock sector's growth and predominantly comes

21 Overuse means farmers apply/use inputs (materials such as seeds, fertilizers, pesticides, and so on) higher than the inputs' quantity recommended by crop experts, local technicians, and technical guidelines. For example, in rice production, seed density is recommended to be applied about 80–120 kg/ha for many kinds of soils in the MKD using hand sowing method. This recommendation is indicated in 1M5R technology developed by the International Rice Research Institute (IRRI) in collaboration with the An Giang DARD. However, in reality, famers used more than 120 kg/ha, which means farmers overuse seeds in rice production.

from imported sources, at least for the time being and in the near future, because local maize production is not able to keep up with the fast growing demand of the animal feed industry. Currently, the feed industry needs about 1.8–2.0 million tons of imported maize to satisfy demand. However, the real imported volume depends greatly on the availability of other alternative products like broken rice, rice bran, and cassava locally and the price competitiveness of imported feed wheat and distiller's dried grains with solubles (DDGS). The annual increase of maize use both for food and feed is about 200,000–400,000 tons depending on the abovementioned factors (Tran 2015).

Maize production has two to three maize crops per year (spring, autumn, and winter). The spring crop starts from the first half of February to the second half of May, the autumn crop starts from the end of May to early September, and the winter crop starts from the end of September to early January. In terms of farming, inputs used in maize production such as chemical fertilizer and pesticides were used much more than for rice. In the north, fertilizer applications are around 150-200-60 N-P-K kg/ha/crop, and pesticides are applied many times per crop (Cục Trồng Trọt 2011). In the south, fertilizer applications are around 180-146-77 N-P-K kg/ha/crop and those numbers have not changed much within cropping seasons in a year. Farmers used more than 20 kinds of leaf fertilizers on maize. For pesticides, farmers apply many times per crop, including 3 kinds of herbicide, 23 kinds of insecticide, and 18 kinds of fungicide (Lam 2013).

Coffee system practices

Coffee trees are aging and yields are decreasing. About 14 percent of about 640,000 ha of coffee trees are older than 20 years and a further 20 percent are between 15 and 20 years old, which need to be replaced (Khanh 2014). Coffee plants older than 20 years produce an average of 1 ton/ha of beans, compared with about 2.5 tons/ha per year for younger trees of 10–15 years. In addition, bean quality from older trees is also lower. Vicofa estimates that about 90 percent of the total area (120,000 ha) of old coffee trees in the CH needs to be replanted by 2020.[22] Areas with old trees are increasing with time. For instance, in Dak Nong Province, the area with old trees that need to be renewed from 2012 to 2020 was estimated of 24,650 ha, covering 22 percent of the total coffee area in the province (Trương 2013). The replacement of old trees takes at least five years for seedlings to develop and produce beans. Capital investments for the replacement are high while financial capital of most of the farmers is low.

Farmers mostly harvest both ripe and green cherries at the same time and then mix them together. In addition, poor processing technologies of beans make low value of products. In Dak Nong, about 30 percent of farmers harvested cherries with a proportion of ripe cherries below 70 percent. Green cherry has lower quality than ripe cherry and hence lower market prices and lower income for farmers (Trương 2013). In addition, poor postharvest technologies (that is, drying, storing, and processing) and poor marketing (that is, exporting raw material through intermediate dealers) also contribute to low value of Vietnamese coffee at international markets (Nguyen, B. K. 2006). Consequently, farmers try to intensify the production for higher yields with the hope of higher income, and this constrains the sustainability of production in the long-run.

Water shortage for irrigation severely constrains coffee production. Water requirement for irrigation are high in the dry season. The irrigation water relies on pond (21 percent in volume), lakes or streams (28 percent), and underground sources (51 percent) while the groundwater level is dropping (Amarasinghe et al. 2013; IDH Vietnam 2013). Dak Lak is facing severe groundwater depletion issues in dry years because current irrigation consumes up to 70 percent of total water resources (Cheesman and Bennet 2005). Combined with water shortages, weather or climate variability (prolonged droughts and high temperatures) further exacerbates water scarcity for irrigation (Haggar and Schepp 2012). In 2005–2006, droughts caused water shortages and wells to dry

22 http://news.asiaone.com/news/asia/vietnam-coffee-output-likely-slow#sthash.ZzLfUexU.dpuf.

up, damaging about 20 percent of total production (IDH 2013). In 2010–2011, output was expected to reduce by 20 percent compared with the previous harvest due to extreme drought period and delayed rains (Haggar and Schepp 2012). In 2015, about 48,000 ha of coffee in the CH were highly vulnerable to prolonged droughts in the dry season. As a result, bean production dropped by 70,000–90,000 tons (15–20 percent), compared with that in the previous crop in Dak Lak Province.[23]

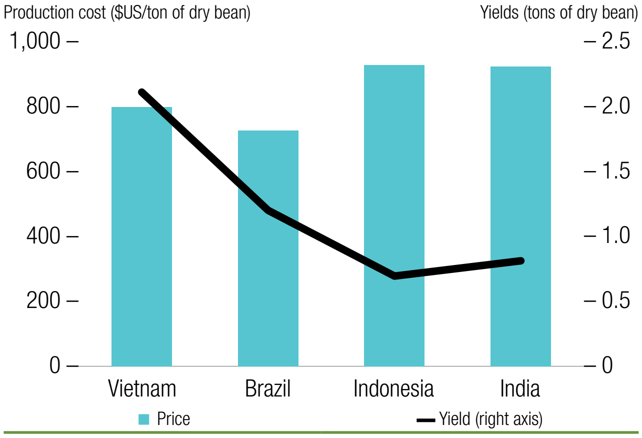
Farmers overirrigate coffee, even though Robusta coffee does require higher quantities of water for growth and bean production compared with Arabica coffee. Annually in January–April, farmers irrigate two times higher than the level recommended by MARD (605 L/tree/round in three rounds). Farmers in Dak Lak even irrigate on average of 4.17 m^3/tree in January–April (Amarasinghe et al. 2013). Irrigation cost account for 15–20 percent of the total production costs in terms of labor, energy, and equipment costs. In Dak Lak and Dak Nong Provinces, the largest share of coffee growing area in Vietnam, about two-thirds of farmers irrigated the crop with excessive amounts of water (Truong 2015). Improving irrigation water management, therefore, is an important issue, not only addressing the groundwater problem but also reduced production costs for further improving profits and economic water productivity (D'haeze, 2008, 2014). The vulnerability could be even higher with El Nĩno phenomenon in 2015–2016, which results in lower rainfall and higher temperatures than in normal years (Khanh 2014). Amarasinghe et al. (2013) suggested that it is possible to improve water consumption per kg of beans and to save 30 percent of irrigation water by appropriate irrigation and crop husbandry practices to achieve the current or even higher yields. In fact, rainfall provides only 25 percent of total crop water requirements between January and April, which includes the critical initial and development stages of crop growth, and coincides with breaking the dormancy of flower buds and initiation of cherry development. Trained and/or advanced farmers in Dak Lak supplied an optimal rate of 365–455 L/plant/round in three rounds for achieving yield up to 4 tons/ha, which is significantly lower than the level of 650 L/plant/round recommended by MARD (Amarasinghe et al. 2015). Two-thirds of farmers in Dak Lak and three-fourths of farmers in Dak Nong Province used an amount of water greater than the optimal irrigation level (Amarasinghe et al. 2015). Assuming that farmers overirrigate by 300 m^3/ha/year, then about 150 million m^3 of water per year is not used efficiently in the CH. Consequently, this would exacerbate the unbalanced water resources in the region, particularly in the context of projected climate change (Phan Viet Ha 2013).

Farmers apply high and unbalanced rates[24] of chemical fertilizer. In the CH, farmers apply excessive rates of N- and P-based fertilizers (for example, urea and generic NPKs). The application rate ranges are 260–643 kg N, 71–230 kg P_2O_5, and 185–507 kg K_2O (Truong 2015), costing an average of US$534/ha/year (Amarasinghe et al. 2015). About 65 percent of farmers applied a surplus amount of chemical fertilizers (42–55 kg N, 40–60 kg P_2O_5, and 20–22 kg K_2O), at an extra cost of about VND 2.2 million/ha/year (Truong 2015). Many farmers achieve over 3.5 tons/ha/year with high irrigation and fertilizer input levels. This yield level is much higher than that in other Asian and South American countries (Figure A8). Robusta yield has been shown to be very responsive to high farm inputs with inputs of 1 ton/ha of NPK fertilizer giving coffee yields of 1 ton/ha, with inputs of 1.5 tons/ha of NPK fertilizer raising the output to 2.5 tons of coffee/ha, and with 2.5 tons/ha of NPK fertilizer raising the yields to 3.5 tons/ha (World Bank 2004). Most farmers fertilize using direct surface broadcast combined with irrigation for lower labor inputs. However, this practice results in a large amount of fertilizer being lost through volatilization (that is, N) and/or flushing by run-off, which causes negative environmental impacts and lower efficiency in fertilizer use (Phan Viet Ha 2013).

23 http://agro.gov.vn/news/tID24272_San-luong-ca-phe-nhan-cua-Dak-Lak-giam-nam-thu-2-lien-tiep.htm.

24 Unbalanced rates mean not a balanced rate between N P K, macro, and micro fertilizers, while excessive rates mean overuse (used higher amount or rate than the required/recommended amount of fertilizers).

Figure A8. **Coffee production costs and yields in Vietnam and other major producing countries**



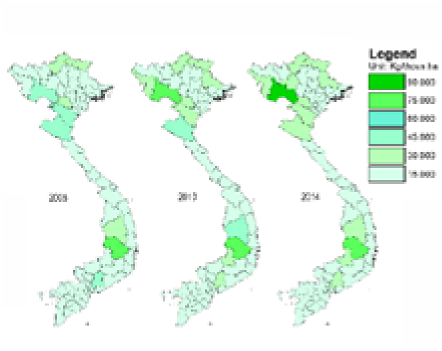
Source: Based on Truong 2015.

Farmers apply pesticides expecting to achieve higher yields. About 97 percent of farmers use chemical pesticides 1–4 times/year with a dose ranging between 1 and 5 L/ha/year. About 34 percent of farmers apply pesticides periodically regardless of pest occurrence, about 62 percent of farmers apply pesticides as pests occurred on some trees in their farms, and only 10 percent farmers follow sustainable standards as recommended. However, pesticide input costs for Robusta coffee in Vietnam are still lower than that in other countries. IPM techniques are not commonly used by farmers. Pesticide costs, however, only account for about 5 percent of total production costs (Truong 2015).

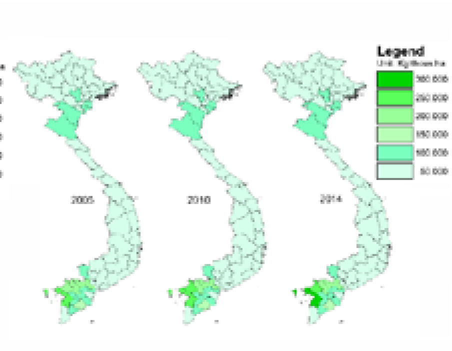
5 Chemical fertilizer used in rice, maize, and coffee production

Figure A9. Net N, P, and K used in rice, maize, and coffee production in Vietnam, 2005–2014

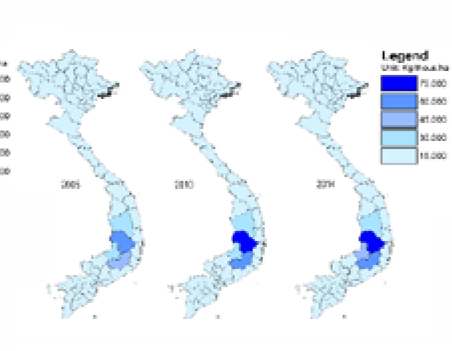
Nitrogen used in maize production



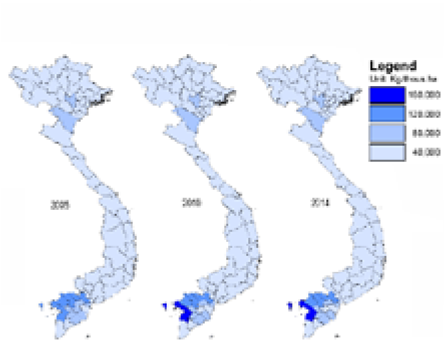
Nitrogen used in paddy production



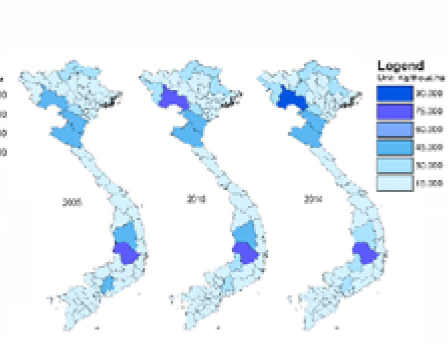
Nitrogen used in coffee production



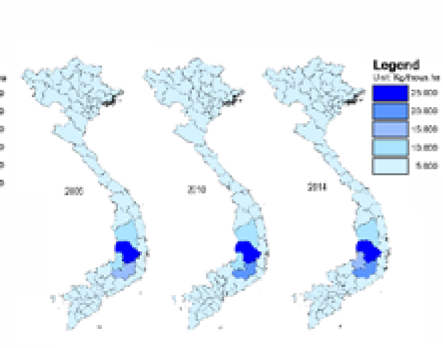
Phosphorus used in paddy production



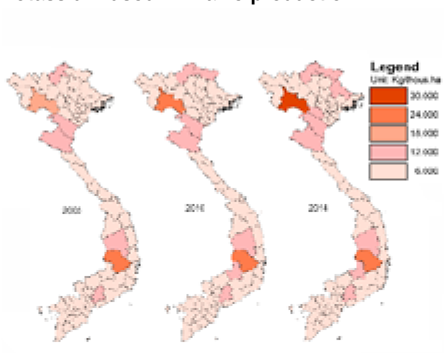
Phosphorus used in maize production



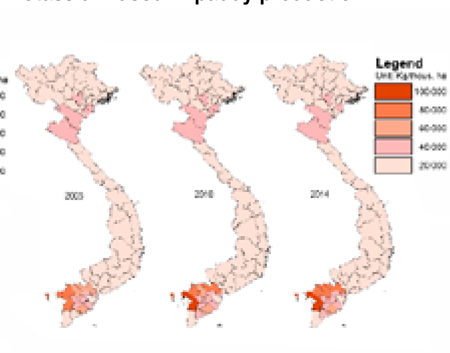
Phosphorus used in coffee production



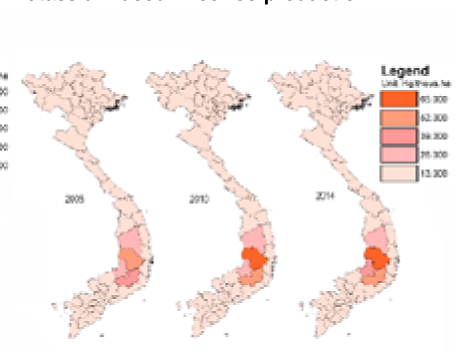
Potassium used in maize production



Potassium used in paddy production



Potassium used in coffee production



Source: Estimated by author based on harvested area, yield, production, and fertilizers used for each crop.

6 1 Must and 5 Reductions

1M5R is an effective package of rice production technologies. It calls for reducing the amount of seed, chemical fertilizer, pesticide, and water that are used, as well as postharvest losses. It was certified on February 22, 2012, by the Department of Crop Production (MARD, Vietnam) as a new technical innovation in rice production. The 1M5R techniques are flexibly recommended to farmers in using inputs in rice production as follows:

- **Seed quantity applied.** 80–120 kg/ha depending on specific land conditions and farming practices.
- **Chemical fertilizers used.** Flexibly varies between rice varieties, cropping seasons, and soil types (average fertilizers used is present in Table A6).
- **Pesticides used.** Limited as much as possible and encouraged farmers to apply IPM approach.
- **Water management.** Used water-saving technique such as AWD. This technique did not allow water inundation overtime on the rice field. In contrast, water is supplied when is is needed by the rice.
- **Postharvest loss.** Applied combined harvesters to harvest rice when 85 percent rice grains are matured.

Table A6. Fertilizer use in rice production

Soil type	Net chemical fertilizer used for 1 ha of rice					
	N (kg)		P_2O_5 (kg)		K_2O (kg)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Alluvium near rivers	90–100	75–90	30–40	30–40	30–40	25–30
Slight acid sulphate soil	80–100	70–80	40–50	40–50	25–30	25–30
Medium acid sulphate soil	60–80	60–65	50–60	50–60	25–30	25–30

Source: Department of Agriculture and Rural Development, An Giang Province. 2011. Handbook on guiding modern rice production according to "1 Must 5 Reductions". Internal circulation book in Vietnamese.

Note: This fertilizer formula applied for modern rice varieties with duration 85–100 days.

Figure A10. Cover page of the 1M5R handbook for rice production

Figure A11. Rice straw is rolled and moved for multiple uses

Source: Author.

Figure A12. Rice straw burning in the early spring-autumn season in Long An province, April 2017

Source: Author.

Figure A13. Northern rural area with low air pollution

Source: Author.

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