Designing and testing permanent vegetable production systems for the Red River Delta, Vietnam

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Pham Thi Thu Huong

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Abstract

Permanent vegetable production systems in the Red River Delta (RRD) of northern Vietnam were designed and tested to increase income for farmers and to improve soil conditions for vegetable growing. The research consisted of four steps. In step 1, we analyzed constraints and opportunities for year-round vegetable production in the RRD and recommended options to alleviate the constraints. In step 2, we set up a database with data on profit, labour requirement, costs of pesticide use and planting period of vegetable crops grown in the RRD. In step 3, we developed the model PermVeg, to generate crop sequences for permanent vegetable production systems in the RRD, using the database created in step 2. Five different permanent vegetable production systems were designed based on the following scenarios (i) increase profit, (ii) reduce labour requirement, (iii) decrease the costs of pesticide use, (iv) maximize crop biodiversity, and (v) select crops with low perishable products, respectively. The production systems were called Profitability, Labour, Pesticide, Biodiversity and Perishability system, respectively. In step 4, we tested during two years the performance in the field of the designed systems in terms of profit, labour requirements, pesticide use and soil improvement in comparison with the traditional system, in which vegetables were rotated with rice. We found that when wholesale market prices were taken into account, all permanent vegetable production systems, except the Perishability system, improved farmer's income in comparison with the traditional system. When local prices were taken into account only the Profitability and Labour systems improved the farmers' income. The permanent vegetable production systems required more labour and pesticides than the traditional system. Soil conditions for growing vegetables were improved substantially after the two-year experiment in permanent vegetable production systems as well as in the traditional system. We concluded that 1) PermVeg is a useful tool to design crop sequences for permanent vegetable production systems in the RRD or other regions, where vegetables are grown continuously. 2) Permanent vegetable production systems can improve farmer's income. 3) Vegetable production influences positively soil physical and chemical properties in both permanent vegetable production systems and the traditional system.

Keywords: Red River Delta, Vietnam, permanent vegetable production, cropping systems, profit, labour, pesticide use

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Chapter 1

General introduction

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This chapter provides general information about Vietnam with emphasis on agriculture and the impact of vegetable production on livelihood. The role of modelling in cropping systems is also discussed. The agronomic and institutional problems in the research area, the Red River Delta (RRD), are analyzed, but addressed in more detail in Chapter 2. From this information, we formulate the research hypothesis, research questions and objectives of the study. The methodology used in the study is described briefly. At the end of the chapter the structure of the thesis is outlined.

1. Background

1.1. General information about Vietnam with emphasis on agriculture

Vietnam is an agricultural country. The total area is 330,000 km^2, of which 96,000 km^2 is used for agriculture production. In 2010, the population of Vietnam was about 87 million, 64% of which was rural. Agriculture production accounted for 15.3% of the Gross Domestic Product (GDP) in 2010. GDP per capita in 2009 was 1000 USD (General Statistics Office (GSO), 2011).

The 63 provinces in Vietnam have been divided into six agricultural regions based on the variation in natural conditions: climate, soil, water resources, and topography. They are 1) the RRD; 2) the Northern midlands and mountain areas; 3) the North Central and Central coastal areas; 4) the Central Highlands; 5) the South East; and 6) the Mekong River Delta. The RRD and the Mekong River Delta are the two main agricultural production zones of the country. They contributed 17.6% and 33.1%, respectively, to gross output of agriculture in Vietnam in 2010 (GSO, 2011).

Initially, economic development was slow after the war ended in 1975 until 1986, indicating that attempts to improve policies only had limited success. A comprehensive package of economic reform in the country, “Doi Moi”, was proposed at the Six Party Congress in 1986. The key components of the reform package directly influencing agriculture production were:

1) Reorganization of agriculture on a household basis rather than based on cooperatives;

2) Abolition of almost all subsidies and price controls (Linh, 2001).

In 1988, the reform was implemented. Land use was granted to individual farmer households for a long term (Linh, 2001; Castella *et al*., 2005) in that year.

The economic reform turned Vietnam from a rice importer into the second rice exporter in the world in 1997 (Linh, 2001). In 2010, Vietnam produced 40 million Mg of rice, of which about 10 million Mg (equal to about 7 million Mg of milled rice) was exported (GSO, 2011).

During the period of 2010-2020, the government strategy to further develop agriculture and the rural economy focuses on:

- Improving productivity and quality.
- Adjusting cropping systems based on changes in demand of consumers triggered by income improvement: reducing consumption of staple food, increasing consumption of vegetables and fruits.
- Continuing to produce food crops at suitable scale to ensure food security.
- Producing tropical crops that can grow well in Vietnam and suit the world markets' demand, e.g., rice (*Oryza sativa*), coffee (*Coffea canephora*), rubber (*Hevea brasiliensis*), cashew nut (*Anacardium occidentale*), pepper (*Piper nigrum)*, tea (*Camellia sinensis*), tropical fruits, and vegetables.

1.2. Impact of vegetable production on livelihood

Vegetable production plays a major role in ensuring nutritional diversity and security. Vegetable consumption of less than 200 g capita^{-1} day^{-1} in many countries, often together with poverty and poor medical service, is associated with unacceptably high levels of mortality and underweight of children under five years of age (Keatinge *et al*., 2011). Having diversity of diet with vegetables and fruits is a sustainable way to overcome vitamin and mineral deficiencies because vegetables and fruits are sources of all vitamins, minerals and other essential components for human health such as for example folate (Keatinge *et al*., 2011). According to the World Health Organization, daily consumption of vegetables and fruits should be at least 400 g/capita/day to have a healthy and balanced diet (Nishida *et al*., 2004).

Vegetables help people to recover more quickly from natural disaster, e.g., flood. By rapidly growing, leafy vegetables, e.g., leafy crucifers, amaranth (A*maranthus tricolour*) and kang kong (*Ipomoea aquatica*) the first food can reach the table within a month after sowing in sub-tropical or tropical climate (Keatinge *et al*., 2011).

Vegetable production contributes to trade development. China has succeeded in exporting several vegetable products. Its value of vegetable products in top 20 agricultural products exported increased from 1.09 billion USD in 2000 to 2.84 billion USD in 2009 (FAOSTAT 2011). Vietnam should be aiming to undergo the same development.

Vegetable production contributes to income generation. Profit of a vegetable system has been 1.78 times that of a rice-vegetable system and 5.54 times that of a rice system (Lu *et al*., 2010). Income per labour day in the agriculture sector is generally several times less than that in the non-agricultural sector, e.g., services and industry. As a means to increase income for farmers, growing vegetables is considered a tool to prevent a further widening of rural-urban income gap (Van den Berg *et al*., 2007).

Vegetable production generates employment for rural and peri-urban areas. Employment generated by a vegetable system has been 1.47 times that by a rice-vegetable system and 3.12 times that by a vegetable system (Lu *et al*., 2010). This is meaningful for countries with high proportion of the population in the rural areas, such as Vietnam.

1.3. Impact of vegetable production in the Red River Delta on food security and farmers' income

The Red River Delta (RRD) is the main source of vegetables for the urban citizens in the region and ensures vegetable security for the region. In the Hanoi market, vegetables, which can be grown year-round or in summer in the RRD, come from the peri-urban region around Hanoi and the nearby provinces in the RRD. Temperate vegetables come from the northern midlands and highlands (Bac Giang and Son La), the central highlands (Lam Dong) and China during the hot season. They come from the RRD in the cool season when the weather is suitable for their growth (An *et al*., 2003). The RRD also provides vegetables to the Central provinces of the country, including Nghe An, Ha Tinh, Hue and Da Nang (Huong *et al*., 2011).

Vegetables are cash crops in the RRD. A study by Ha (2008) showed that income from vegetable cultivation comprised 83% of the income from crop production in peri-urban areas and 89% in rural areas. More details about the role of vegetables on food security and farmers' income in the RRD will be provided in Chapter 2.

1.4. Role of models in cropping systems

Crop rotation plays a key role in cropping systems. The combination, frequency and sequence of crop species influence crop yields, soil borne pests and diseases, weed populations, and the physical, chemical and biological fertility of the soil (Struik and Bonciarelli, 1997).

Models have been useful tools to design crop rotations with multiple goals in different environments and under various economic conditions. ROTAT (Dogliotti *et al*., 2003) is a software tool designed for generating crop rotations based on defined objectives. ROTAT generates all possible crop rotations. Feasible crop rotations are selected by a number of filters, exclusion criteria or rules defined by users, e.g., weed infestation risks, nitrogen balance and phytosanitary aspects, and ranked based on economic performance. The tool has been applied to design crop rotation with objectives to improve crop yields, reduce soil erosion and input, and improve efficiency of resource use and farm income for vegetable farms in South Uruguay (Dogliotti *et al*., 2004, 2005). In those studies, maximum crop frequency was set up low enough to avoid negative effects on biological soil property: crop frequency of 1 in 2 years to 1 in 4 years in a rotation length of 8 - 9 years.

ROTOR (Bachinger and Zander, 2007) is a model used to generate 3-8 year crop rotations for organic farming. The crop rotations are ranked based on economic performance with restrictions on nitrogen supply and weed infestation, and frequencies and sequences of crops and crop types within rotations, to control nitrogen balance, weed infestation and soil borne diseases.

In this thesis it will be tried to develop a tailor-made cropping systems model, PermVeg, and use it for designing suitable vegetable cropping systems.

2. Problem statement

The present vegetable production system in the RRD, in which vegetables are rotated with rice, has disadvantages. Wet puddling, necessary for paddy rice, alternated with drying, necessary for vegetables, affects soil structure, creating physical soil conditions unfavourable for vegetable production (Kleinhenz *et al*., 1997; Everaarts *et al*., 2006). In addition, it is hard to improve farmers' income via improving rice productivity, as the level of rice intensification is already high and the acreage can hardly be increased. In 2010, the average rice yield for two crop seasons (spring-summer and summer-autumn) in the RRD was 5.9 Mg/ha (GSO, 2011). It was a bit lower than rice yield in China, 6.5 Mg/ha, but higher than the national average rice yield (5.3 Mg/ha) and the average rice yield elsewhere in the region (2.9 Mg/ha in Thailand, 5.0 Mg/ha in Indonesia and 3.6 Mg/ha in the Philippines) (FAOSTAT, 2012).

As vegetables can provide additional income to farmers, permanent vegetable production systems can be an option to improve farmers' income. However, such systems need to be designed and optimized for the RRD, taking into account the specific conditions in the warm and in the cool season.

3. Hypothesis

The hypothesis to be tested is whether continuous vegetable production results in higher financial returns and improved soil conditions as compared to vegetable growing in rotation with flooded rice.

4. Research questions

Research questions to be answered are:

- What are suitable and profitable crop sequences for vegetable production systems in the RRD?
- What are the financial returns with continuous vegetable production?
- Are soil conditions for vegetable crop growth improving with continuous vegetable production?

5. Objectives

5.1 Agronomic design and testing of a vegetable cropping system

Taking into account the agro-ecological conditions of the area, phytosanitary aspects of crop sequences and the market potential of crop products, permanent vegetable production systems will be designed, in which a variety of vegetable crops are grown. The crop sequences within a two-year period and the financial returns are described and estimated by a model. With this model the most promising crop systems for permanent vegetable production will be identified.

5.2. Assessing economic performance

The most promising options obtained with the model are tested for economic performance under field conditions. The actual economic result of the continuous vegetable cropping system is compared with the economic results of the system containing vegetables rotated with flooded rice.

5.3. Evaluation of the impact of the systems on soil quality

Based on periodic sampling, the trends in soil physical and soil chemical properties in the continuous vegetable cropping system and in the rotation of vegetables with flooded rice will be compared to assess whether soil conditions for vegetable crops will indeed improve under continuous vegetable production.

6. Methodology

The work started with research on the possibilities for permanent vegetable production systems, suitable for the RRD conditions. The following step was to prepare a database of vegetable crops, which could be used for the theoretical design of permanent vegetable production systems. Given the agro-ecological conditions a well motivated choice of crops was made. The design was tested, both quantitatively and economically, by modelling of the various options in the design. The design should have universal characteristics and should be easily adaptable for other situations. The next step was to test the most promising options in the field. The actual economic result of the permanent vegetable production systems and changes in soil conditions complemented the studies. Basic indications for the design of a permanent dry land vegetable production system have been given by Everaarts *et al*. (2006).

7. Outline of the thesis

In Chapter 2, we analyze the natural and socio-economic conditions influencing vegetable production and supply in the RRD. We also analyze factors which enhance or impede growing vegetables year-round in the RRD.

In Chapter 3, we describe the data collected on vegetable production in the RRD to set up the database of vegetable crops grown in the RRD with growth durations in the field, planting periods, profits, labour requirements and costs of pesticide use. The database can be used for the design of innovative vegetable production systems for the RRD.

In Chapter 4, we formulate requirements of innovative permanent vegetable production systems and describe the model PermVeg used to generate the vegetable crop sequences with the objectives improving farmers' income and improving soil conditions for growing vegetables.

In Chapter 5, we compare the performance of the five designed permanent vegetable systems with that of the traditional system in terms of profit, labour requirement and pesticide use. We also evaluate the performance of the PermVeg model in the field.

In Chapter 6, we compare the chemical and physical properties of the soil under the permanent vegetable systems with those of the traditional system during the 2-year experiment.

Finally, in Chapter 7, we discuss the strengths, opportunities, weaknesses and threats of the PermVeg model and of the permanent vegetable production systems in the RRD. Moreover, recommendations are made that may help farmers to improve their production and marketing of vegetables.

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Chapter 2

Vegetable production in the Red River Delta of Vietnam. I. Opportunities and constraints

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Abstract

An overview is given of the natural, socio-economic, agronomical and marketing conditions for vegetable production in the Red River Delta (RRD) of Vietnam. The seasonal variation in temperature in the RRD is the main determinant for the production season of vegetables. Heavy rainfall in the hot season increases production risks, as it may physically damage crops. Frequent rainfall in this period may enhance disease incidence. Landholdings are small and individual plots are the smallest of Indochina. Vegetables typically are produced in flooded rice based systems. Such systems are characterized by poor soil structure for vegetable production and high labour demand for the construction of raised beds. Highly perishable crops can only be grown close to the markets in the peri-urban areas. Less perishable crops can be produced further away from the city markets. Generally, large quantities of pesticides are used and there is increasing public concern about pesticide residues on products. The small landholdings, small plots and consequently the small amounts of product, limit effective marketing and make the producers dependent on collectors. Given the trends in population dynamics and human diets, urban vegetable demand in the RRD, however, has ample opportunities to grow.

Effects have been analysed and categorised in opportunities and constraints for adopting improvements. A potential pathway to sustainable development is the development of permanent vegetable production systems, with producers co-operating in producers organizations, enabling them to work on a larger scale, produce larger volumes, introduce harvest date planning and quality control and aim for the integration of production with marketing in a vegetable value chain. By simultaneously adopting Good Agricultural Practices, consumers' food safety concerns can be addressed. The expected increase in vegetable demand is likely to open new opportunities for the RRD vegetable producers.

Keywords: Red River Delta, Vietnam, vegetable production, demand, supply, marketing, constraints, opportunities

1. Introduction

The global demand for vegetables is increasing. Global vegetable consumption, as defined by FAO (FAOSTAT, 2009), has increased from 190 million Mg in 1961 to 880 million Mg in 2009, because (1) the global population has increased from 3.1 billion in 1961 to 6.8 billion in 2009, and (2) the daily vegetable intake has increased from 170 g per capita per day in 1961 to 360 g per capita per day in 2009 (FAOSTAT, 2009). The daily vegetable intake is increasing because of a growing awareness of the important positive effect of vegetables on health, and because of a demand for year-round availability and diversity of foods (Weinberger and Lumpkin, 2005).

Continuing urbanization and increasing welfare in the cities result in an increasing year-round demand for commercially produced vegetables (Ali, 2007; Everaarts and de Putter, 2009). With populations of about 9 million for Jakarta (Basuki *et al.*, 2006) and 5 million for Ho Chi Minh City (General Statistic Office (GSO), 2007), these cities may serve as examples to illustrate the considerable amounts of vegetables needed to supply such huge cities. With an average vegetable consumption in the beginning of the previous decade of 70 g per capita per day for Indonesia, and 220 g per capita per day for Vietnam (FAOSTAT, 2009), the daily vegetable demand is estimated to be 630 Mg for Jakarta and 1100 Mg for Ho Chi Minh City, excluding the waste removed from the product before preparation. A typical example of a vegetable production area close to a very large city is the Red River Delta (RRD) in Vietnam. The RRD is the economic centre of northern Vietnam with Hanoi as the major city. It consists of 9 provinces (Figure 1). With an area of about 1,500,000 ha, equalling 13% of the total area of Northern Vietnam, the RRD was responsible for 63% of the agricultural output and for 81% of the industrial output of Northern Vietnam in 2005 (General Statistic Office (GSO), 2007). Rice is the principal crop of the delta, but many kinds of vegetables are also grown. The RRD comprises 25% of Vietnam's vegetable-producing area and was responsible for 30% of the total vegetable production in Vietnam in the period 2002–2005 (General Statistic Office (GSO), unpublished data). Vegetables are important cash crops in the RRD, whereas rice is mainly used for home consumption (Linh 2001; Ha, 2008). In the RRD, income from vegetable cultivation comprises 83% of the income from crop production in peri-urban areas and 89% in rural areas (Ha, 2008).

As in many other countries of South-East Asia, in Vietnam field-grown vegetables are often rotated with flooded rice. Despite the potential profitability of vegetable production, this

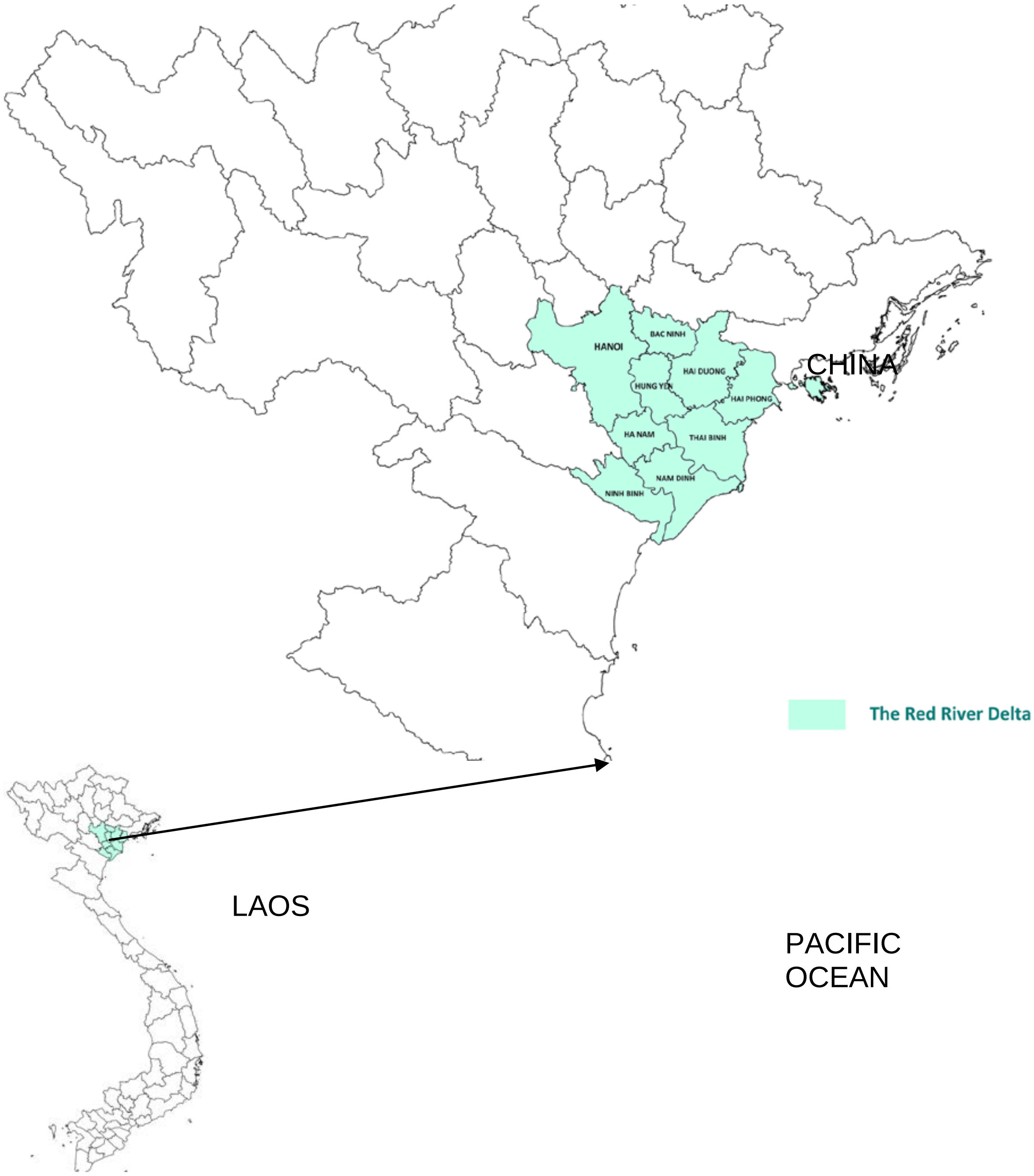

Figure 1. Location of Vietnam and the Red River Delta.

rotation has disadvantages. Wet puddling, necessary for flooded rice, affects soil structure, resulting in restricted water movement in the soil, making the soil less suitable for vegetable production (Kleinhenz *et al*., 1997; So and Ringrose-Voase, 2000). In addition, labour requirements in this rotation are high, caused by laborious practices such as raised bed construction for vegetable production, and flattening and puddling of the soil for rice production after vegetable cultivation (Everaarts *et al*., 2006).

Notwithstanding the disadvantages of the current rotations, vegetable farming can be lucrative in the RRD, as shown by the fact that the output value per labour-day of vegetable production was 2.2 times higher than that of cereal production (Thuy *et al*., 2002). However, seasonality of production and price fluctuations (An *et al*., 2003) are significant problems vegetable farmers and consumers currently face.

The purpose of this paper is (1) to provide an overview of the natural, socio-economic, agronomical and marketing conditions for vegetable production in the RRD, and (2) to analyse and formulate pathways for sustainable development.

2. Natural conditions for vegetable production in the Red River Delta of Vietnam

2.1. Climate and its effects

The RRD is situated around 21^{o} N latitude. According to Köppen's climate classification, the RRD has a tropical monsoon climate. Hanoi's climate is representative for the RRD (Table 1).

The climate of the RRD comprises three seasons: (1) the hot and wet season from May to September, (2) the cool and dry season from October to January, and (3) the cool and humid season from February to April. The hot and wet season is characterized by a high radiation, a high temperature, high rainfall, and moderate relative air humidity (RH). The cool and dry season has a moderate to low radiation, a moderate to low temperature, low rainfall, and a low RH. The cool and humid season has low radiation, a low to moderate temperature, low rainfall, and a high RH. Daylength varies from 10.50 h to 13.20 h during the year (Siemonsma and Piluek, 1993). Daylength is longest in the hot and wet season.

The growing season for vegetables in the Red River Delta is mainly determined by temperature. Vegetables of temperate origin, such as broccoli (*Brassica oleracea* var. *italica*) and carrot (*Daucus carota*) grow well in the cool season. Tropical leafy vegetables such as Ceylon spinach (*Basella rubra*) and fruit vegetables of the *Cucurbitaceae* family grow well in the hot season.

During the hot season, rainfall generally is sufficient for crop growth. During the cool season, with limited rainfall, crops are mostly irrigated. Heavy rainfall in the hot and wet season may cause physical damage to the vegetables. Although not documented in literature, it is known that heavy rainfall may even completely destroy vegetables in the field, making

Table 1. Mean monthly climate data for Hanoi over the period 1996–2006.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	17.4	18.2	20.4	24.7	27.7	29.6	29.6	28.8	27.9	25.9	22.6	18.6
Rainfall (mm per month)	16	26	57	73	210	257	304	328	173	99	59	30
Relative humidity (%)	78	81	83	84	80	78	80	82	79	76	75	74
Sunshine (hours per month ≥ 0.1 kW m^{-2})	68	49	44	91	157	159	163	149	154	150	137	102

Sources: The 1996–1998 data are from Lang Ha Meteo Station, Lang Ha Street, Hanoi, Vietnam (unpublished data). The 1999–2006 data are from Statistical Year Book 2000 - 2006 (General Statistic Office, 2001–2007).

vegetable production in the hot season more risky. In cases of extreme and prolonged rainfall, flooding may occur, resulting in complete loss of production (Anh *et al*., 2004). For example, the flood in Hanoi and some northern provinces from 29 October to 5 November 2008 destroyed large quantities of vegetables and caused a sharp increase in the price of vegetables in Hanoi (Figure 2).

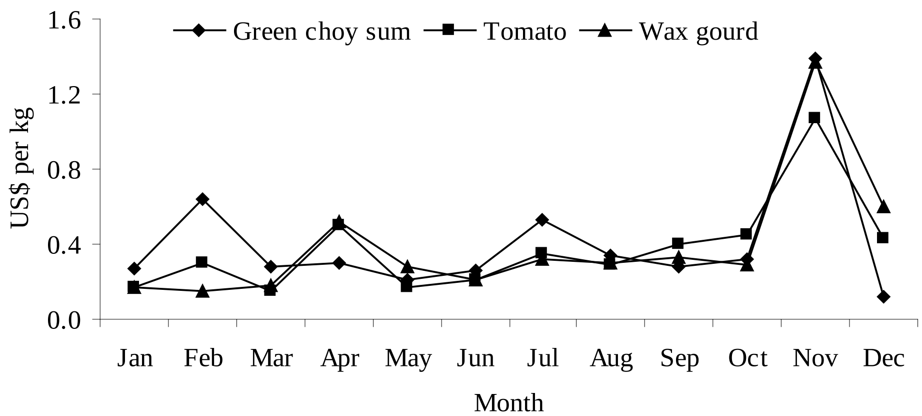

Figure 2. Monthly price of green choy sum, tomato and wax gourd at Long Bien wholesale market in Hanoi, 2008 (Data courtesy of Fresh Studio, Da Lat, Vietnam).

Temperature, rainfall and RH influence the incidence and abundance of diseases and pests in vegetables. The climate allows year-round occurrence of bacterial wilt (*Ralstonia solanacearum*) on tomato (*Solanum lycopersicum*) (Xuyen and Dinh, 2006), whereas late blight (*Phytophthora infestans*), because of its sensitivity to high temperatures, is common on tomato only in the cool seasons. However, late blight in the cool and humid season is more serious than in the cool and dry season (Oanh *et al*., 2004), because of the high RH in the cool and humid season. Flea beetle (*Phyllotreta striolata*) and white fly (*Bemisia tabaci*) are abundant in the hot and wet season, whereas diamondback moth (*Plutella xylostella*) is more abundant in the cool season (Oanh *et al*., 2004). Flea beetles and white flies prefer high temperatures, whereas diamondback moth cannot withstand high intensity rainfall. Frequent rainfall in the hot and wet season may enhance disease infection by prolonging leaf wetness periods.

Although chemicals are often abundantly used to control pests and diseases (Hoi *et al.*, 2009), yield losses due to pests and diseases in the wet season are higher than those in the dry season (Anh *et al*., 2004).

In conclusion, among the climatic factors, temperature is most important for vegetable production as it determines the specific growing season. Heavy rainfall may damage crops physically. Shortage of rainfall is less important, as during dry periods, crops are irrigated. Specific pest and disease incidence may be seasonal.

2.2. Soils and their suitability for vegetable production

Most soils of the RRD are of the alluvial type and vary in soil texture due to irregular river tides. Interposed clay, silt or sandy layers are generally present. Soils near rivers usually have a sandy texture, but soils far from rivers may have a fine texture such as silt or clay. In general, the alluvial soils of the RRD are of medium texture, bright brown in colour and have a neutral pH. Generally, such soils are considered to be suitable for annual crops, including vegetables (Bo *et al*., 2009).

Locally, however, soil conditions may vary and be less favourable for vegetable production. The soils in the Dong Anh district, an important vegetable producing district of the RRD, generally have a sandy loam to medium loam texture, are mostly acid to medium acid and are low in organic matter and nitrogen (Table 2). The light soil texture, low organic carbon content and low cation exchange capacity of the top soil result in a low basic soil fertility, as well as in a limited water and low nutrient holding capacity (Everaarts *et al.*, 2006; Dung *et al*., 2003). In such cases the low soil fertility and low nutrient holding capacity of the soil may be compensated for by the repeated application of large amounts of fertilizer (van Beek *et al*., 2005).

The climatic conditions in the RRD may influence the seasonal pattern of soil nitrogen availability. Soil nitrate accumulates in the root zone during the dry season when evaporation exceeds precipitation, and leaches beyond the root zone in the wet season when precipitation

Table 2. Physical and chemical properties of the top soil in two villages in the Dong Anh district of the Hanoi province (Dung *et al*., 2003).

		Village (soil depth)	
Parameter		Son Du (0–19 cm)	Tang My (0–17 cm)
Soil texture	Sand (%)	36	36
	Silt (%)	50	58
	Clay (%)	14	7
pH KCl		5.0	6.5
Organic carbon (%)		0.91	0.86
N total (%)		0.09	0.09
P_2O_5 total (%)		0.05	0.04
K_2O total (%)		0.39	0.25
N available (mg per100 g soil)		2.80	2.80
P_2O_5 available (mg per100 g soil)		6.24	4.12
K_2O available (mg per100 g soil)		12.70	3.37
Cation exchange capacity (meq per100 g soil)		7.82	4.79

exceeds evapotranspiration (Kleinhenz *et al*., 1997). Especially broadcast applied nitrogen fertilizer can be lost because of surface run-off during severe rainfall. Therefore, farmers may need to apply more nitrogen to vegetable crops in the hot and wet season with high rainfall than in the cool seasons with low rainfall, to maintain production levels.

In conclusion, generally, soils in the RRD are suitable for the production of vegetable crops. Locally less suitable soil conditions are overcome with adapted production methods. More fertilizer nitrogen may be needed under conditions of abundant rainfall.

3. Socio-economic conditions for vegetable production in the Red River Delta of Vietnam

In 2006, the RRD's population was 18.2 million, of which 13.7 million people were living in rural areas (General Statistic Office (GSO), 2007). The rural population is increasing annually with 0.5%, while the annual population in the urban areas increases with 4.9%. By 2020 the RRD population is projected to be 13.9 million in the rural areas and 9.4 million in the cities. Since urbanization and industrialization will lead to a decrease in the area available for agriculture (Ha, 2008; van den Berg, 2003) agricultural production per unit of land will have to increase.

Vietnamese farmers returned to household-based production after two successive reforms (Decree 100 in 1981 and Resolution 10 in 1988). This gradually shifted agricultural production from co-operatives to individual households (Castella *et al*., 2005). In the RRD, vegetables are mostly produced by small landholders. The average area of agricultural land per capita is approximately 700 m^2 (General Statistic Office (GSO), 2007). The average size of vegetable plots in the RRD is 400 m^2, which is the smallest in Indochina (Thuy *et al*., 2002). Vegetable production on such small plots may have advantages, such as intensive investment of labour. On the other hand, efficient mechanization is difficult.

In general, the usually small scale of farming operations has serious disadvantages. Small farms are typically operated by poor or part-time farmers, who may have difficulties to apply new technologies. In addition, small farmers usually have no strategy for harvest date planning and marketing of their products, especially in rural areas (Linh, 2001; Anh *et al*, 2004). Small farmers tend to grow the previously successful crops of their neighbours, thereby increasing production of these crops and putting pressure on prices (Linh, 2001). Especially in rural areas, farmers have no other option than to sell their product to collectors, who determine the price.

In conclusion, the small size of the farming operations and small plots limit the introduction of improved production and marketing systems.

4. Agronomical conditions for vegetable production in the Red River Delta of Vietnam

4.1. Production

4.1.1. Season

The vegetables grown in the RRD can be grouped into three categories according to their growing season: (1) winter crops, suitable for the period November–March, (2) summer crops, especially suitable for the period April–October, and (3) vegetables grown year-round (Table 3). Winter crops are diverse and include root, tuber, fruit and leafy vegetables. They mainly belong to the *Cruciferae* and *Liliaceae*. Summer crops are less diverse than winter crops, and include fruit and leafy vegetables. The summer fruit vegetables mainly belong to the *Cucurbitaceae*. Year-round crops are mainly leafy vegetables, belonging to various botanical families.

The main season for vegetable production is from October to February. A study in five provinces of the RRD (Hanoi, Hai Duong, Hung Yen, Vinh Phuc and Bac Ninh) showed that the land area cropped with vegetables was 84% in that period and only 16% of the area was cropped with vegetables in the hot and wet season (Thuy *et al*., 2002).

4.1.2. Location

Vegetable production in the rural areas differs from that in the peri-urban areas. Peri-urban areas are generally defined as being located within such a distance from a city that farmers with common transport means are able to supply perishable vegetables within a day to city markets (Ha, 2008). Highly perishable vegetables like Indian mustard (*Brassica juncea*), green choy sum (*Brassica rapa* var. *parachinensis*) and lettuce (*Lactuca sativa*) traded in Hanoi markets are from Hanoi peri-urban areas, whereas less perishable vegetables like wax gourd (*Benincasa hispida*), cabbage (*Brassica oleracea* var. *capitata*) and tomato are from both Hanoi peri-urban and rural areas (An *et al*., 2003).

This implies that the vegetables grown commercially in rural areas generally are of the low perishable type, whereas those grown commercially in the peri-urban areas are of both high and low perishable types.

4.1.3. Type of production

In the RRD the acreage of vegetable production, as well as the vegetable yield per ha, increased in the period 2002–2005 (Table 4), likely following increased demand. As for the method of production two main types of vegetable production can be distinguished: (1) the so-called ‘safe vegetable’ production (with restricted inputs of pesticides and fertilizers) and, (2) conventional vegetable production (with often high inputs of pesticides and fertilizers). Because of the very limited area of organic vegetable production, this type of production is not taken into consideration.

Due to public pressure concerning the safety of vegetable products, especially regarding the presence of pesticide residues on the products, the Ministry of Agriculture and Rural Development has implemented a ‘safe vegetable’ production programme since 1995. The programme educates farmers to grow vegetables with restricted inputs of pesticides and fertilizers and stimulates the use of water from wells or non-polluted rivers (Moustier *et al*., 2006).

Table 3. Groups of vegetable crops according to growing season (Everaarts *et al*., 2006; Anh *et al*., 2006; Anh *et al*., 2005a; Anh *et al*., 2005b; Everaarts *et al*., 2008).

Group/ family	Crop		Growing possibility[a]	
	Scientific name	Common name	Apr–Oct	Nov–Mar
Cool season crops				
Liliaceae	*Allium ampeloprasum* var. *porrum*	Leek	1	5
Liliaceae	*Allium cepa* var. *cepa*	Onion	–	4
Liliaceae	*Allium cepa* var. *ascalonicum*	Shallot	–	5
Umbelliferae	*Apium graveolens*	Celery	1	5
Cruciferae	*Brassica oleracea* var. *italica*	Broccoli	–	4
Cruciferae	*Brassica oleracea* var. *capitata*	Cabbage	1	5
Cruciferae	*Brassica oleracea* var. *botrytis*	Cauliflower	–	4
Cruciferae	*Brassica oleracea* var. *gongylodes*	Kohlrabi	2	5
Cruciferae	*Brassica rapa* ssp. *chinensis*	Green pak choi	1	5
Compositae	*Chrysanthemum coronarium*	Garland chrysanthemum	–	5
Apiaceae	*Coriandrum sativum*	Coriander	1	5
Compositae	*Lactuca sativa*	Lettuce	2	5
Solanaceae	*Solanum lycopersicum*	Tomato	2	5
Leguminosae	*Phaselus vulgaris*	French bean	–	5
Leguminosae	*Pisum sativum* var. *macrocarpon*	Snow pea	–	4
Cruciferae	*Raphanus sativus*	Radish	3	5
Cucurbitaceae	*Sechium edule*	Chayote	1	5
Hot season crops				
Basellaceae	*Basella alba*	Ceylon spinach	5	1
Cucurbitaceae	*Benincasa hispida*	Wax gourd	5	2
Malvaceae	*Corchorus olitorius*	Tossa jute	5	–
Cucurbitaceae	*Cucumis sativus*	Cucumber	4	2
Cucurbitaceae	*Cucurbita moschata*	Pumpkin	5	3
Cucurbitaceae	*Luffa acutangula*	Loofah	5	–
Cucurbitaceae	*Momordica charantia*	Bitter gourd	5	–
Leguminosae	*Vigna unguiculata* ssp. *sesquipedalis*	Yard long bean	5	–
Year–round crops				
Amaranthaceae	*Amaranthus tricolour*	Amaranth	5	4
Liliaceae	*Allium fistulosum*	Welsh onion	4	5
Cruciferae	*Brassica juncea*	Indian mustard	4	5
Cruciferae	*Brassica juncea* var. *rugosa*	Wrapped heart mustard	4	5
Cruciferae	*Brassica rapa* var. *parachinensis*	Green choy sum	4	5
Convolvulaceae	*Ipomoea aquatica*	Kangkong	5	4

[a] – = no cultivation advised; 5 = very good cultivation possibility.

Table 4. Yield, area and total production of vegetables in the Red River Delta during the period 2002–2005 (General Statistic Office, 2003–2006).

Year	Yield ($Mg\ ha^{-1}$)	Area (ha)	Total production (Mg)
2002	16.3	142,000	2,300,000
2003	16.5	149,000	2,460,000
2004	17.3	160,000	2,770,000
2005	18.0	159,000	2,850,000

The training programme is based on production protocols provided by the Hanoi Department of Agriculture and Rural Development, the Fruit and Vegetable Research Institute, or the Hanoi Plant Protection Department. ‘Safe vegetable’ production is mostly found in peri-urban Hanoi and in the Soc Son district of Vinh Phuc province. As a result, trained ‘safe vegetable’ farmers’ knowledge on pesticide toxicity classification and on the use of pesticides has been improved (Hoi *et al.*, 2009).

Conventional vegetable production is the type of production based on producers’ experience and expertise. For conventional vegetables, quality standards, and quality control, are virtually absent. Because of the small landholdings, farmers tend to overuse fertilizers and pesticides in order to maximize crop yield (Moustier *et al.*, 2006).

There are no data available on the areas of ‘safe’ and conventional vegetable production in the whole of the RRD. In Hanoi province, ‘safe vegetable’ production covered 30% of the total vegetable production area in 2001 (Moustier *et al.*, 2006).

In conclusion, season and location influence the type of vegetable crops produced. Lack of adequate cool storage and transport facilities limits the production of perishable crops to the peri-urban areas. Public health concern is instrumental in stimulating reduction of pesticide and fertilizer use.

4.2. Crop rotation

Vegetable crop rotations vary throughout the RRD. Documented data on vegetable crop rotations are scarce, but for the districts Vu Thu and Thuong Tin descriptions of vegetable crop rotations are available.

In the Vu Thu district of the Thai Binh province, there are four common crop sequences (Anh *et al.*, 2006):

1. Rice–rice–fallow.

2. Rice–rice–lettuce–lettuce–fennel (*Foeniculum vulgare*).
3. Groundnut (*Arachis hypogaea*)–caisin (*Brassica parachinensis*)–Indian mustard–kohlrabi (*Brassica oleracea* var. *gongylodes*)–radish (*Raphanus sativus*)–coriander (*Coriandrum sativum*).
4. Coriander–lettuce–shallot (*Allium cepa* var. *ascalonicum*)–Indian mustard–Welsh onion (*Allium fistulosum*)–coriander–lettuce–lettuce.

The profitability of sequence 2, i.e., rice in the hot season and vegetables in the cold season, has been 5.2 times that of sequence 1. Although the profits of sequences 3 and 4 were again considerably higher than that of sequence 2 – especially the profit of sequence 4 was 2.1 times that of sequence 2 and even 10.6 times that of sequence 1 – sequence 1 and sequence 2 covered 26% and 66% of agricultural land in the district, respectively. Sequences 3 and 4 are not implemented more often because of (1) a less predictable production compared with rice, resulting in higher risks for the producer, (2) insecurity about the ultimate product price and, (3) because of higher labour needs with vegetable cultivation. On a national scale, the continuous emphasis on food security, i.e., rice production, also plays a role.

In the Thuong Tin district of Hanoi province, most of the farmers grow vegetables year-round to supply the Hanoi market. Farmers grow other food crops if their land is not suitable for vegetables or if their labour availability is insufficient for vegetable production. Leafy vegetables with a short growth duration, such as Indian mustard, green choy sum, green pak choi (*Brassica rapa* ssp. *chinensis*), garland chrysanthemum (*Chrysanthemum coronarium*), leek (*Allium ampeloprasum* var. *porrum*), and coriander are commonly grown in this area (Anh *et al*., 2005a).

Especially crops of the *Brassicaceae* family are grown year-round in both Vu Thu and Thuong Tin districts, resulting in the continuous presence of family-specific pests and diseases (Anh *et al*., 2006; Anh *et al*., 2005a).

In conclusion, year-round vegetable production may be limited by perceived production and marketing risks, and because of higher labour needs. On the other hand, vegetable crops grown in continuous vegetable sequences, especially with a high number of species of the same family, may possibly suffer more from biotic stress than crops grown in rotation with the traditional food crops.

5. Marketing conditions for vegetables produced in the Red River Delta of Vietnam

5.1. Demand and supply

Vegetable consumption in urban Hanoi is on average 270 g per capita per day (Ali *et al*., 2006). Hanoi with an urban population of 2,101,600 people (General Statistic Office (GSO), 2007) thus requires about 570 Mg per day. This is excluding the waste that is removed from the product before preparation. So the ultimate daily demand is even higher. All the other cities of the RRD with a total urban population of 2,445,200 (General Statistic Office (GSO), 2007) require about 660 Mg per day.

Vegetable consumption is lowest in June and July and highest in February and March (Ali *et al*., 2006). This variation appears to be related to the seasonality of vegetable supply. Supply of temperate vegetables such as cabbage and Chinese cabbage is strongly seasonal (An *et al*., 2003). In the period November–March large amounts of these vegetables produced in the RRD are sold at wholesale markets, whereas in June only small amounts of these vegetables, imported from China, are sold at wholesale markets. Vegetables grown year-round in the RRD, such as green choy sum, however, are sold in large amounts in August, the more difficult time for temperate vegetable production (Table 5).

In conclusion, the amount and type of vegetable consumption appears to be related to the seasonality of vegetable supply.

Table 5. Quantity (Mg) of three vegetables sold daily in wholesale markets in Hanoi over the period March 2002–January 2003) (An *et al*., 2003).

Month	Cabbage	Chinese cabbage	Green choy sum
March	20.7	6.3	11.4
June	6.5	0.4	11.7
August	17.7	0.0	26.2
November	36.3	5.9	18.3
January	30.3	3.4	11.0

5.2. Marketing channels

Vegetable marketing studies in the RRD generally focus on Hanoi. When divided according to production method, the two types of products, i.e., ‘safe vegetables’ and conventional vegetables, are traded in Hanoi with partly overlapping marketing channels.

'Safe vegetables' are traded through co-operatives, collectors or distribution companies to 'safe vegetable' shops or supermarkets (Figure 3). Although 'safe vegetable' production covered 30% of the total vegetable production area in Hanoi in 2001 (Moustier *et al.*, 2006), the share of 'safe vegetables' sold through 'safe vegetable' shops and supermarkets is only 8% (Son *et al.*, 2006). This is because only part of the 'safe vegetable' products is sold to schools, restaurants, supermarkets, factories or retail stalls. The remaining part is sold in free markets. For instance, in 2010, the Van Duc co-operative, near Hanoi, produced 'safe vegetables' on 286 ha, but only 15% of the products could be sold directly to schools, restaurants, hotels and factories. The remaining part was sold in free markets at conventional vegetable prices, which were only about 75% of the 'safe vegetable' prices (Huong *et al.*, 2011).

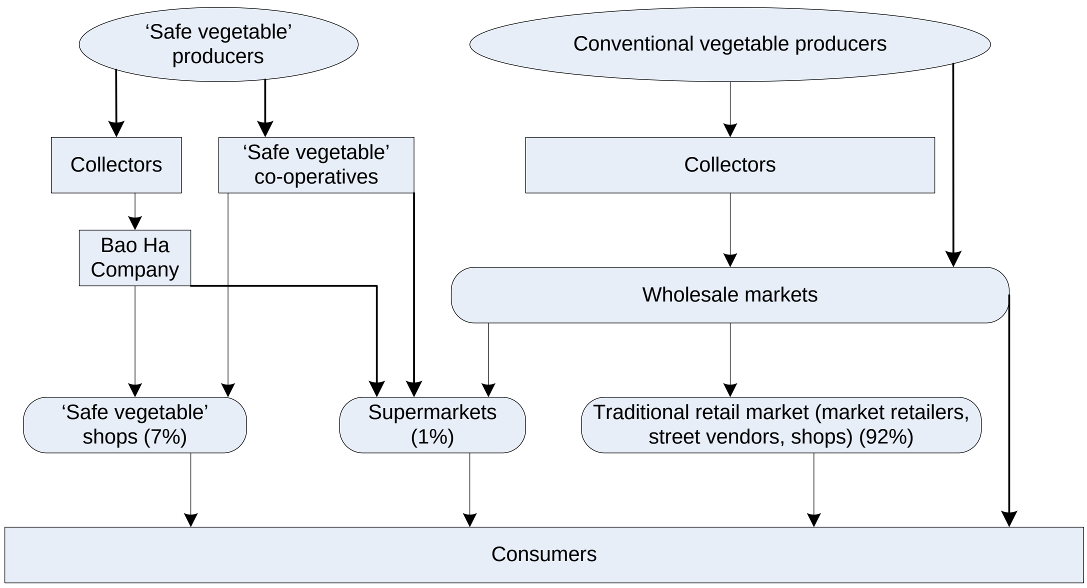

Figure 3. Marketing channels and market share (%) for vegetables in urban Hanoi (Adapted from Son *et al.*, 2006).

Despite the attested preference for safe products in the public media, it appears that demand for 'safe vegetables' remains modest. The reason may be that consumers are unaware of the availability of 'safe vegetables' or do not know where they are sold (Moustier *et al.*, 2006). In addition, the lack of enforced quality standards and the absence of guaranteed quality indications on the product, encourages consumer's distrust of the origin of 'safe vegetables'.

For conventional vegetables, the producers and collectors deliver the vegetables to wholesale markets, where they sell the vegetables (1) to traditional retailers such as market retailers, who sell vegetables at city district retail markets, (2) to street vendors who sell vegetables at a fixed place in the streets, or who walk around with the products, (3) directly to consumers, (4) to restaurants, and (5) to hotels. Wholesalers are involved in trading vegetables produced in the RRD or in trading off-season vegetables from outside the RRD. In that case collectors sell the vegetables to the wholesalers, and then the retailers and the consumers buy the vegetables from wholesalers at wholesale markets (Son *et al*., 2006). At the retail-market level, most of the conventional vegetables are sold at traditional retail markets. The market share of traditional retail markets is 92%.

On the long term, the rise of supermarkets in Vietnam, from 1 in 1993 to 130 by the end of 2002, may offer new and potentially profitable methods of marketing for vegetables. On the short and mid-term the traditional retail system will remain the most important marketing channel (van Wijk *et al*., 2006).

In conclusion, the data indicate that most vegetables are traded through the traditional marketing channels, in which there are no fixed price agreements between producers, collectors or retailers. Consequently, producers depend on the prices offered by the collectors. Demand for 'safe vegetables' remains modest.

5.3. Vegetable prices

Prices of vegetables in the traditional markets vary with the season. In the hot season, notably in July and August, temperate vegetables such as cabbage, tomato and carrot fetch high prices in the Hanoi market (Table 6), since it is not possible to produce these vegetables in the RRD at that time (An *et al*., 2003). Vegetables like kangkong (*Ipomoea aquatica*) and wax gourd fetch lower prices during the hot season (Table 6), as they grow and yield well at high temperatures (Siemonsma and Piluek, 1993), resulting in a large supply. In general, prices for vegetables are high from June through November as a result of the low productivity because of wet and hot weather conditions and because of the limited area of land used for vegetable production during summer (Thuy *et al*., 2002).

In contrast, prices of vegetables in supermarkets are more stable. Vegetable prices in supermarkets do not drop sharply in the main season. Compared with the main season, prices in the supermarkets in the off-season are only 2% higher for tomato and 11% higher for kangkong (An, 2006). However, because supermarkets supply only 1% of the vegetables traded in Hanoi, the vast majority of the vegetable producers in the RRD do not take

Table 6. Monthly price indexes[a] of vegetables sold in Hanoi over the period 1996–2001 (Anh *et al*., 2004).

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Welsh onion	100	110	136	146	123	143	151	127	129	126	125	106
Carrot	100	94	90	111	139	155	189	214	197	166	155	135
Cabbage	100	106	92	107	236	347	492	511	448	385	211	153
Tomato	100	107	83	97	155	176	236	314	351	302	253	175
Kangkong	100	101	100	86	73	62	69	74	60	67	87	103
Wax gourd	100	130	101	108	97	76	68	60	67	86	143	101
Average	100	108	100	109	137	160	201	217	209	189	162	129

[a] Monthly price index = [(average price of each month – average price in January) /100 + 1] × 100.

advantage of the more stable prices of vegetables in the supermarkets.

In conclusion, vegetable prices for consumers vary during the year, as related to the seasonality of vegetable production.

5.4. Consumer perception of products

Many consumers believe that vegetables are unsafe because of chemical contamination. Being asked which foodstuffs were most dangerous to consumers' health, 89% of the respondents answered that vegetables were the most dangerous, followed by meat (70%), fruits (46%) and fish (37%). Among chemical contaminants, pesticides are a major concern, followed by growth regulators and overdoses of fertilizer (Figuié, 2003). This concern, however, has no discernible effect on vegetable consumption. Eighty-nine per cent of the Hanoi interviewees trust their own health and preparation practices to avoid health risks (Figuié, 2003). The criteria by which clients perceive vegetables to be good have been listed (Ali *et al*., 2006) as follows:

1. Desirable appearance, freshness, taste, tenderness and size.
2. Clean, healthy, good nutritional quality, locally grown during the main growing season, and grown in a healthy environment with minimal use of chemical agents.
3. Well preserved and well packed.
4. Good price.

In conclusion, despite the indicated distrust of the safety of conventionally produced vegetables, conventionally produced vegetables still make up the majority of vegetables sold.

6. Opportunities and constraints of vegetable production in the Red River Delta of Vietnam

6.1. Opportunities

Vegetable production in the RRD plays an important role in providing vegetables to the urban areas of the region. Among conventional vegetables traded in Hanoi, the leafy vegetables, such as kangkong, green choy sum, Indian mustard and lettuce, and summer fruit vegetables, such as wax gourd and yard long bean (*Vigna unguiculata* ssp. *sesquipedalis*), are all produced in the RRD. In their main season (November–January), temperate vegetables, such as tomato and cabbage, originate entirely from the RRD and in their off-season up to 11% (An *et al*., 2003). Given the increasing urbanization in the RRD, the demand for vegetables is likely to grow.

Heavy rainfall and a high incidence of pests and diseases during the hot season may damage crops and reduce productivity. Protected cultivation in tunnels, plastic houses or net houses, could improve productivity and yield (Everaarts and de Putter, 2009; Ha, 2008). However, because of the insecure marketing conditions, farmers are reluctant to invest in protected cultivation.

Presently, mulching of crops is not common practice. Mulching, e.g., with rice straw or rice husks, material that is abundantly available, could help to reduce (1) leaching of nutrients, (2) soil surface erosion, and (3) labour demand for weed control, while at the same time preventing soil surface compaction and adding organic matter to the soil.

Vegetable production in the RRD has advantages. Farmers can earn a higher income with vegetable production than with rice and corn production (Thuy *et al*., 2002). As continuous vegetable production brings in greater profits than the vegetable–rice–rice rotation (Anh *et al*., 2006), farmers may be stimulated to grow vegetables year-round.

Permanent vegetable production systems indeed may be an option to improve vegetable production systems in the RRD. By taking out flooded rice, permanent vegetable production systems may improve soil physical properties by eliminating the repeated wetting, puddling and drying of the soil, possibly resulting in greater yield stability and higher crop yields. In addition, it would reduce labour costs because of eliminating the need for raised bed construction and subsequent flattening after vegetable production. Permanent raised beds would be fixed in place, offering opportunities for long-term soil improvements.

An opportunity therefore would be to design, test and implement innovative permanent vegetable production systems for the RRD. Taking into account the agro-ecological conditions of the area and the potential of crop rotations in terms of product marketability, profitability and plant-health aspects, vegetable production systems could be designed to achieve the following objectives: (1) to facilitate year-round vegetable supply for the RRD's increasing population, (2) to increase the income of small farmers by growing potentially profitable crops, and (3) to improve soil conditions for better growth and yield stability of vegetables.

By designing and implementing systems that couple greater yield stability with better timed marketing and higher profits, farmers could gradually improve their position. With an improved financial situation and greater professional confidence, farmers would have the opportunity to get better organized, enlarge their operations in terms of hiring additional land and labour, and explore opportunities to improve their marketing.

Product prices influence the profitability of vegetable production in the RRD more than intensification of production would do (Yanagisawa *et al.*, 2001). In order to improve their bargaining position with collectors, wholesalers or retailers, growers would need to be able to offer their product in larger quantities and on a regular, planned basis. Farmers' participation in commercial co-operatives or producer organizations would be an option to achieve this goal. Further co-operative integration, involving exchange of land to obtain larger or neighbouring plots would open opportunities to work on a larger scale in order to reduce costs of operation. Furthermore, it may offer opportunities to collectively implement harvest date planning and product quality control and aim for integration of production and marketing in a value chain. The introduction of cool storage and transport would widen the choice of crops to grow and would reduce post-harvest losses.

For 'safe vegetables', although on a modest scale, there already are co-operatives that organize their own harvest planning, quality control, integrated pest management training and retailing, with farmers sharing the profits of joint activities (Moustier *et al.*, 2006).

6.2. Constraints

The seasonal variation in temperature in the RRD poses limits on the year-round production of vegetables of tropical or temperate origin. Presently, most of the vegetable crops are produced in the period with low temperatures. Heavy rainfall in the hot and wet period from

May to September may cause low vegetable productivity because of mechanical damage and may result in loss of nutrients by leaching or surface erosion. Yield losses due to pests and diseases are higher in the wet season than in the dry season.

Flooded rice is the dominant crop in the period with high temperatures. This dominance exists because (1) national food security in rice was promoted by the government (Linh, 2001; Nguyen and Grote, 2004), and (2) farmers grow rice in the hot season to ensure that at least they will have enough food when other crops fail or when they lose other sources of income. This is especially true in the RRD, where the average area of agricultural land per capita is comparatively low. So rice contributes to the seasonality of supply and prices of vegetables because in the hot season most of the land is used for rice production.

Growing flooded rice has a negative effect on soil structure because of the repeated wetting, puddling and drying of the soil. In addition, the yearly build-up and break-down of raised beds requires high labour inputs.

High labour requirements and high costs of production may limit vegetable production. Production costs of vegetables are often twice as high as those of cereals (Thuy *et al*., 2002). Without some form of secure marketing, for most farmers vegetable cultivation is substantially more risky than rice, maize (*Zea mays* ssp. *mays*) and corn (*Zea mays* var. *rugosa*) production.

Urbanization and industrialization may negatively influence vegetable production in the RRD. Whereas peri-urban vegetable growers may have better connections to markets, consumers and knowledge (Ali, 2007) than their rural colleagues, they face higher risks in terms of pollution and the possibility of losing their land to urban and industrial development (van den Berg *et al*., 2003).

Product safety is becoming a major concern in society. Official protocols to produce vegetables and to control their quality are lacking, except for the comparatively small quantities of ‘safe vegetables’ produced by ‘safe vegetable’ co-operatives. Presently most of the vegetables produced in the RRD are produced conventionally with high inputs of pesticides (Hoi *et al.*, 2009). Excessive use of organic and inorganic fertilizers may result in soil and water pollution (Khai *et al*., 2007) and high nitrate contents in vegetables. Samples of conventionally produced Indian mustard and green choy sum all had nitrate contents above the threshold level (Ha, 2008). Consumers are concerned about pesticide residues, over-application of fertilizers and the use of growth regulators in vegetable production in the RRD (Ali, 2007; Figuié, 2003).

The insecure marketing conditions have been considered the most important constraint on vegetable production in the RRD (Anh *et al.*, 2004). Because there are no contracts between producers and traders, except for the small amount of safe vegetables traded through co-operatives and distribution companies, producers depend on fluctuating free market prices. In general, the small vegetable producers are planning their operations without market information or product price agreements. Producers try to grow temperate vegetables as early as possible to benefit from the generally high prices in the period September–November. As a consequence, vegetables are sold at high prices when demand still exceeds supply, but they are sold at low prices, or may not be sold at all, when supply starts to exceed demand.

The small scale farming operations and the comparatively high costs of the marketing of only small amounts of product, limit the farmer in organizing his own supply directly to a retailer. The small amounts of product offered, and the perishable nature of the product, reduce his bargaining power with collectors, who try to maximize their own profit.

7. Analysis and pathways for sustainable development

We reviewed the available knowledge and documentation on vegetable production and marketing in the Red River Delta (RRD) of Vietnam in a holistic approach, covering climate, soils and socio-economic, agronomical and marketing conditions. Effects were summarised and, where applicable, categorised in opportunities and constraints. The result is a comprehensive multi-disciplinary overview. The emerging picture is that of an intricate system in the sense that multiple physical and socio-economic factors simultaneously influence present vegetable production and marketing in the RRD. The challenge is to analyse and formulate pathways for sustainable development taking these multiple issues into account.

The physical constraints: less favourable soil conditions, high intensity rainfall and long distances to markets are considered mono-factorial issues, for which issues technical solutions, e.g. adapted fertilizer application strategies, protected cultivation and cold storage and transport, are available. The application of these solutions depends on the availability of the knowledge and materials for the farmers and on funds to invest in the necessary equipment (Everaarts and de Putter, 2009). Provision of government extension service and credit facilities would address these constraints. At a certain scale, this issue is being addressed by the Ministry of Agriculture and Rural Development of Vietnam (Ministry of Agriculture and Rural Development, 2013).

The major constraint to development, i.e. the small landholdings and extremely small plots, resulting in small production volumes and consequently lack of control in marketing, is unique for South East Asia and of an intricate socio-economic nature. Its origin is found in the redistribution of land in separate quality categories to each family after de-collectivisation in 1988 (Linh, 2001). An increase in rural population of 59% after collectivisation in the 1960s, contributed to very small plots allocated per family with de-collectivisation. This issue is not easy to address and no technical solution is available. Given the relatively new, and cherished, private land-ownership, enlarging land-ownership per family by buying, is not common. Also hiring additional land for vegetable production is not often found in the RRD.

To break the cycle of small landholdings, small plots, small product volumes and consequently lack of control of marketing, a solution would be to develop permanent vegetable production systems with farmers co-operating in producer organizations to enable production of vegetables across larger areas, resulting in greater volumes, with harvest date planning and quality control (Everaarts and de Putter, 2009), and integration of year-round production with marketing in a vegetable value chain (Shepherd, 2008). In recent years, on a small scale, a number of cooperatives that produce ‘safe vegetables’ have succeeded to build up regular supply to supermarkets, market stalls or shops, because they started to produce vegetables year-round and diversified their products (Moustier and Loc, 2010). The realisation of such an approach on a large scale goes beyond the organisational capacities of individual, small farmers. Co-operation between public (agricultural research and extension) and private (producer organisations, wholesalers, retailers) parties would be required. The emergence of supermarket retailing may offer opportunities to pioneer direct producer organisation-retailer marketing configurations (Moustier *et al*., 2010). The adoption of guaranteed Vietnam Good Agricultural Practices (VietGAP Trong trot, 2008), will address consumers’ food safety concerns. The increase in urban vegetable demand will be conducive to create new opportunities for the RRD vegetable producers.

As a first step in this approach, from the production point of view, we investigated the potential of permanent vegetable production in terms of profitability and the expected higher labour demand. From an analysis of three hundred sixty data sets of the production of 42 different vegetable crops in the RRD, it was concluded that permanent vegetable production has the potential to significantly increase household income, while increased labour demand can be absorbed within the family (Huong *et al*., 2013).

From the marketing point of view, a next step would be to investigate the opportunities in the RRD for setting up public private partnerships in order to structure vegetable production and marketing in vegetable value chains, benefitting all partners (Shepherd, 2008).

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Chapter 3

Vegetable production in the Red River Delta of Vietnam. II. Profitability, labour requirement and pesticide use

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Abstract

Vegetable production plays an important role in the rural economy of the Red River Delta (RRD), Vietnam. Data were collected on present vegetable production in the RRD, with the aim to characterize the vegetable production in terms of profitability, labour requirement and pesticide use and to evaluate vegetable production for its potential to increase rural household income.

Three hundred and sixty data sets consisting of qualitative (planting and harvesting dates) and quantitative (yield, product price, material and labour input) data were collected from 42 different vegetable crops presently produced commercially in the RRD. Variables were converted into value (thousand Vietnamese Dong, kVND) or days per hectare per growing day in the field (Gday), enabling analysis of data independent of crop growth duration.

The income derived from vegetable production ranged from 100 to 400 kVND/ha/Gday. Labour input varied from 3 to 9 days/ha/Gday. Profit increased with an increase in the labour input per growing day. Short growth duration crops required a higher labour input per growing day. The average cost of pesticide use was 25.7 kVND/ha/Gday. Planting in the summer season may result in a shorter growing period as compared to planting in the winter season. The range of variation in the data reflects the diversity in crops and cropping conditions in the RRD.

The results indicate that permanent vegetable production has the potential to substantially contribute to an increase in rural household income in the RRD, while increased labour demand can likely be fulfilled by the family household. Thereby, developing permanent vegetable production systems may be a pathway for development of the vegetable production sector in the RRD.

Keywords: Red River Delta, Vietnam, vegetable production, profitability, labour requirement, pesticide use, rural household income

1. Introduction

In Vietnam, agricultural potential and market access affect the economic development of rural areas. The poverty rate in remote areas is closely associated with low agricultural development potential and with lack of access to markets (Minot *et al*., 2006). As crop production contributes 77% of the profit from agricultural production (1990-2008) (General Statistic Office (GSO), 2009), crop production plays an important role in the economy of rural areas in Vietnam.

Vegetables are important crops in the Red River Delta (RRD) in the northern part of Vietnam (Huong *et al*., 2013). In 2008, the rural population of the RRD was 14 million, constituting 73% of the total population of this region and earning a living mainly from agricultural production (General Statistic Office (GSO), 2009). Vegetables are cash crops in the RRD (Ha, 2008; Linh, 2001). Income from vegetable production contributed 83% and 89% of total income from crop production in peri-urban areas of the capital Hanoi and in rural areas of the RRD, respectively (Ha, 2008).

However, current cropping systems for vegetable production in the RRD suffer from drawbacks. Vegetables usually are rotated with flooded rice, causing unfavourable soil structure and requiring extra labour for land preparation for vegetables grown after rice (Everaarts *et al*., 2006). In this rotation, vegetables are grown in the cold season and rice is grown in the hot season, causing seasonality of vegetable supply and of consumer prices (Huong *et al*., 2013). When vegetables are grown year round, land is planted with crops of the same family at high frequencies (Anh *et al*., 2006; Anh *et al*., 2005), resulting in a high pest and disease incidence of family specific pests and diseases. In addition, vegetable producers plant their crops without having access to market information (Huong *et al*., 2013). The discrepancy in timing between production and demand leads to vegetables being sold at high prices when demand exceeds supply, but vegetables are sold at low prices, or may not be sold at all, when supply exceeds demand. These negative characteristics of the present vegetable cropping systems in the RRD call for the design of permanent cropping systems that better address physical vegetable production requirements, reduce pest and disease incidence and take into account timing of production and marketing in a vegetable value chain (Huong *et al*., 2013).

Profit, labour requirement and pesticide use are major concerns of vegetable growers, the government and consumers. With the poverty threshold level defined as a minimum monthly available expenditure of 213 kVND per capita, the RRD had a household poverty rate of 9% in 2006 (General Statistic Office (GSO), 2009). With a population of 19 million in 2006 (General Statistic Office (GSO), 2009), this implies that the RRD had 1.7 million people living in poverty. To alleviate poverty and to contribute to economic growth in rural areas, the potential profit of vegetable production therefore is a major issue for the government and vegetable producers alike. Vegetable production requires more labour than rice production (Thuy *et al*., 2002). When intensifying vegetable cultivation or extending the production area, producers have to consider the availability of the labour required to grow the crops. The use of pesticides not only has an impact on production costs and labour required for application, but especially there is serious concern about the impact of pesticides on the environment and human health (Hoi *et al*., 2009a; Hoi *et al*., 2009b). The profitability of vegetable production, the labour requirement, and the use of pesticides, therefore are important variables to be taken into account when designing new vegetable cropping systems.

When taking account of the distance between production areas and markets, information on the perishability of a vegetable product is needed in the design of cropping systems for vegetables. Without cool stores and refrigerated transport, as is the case in the RRD, products with high perishability should be sold within a day after harvesting, limiting the distance over which produce can be transported from production area to commercial market.

The objectives of the present study are to characterise vegetable production in the RRD in terms of profitability, labour requirement and pesticide use and to evaluate the potential of permanent vegetable production to increase rural incomes. To those purposes data were collected on planting and harvesting dates, on the profitability of production, on labour requirement and on pesticide use of 42 vegetable crops presently grown in the RRD, while the perishability of the products was ranked.

2. Materials and methods

2.1. Sources of data

Qualitative (planting and harvesting dates) and quantitative (yield, price, material and labour input) data (Table 1) were collected from 42 different vegetable crops presently produced commercially in the RRD (An *et al*., 2003; Anh *et al*., 2005; Thuy *et al*., 2002). Data were

Table 1. Data collected per data set on a per ha basis. VND = Vietnamese Dong.

Variable	Unit	Variable	Unit
Planting date	day nr	Other materials	
Harvesting date	day nr	Bamboo stick	VND
Yield	kg, bundle, head, tuber, cob	Plastic mulch	VND
Product price	VND	Bamboo and plastic for shelter	VND
Seeds, seedlings	kg, number	Labour	
Price of seed, seedlings	VND	Land preparation	day
Fertilizers		Sowing, planting	day
Amount applied	kg	Crop protection	day
Price	VND	Irrigation	day
Pesticides		Weeding	day
Amount applied	kg, ml	Other crop management activities	day
Price	VND	Harvesting and packing	day
Pesticide costs	VND		

Table 2. Number of data sets obtained from the VEGSYS project (VEGSYS, 2005), by interviews and from the Field Crops Research Institute (FCRI), Hanoi.

Source	VEGSYS project	Interviews	FCRI	
			Survey	Report
Year	2002-2003	2006	2006	2005
District (Province)				
Gia Loc (Hai Duong)	-	17	-	2
Dong Anh (Hanoi)	197	65	-	-
Gia Lam (Hanoi)	-	13	-	-
Hoai Duc (Hanoi)	-	7	7	-
Thuong Tin (Hanoi)	-	9	43	-
Total = 360	197	111	50	2

obtained from three sources: (i) from the VEGSYS project data base (VEGSYS, 2005), (ii) by interviewing growers, and (iii) from the Field Crops Research Institute (FCRI), Hanoi (Table 2).

2.1.1. VEGSYS project data

Data were obtained from the data base of the project: ‘Sustainable technologies for pest, disease and soil fertility management in small holder vegetable production in China and Vietnam”, with the acronym ‘VEGSYS’, which ran from 2002 to 2005 (VEGSYS, 2005). Data obtained were collected in 2002 and 2003 in two villages, Tang My and Son Du, in the Dong Anh district, Hanoi province (Figure 1). Annex 1 describes the methodology to assess the duration of growth of the crop based on course data in the VEGSYS data set.

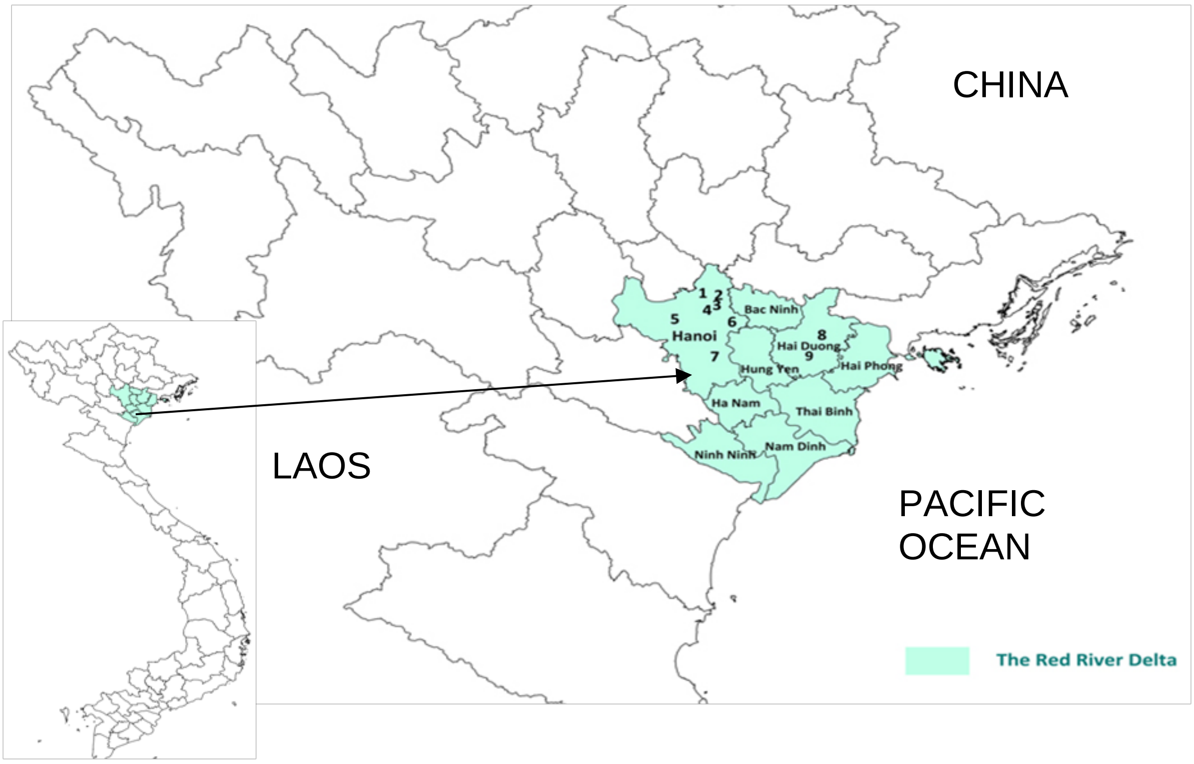

Figure 1. The location of the Red River Delta in Vietnam and the location of the villages where data were collected. 1: Tang My; 2: Son Du; 3: Tien Kha; 4: Vien Noi; 5: Phuong Vien; 6: Vien Ngoai; 7: Quang Trung; 8: Phu Tho Trai; 9: Buom.

2.1.2. Interview data

Four peri-urban locations (i-iv) about 30 km from Hanoi, supplying perishable vegetables to Hanoi daily, and one rural location (v), about 60 km from Hanoi, supplying low-perishable products to distant markets (Figure 1), were chosen to collect data by interviewing farmers:

i) Son Du village, Nguyen Khe commune, Vien Noi village, Van Noi commune, and Tien Kha village, Tien Duong commune, Dong Anh district, Hanoi province where vegetables are mainly grown in winter, after two rice crops in the hot season.

ii) Vien Ngoai village, Dang Xa commune, Gia Lam district, Hanoi province, where vegetable cultivation is similar to Dong Anh district.

iii) Quang Trung village, Ha Hoi commune, Thuong Tin district, Hanoi province, where perishable vegetables, such as coriander (*Coriandrum sativum*), fennel (*Foeniculum vulgare*), tossa jute (*Corchorus olitorius*), ceylon spinach (*Basella alba*) and lettuce (*Lactuca* *sativa*) are grown year-round.

iv) Phuong Vien village, Song Phuong commune, Hoai Duc district, Hanoi province, where crops with a growth duration of 3 months or more, e.g., cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), French bean (*Phaseolus vulgaris*), snow pea (*Pisum sativum*) and tomato (*Solanum lycopersicum*) are grown.

v) Phu Tho Trai village, Thach Khoi commune and Buom village, Toan Thang commune, Gia Loc district, Hai Duong province, which supplies low-perishable vegetables, such as cabbage, wax gourd (*Benincasa hispida*), onion (*Allium cepa* var. *cepa*) to Hanoi and other provinces.

Nineteen farm households in Son Du, one farm household in Vien Noi, one farm household in Tien Kha, two farm households in Vien Ngoai, 15 farm households in the villages Quang Trung, Phuong Vien and Phu Tho Trai respectively and two farm households in Buom were chosen by the village's leader for interviews. One farmer in each household was interviewed separately for data of crops grown by the household in 2005 or in the first half of 2006. Interviews took place from May to September 2006.

2.1.3. Data obtained from the Field Crops Research Institute (FCRI)

Data were obtained from researchers of the FCRI, who interviewed vegetable farmers in Phuong Vien village, Song Phuong commune, Hoai Duc district, Hanoi province and in Quang Trung village, Ha Hoi commune, Thuong Tin district, Hanoi province between May to September 2006. Season and growth duration of the crops were recorded, but not the exact planting date or harvesting dates. Two data sets were obtained from FCRI internal research reports.

2.2. Variables

The information collected was used to calculate the following variables: (i) the profitability of the cultivation, (ii) the labour requirement, (iii) pesticide use, and (iv) growth duration of the crop in the field. Because the growth duration of vegetables may differ considerably, in order to be able to compare the crops, the variables needed not only to be calculated per unit of area, but also per unit of time in the field. The values, therefore, were converted to units per hectare (ha) and per growing day (Gday). As the vegetable crops are grown on raised beds, the unit of area includes the furrows, which make up about 25% of the area.

i) Profit: Profit was calculated in thousand Vietnamese Dong (kVND) per hectare per growing day (kVND/ha/Gday). Profit was defined as gross return minus production costs. Production costs included costs of seeds or seedlings, paid land preparation (ploughing), fertilizers, pesticides, and other inputs, e.g., plastic mulch and bamboo sticks. With the generally small landholdings in the RRD, approximately 700 m^2/capita (General Statistic Office (GSO), 2007), farmers in the RRD grow vegetables using family labour. Production costs, therefore, excluded labour costs.

ii) Labour: Labour requirement was calculated in days (1 labour day = 8 hours) for a hectare per growing day (day/ha/Gday). Labour comprised labour requirement for land preparation, sowing or transplanting, fertilizer application, hand weeding, irrigation, pest and disease control, other crop management activities, e.g. hand pollinating and framing, and harvesting and packaging.

iii) Pesticide use: Most of farmers interviewed did not remember all of the exact names, active ingredients, weight or volumes of pesticides used, but all were able to provide data on the costs of pesticides used. Pesticide use therefore was expressed in thousand VND (kVND/ha/Gday), assuming a proportional relationship between costs and amount of pesticides used.

iv) Growth duration: The duration in days between the day of sowing or transplanting in the production field and the last harvest date.

2.3. Perishability

The perishability of crop products was ranked according to the scale in Table 3. Under the local conditions of usually high ambient temperatures and the absence of cooled storage or transport, most fresh vegetables have a shelf life of up to four days. Some vegetables, like a number of fruit vegetables, can be kept up to a maximum of three weeks (21 days). The duration of 180 days applies to conserved vegetable products, e.g. dried garlic.

Table 3. Ranking of product perishability.

Perishability class	Maximum duration (days) from harvest to selling
1	≥180
2	21
3	4
4	2
5	1

2.4. Defining planting periods

Most vegetable crops in the RRD are planted during certain periods of the year only (Huong *et al*., 2013). In order to be able to convert individual data sets to data generally applicable for a certain planting period, first specific crop planting periods had to be defined. Based on crop characteristics, climate, marketing opportunities and collected planting dates, crop planting periods were determined for each of the vegetable crops. Multiple data sets of one planting period were averaged.

Temperature, rainfall, sunshine and relative humidity (Figure 2), were taken into account when defining planting periods. For instance, vegetables that are grown in both the hot and the cool season, but that grow better in the cool – dry season as compared to the hot - wet season, e.g., Indian mustard, wrapped heart mustard, fennel, and coriander, were divided into two groups: planted in April – August and planted in September – March. Relative humidity was taken into account with crops like shallot (*Allium cepa* var. *ascalonicum*), garlic (*Allium sativum*), onion (*Allium cepa* var. *cepa*), cauliflower (*Brassica oleracea* var. *botrytis*) and broccoli (*Brassica oleracea* var. *italica*), as they perform better with low relative humidity conditions during the harvestable plant part formation and the harvesting period.

Where relevant, marketability of the product, as evidenced by high prices, was taken into account as well. Vegetables grown off-season, when the climatic factors are not optimum for growth and development, often fetch good prices. Crops like cabbage, broccoli, cauliflower and kohlrabi were therefore each defined in an early crop and a main crop.

2.5. Data analysis

To study the relationships between the variables profit, labour requirement, pesticide use and growth duration, we used linear and non-linear regression analysis (Payne *et al*., 2009). Both individual data and data for planting periods were analysed, to check whether relationships found in the individual data were maintained in the data for planting periods. This procedure served as a check on the correctness of defining the planting periods.

Because both the individual data and the data of the planting periods on profit, labour requirement and pesticide use were non-normally distributed (skewness and kurtosis significantly differed from zero), the response data were transformed to square root. Because the individual data on profit included negative values, they were subtracted by the lowest

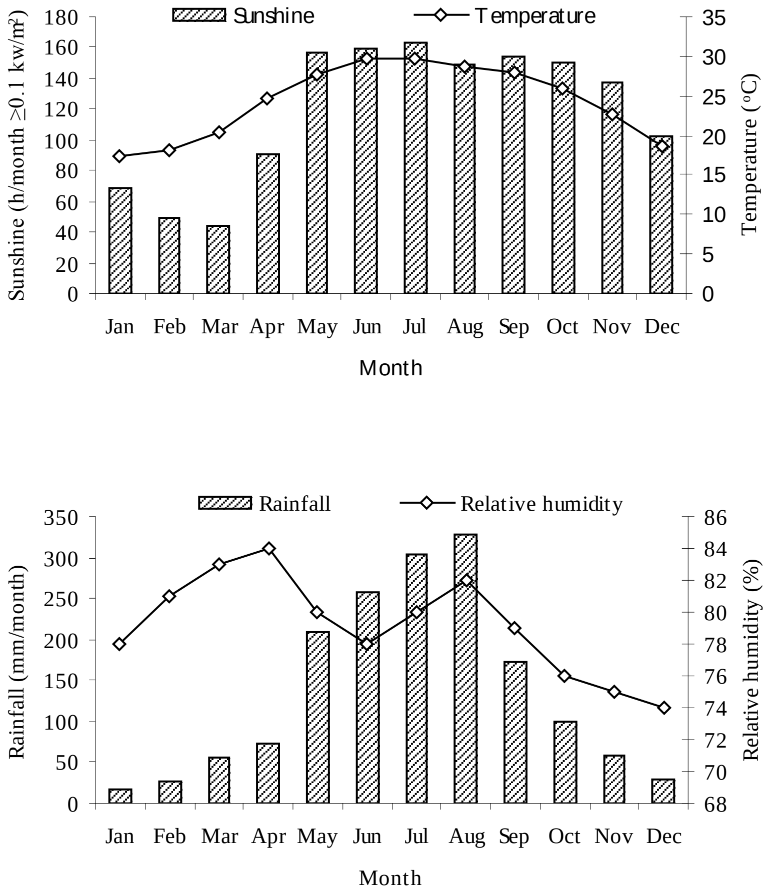

Figure 2. Mean monthly climate data of Hanoi (1996 - 2006). Source: Data of 1996 - 1998 are from Lang Ha Meteo Station, Lang Ha Street, Hanoi, Vietnam (unpublished data). Data of 1999 - 2006 are from Statistical Year Book 2000 - 2006 (General Statistic Office, 2001-2007).

(negative) value before transforming to square root.

To study whether there was an effect of seasonal variation in temperature and radiation (Figure 2) on crop duration in the field, we analysed the relation between crop duration and planting day for one crop (wax gourd), with a sufficient number of year-round planting data available. Data on growth duration were transformed to logarithms, to meet the requirement of normal distribution.

3. Results

A total of 360 data sets for growth duration, profit, labour requirement, and the costs of pesticides used, were collected for 42 vegetable crops, belonging to 13 botanical families

(Table 4). Sixty eight planting periods were defined. The *Cruciferae* and the *Cucurbitaceae* were the families of vegetables with the highest number of vegetable crops of which data were collected. According to the seasonal classification for vegetable crops grown in the RRD (Everaarts *et al*., 2008; Huong *et al*., 2013), *Cruciferae* crops are either winter crops, e.g., cabbage, broccoli, and cauliflower, or year-round crops, e.g., green choy sum (*Brassica rapa* var. *parachinensis*), Indian mustard (*Brassica juncea*), Chinese kale (*Brassica oleracea* var. *alboglabra*) and wrapped heart mustard (*Brassica juncea* var. *rugosa*). Except for broccoli and cauliflower grown in their main season, all members of this family had growth durations less than the average growth duration of 91 days. Except for Chinese kale and Indian mustard, crops in this family with a profit above the average (390 kVND/ha/Gday) were either grown in the early season, such as broccoli and cauliflower planted from September 1 to October 10, or in summer, such as green choy sum and wrapped heart mustard. *Cucurbitaceae* crops were all summer crops. All the crops in this family with a growth duration less than the average, had a profit higher than the average, except for cucumber planted in September and pear shaped melon. All *Solanaceae* crops had growth duration above the average. Except for sweet pepper, crops in this family had profits below the average. *Liliaceae* and *Umbelliferae* comprised winter crops, but coriander and fennel are grown in summer as off-season vegetables. Among the small families comprising one or two vegetable crops, the families *Basellaceae*, *Malvaceae*, *Convolvulaceae* and *Chenopodiaceae* comprised crops with the lowest pesticide use. Except for green choy sum planted in April – August and radish planted in August and September, all crops with a growth duration ≤ 46 days had a labour input above the average of 8.1 day/ha/Gday.

Based on the frequency distribution of the individual data (Figure 3), the majority of the vegetable crops had a profit in the range of 100 to 400 kVND/ha/Gday, required a labour input of 3 to 9 days/ha/Gday, had a cost of 0 to 40 kVND/ha/Gday for pesticide use and a growth duration of 30 to 120 days. The most frequent perishability class was class 3.

The most significant relationships found between variables as based on the individual data, were those between labour and profit and between growth duration and labour, although the percentage variance accounted for was low (Figure 4). Crops that required a higher amount of labour invested per growing day brought a higher profit. Crops that had a long growth duration required less labour per growing day. Other relationships between variables were significant, but percentages variance accounted for were very low. Pesticide use tended to go up with an increase in growth duration and profit seemed to be positively related to

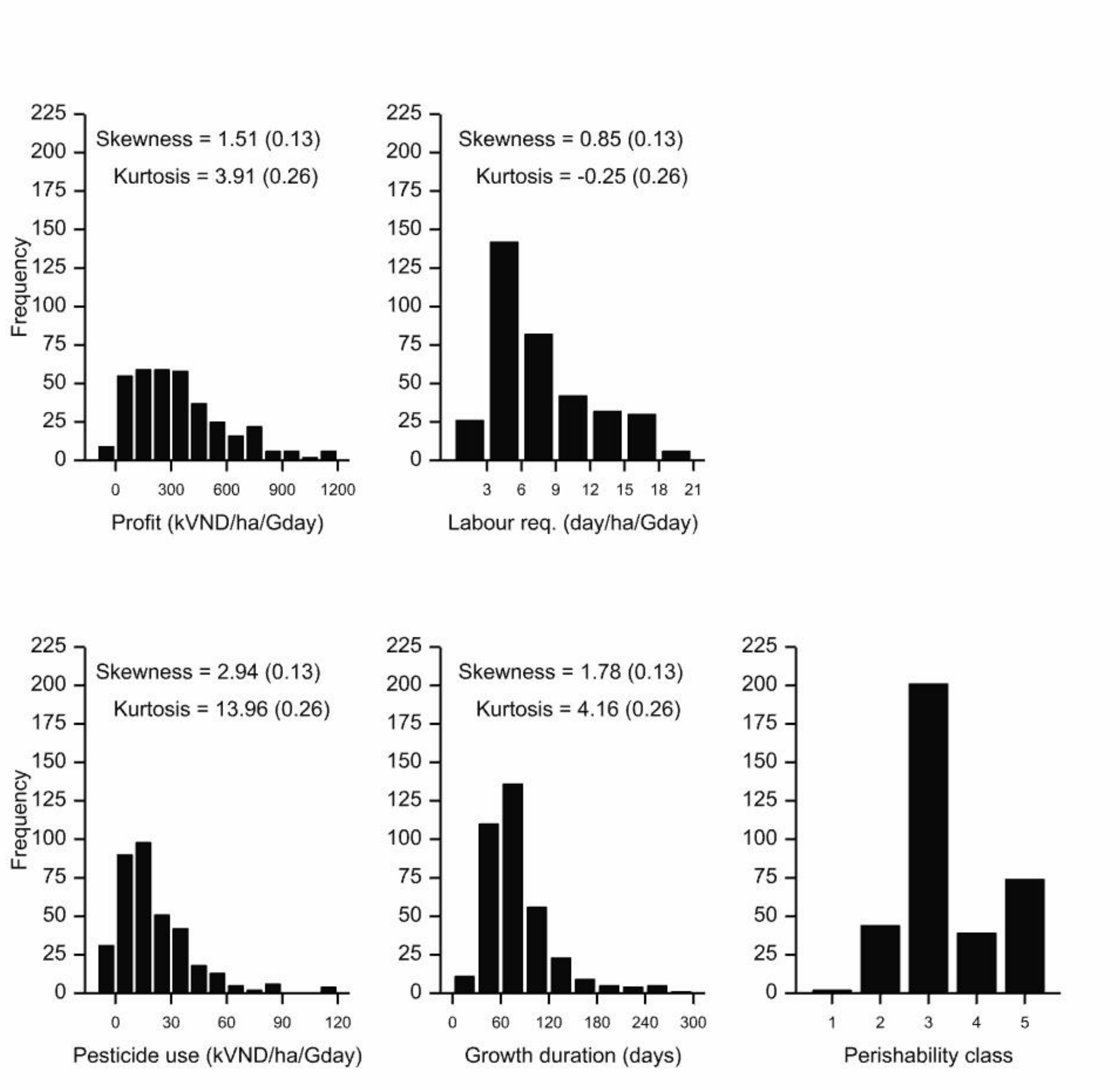

Figure 3. Frequency distribution for profit, labour requirement, pesticide use, crop growth duration and perishability class of the 360 individual data sets (values between brackets denote Standard Error).

pesticide use, but the significance of the regressions was brought about by a few crops only.

With the data averaged per planting period the normality of the variable frequency distributions increased, as skewness and kurtosis of the averaged data were reduced as compared to those of the individual data (Figure 5). With these data profits ranged mostly between 100 and 500 kVND/ha/Gday and labour requirements were still mostly between 3 and 9 days/ha/Gday.

The relationships found in the individual data set between labour and profit and between growth duration and labour were maintained in the data averaged per planting period. Profit was positively related to labour requirement, while labour requirement decreased with growth duration. (Figure 6). The validity of the other regressions between variables based on

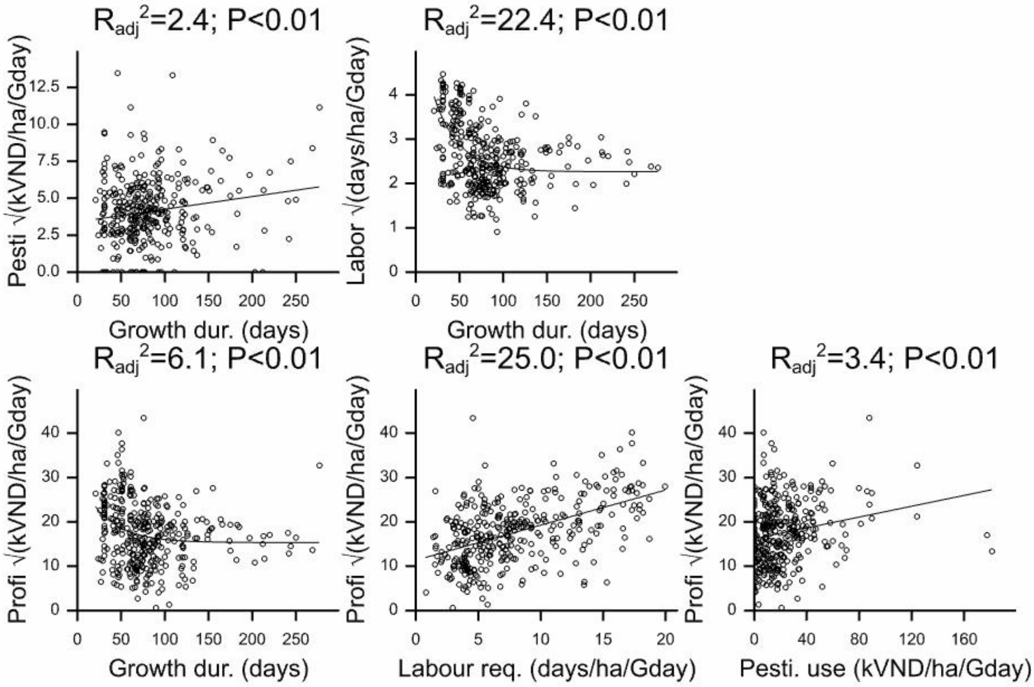

Figure 4. Regressions between profit, labour requirement, pesticide use and crop growth duration of the 360 individual data sets (R_{adj}^2 = percentage variance accounted for).

these data was comparable to those as based on the individual data set. The similarity of the relationships in the individual data set and in the data averaged per planting period, supports the correctness of the estimation of the planting periods.

With wax gourd, planting date significantly influenced the duration of growth in the field (Figure 7). The duration of growth of wax gourd planted in the hot season (day 121-273) was considerably shorter than that of a crop planted in the cool season (day 274-120).

4. Discussion

Although the sites from where the data were collected, were located mainly near Hanoi, and thereby were not distributed uniformly across the RRD, the data are still considered representative for vegetable production in the whole of the RRD. Soil and climatic conditions of the lowland area of the RRD are quite identical. We surmise that there are no restrictions in soil and climate conditions for growing all the vegetables in Table 4.

The results show that high profits are associated with a high labour input per growing day. Short growth duration crops tend to have a higher labour requirement per growing day. If labour is limited, farmers can balance between labour and profit and use the income per

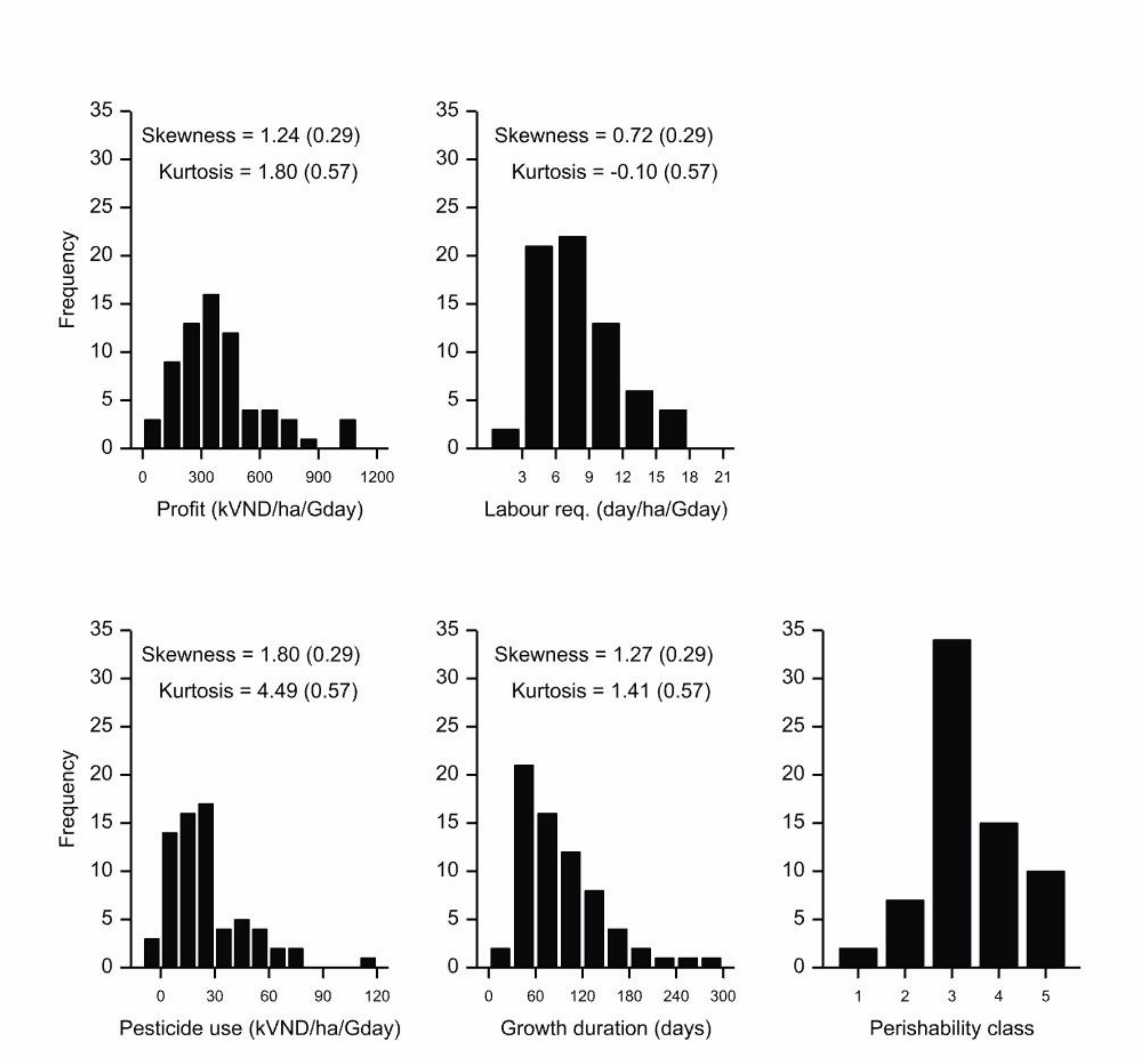

Figure 5. Frequency distribution for profit, labour requirement, pesticide use, crop growth duration and perishability class of the 68 planting periods (values between brackets denote Standard Error).

labour day to reach a decision.

Pesticide use was positively related to growth duration and profit, but the percentage variance accounted for was very low. One crop, sweet pepper, grown in August – September, had a large influence on the significance of the regressions.

Crops with a short growth duration required more labour per ha per growing day than crops with a long growth duration. This is because labour for land preparation, planting and harvesting comprises a high proportion of labour invested in vegetable production with short duration crops. For example, radish (*Raphanus sativus*) with a growth duration of 46 days required a labour input of 9.5 day/ha/Gday, whereas broccoli (*Brassica oleracea* var. *italica*) with a growth duration of 96 days required a labour input of 5.2 day/ha/Gday (Table 4). The

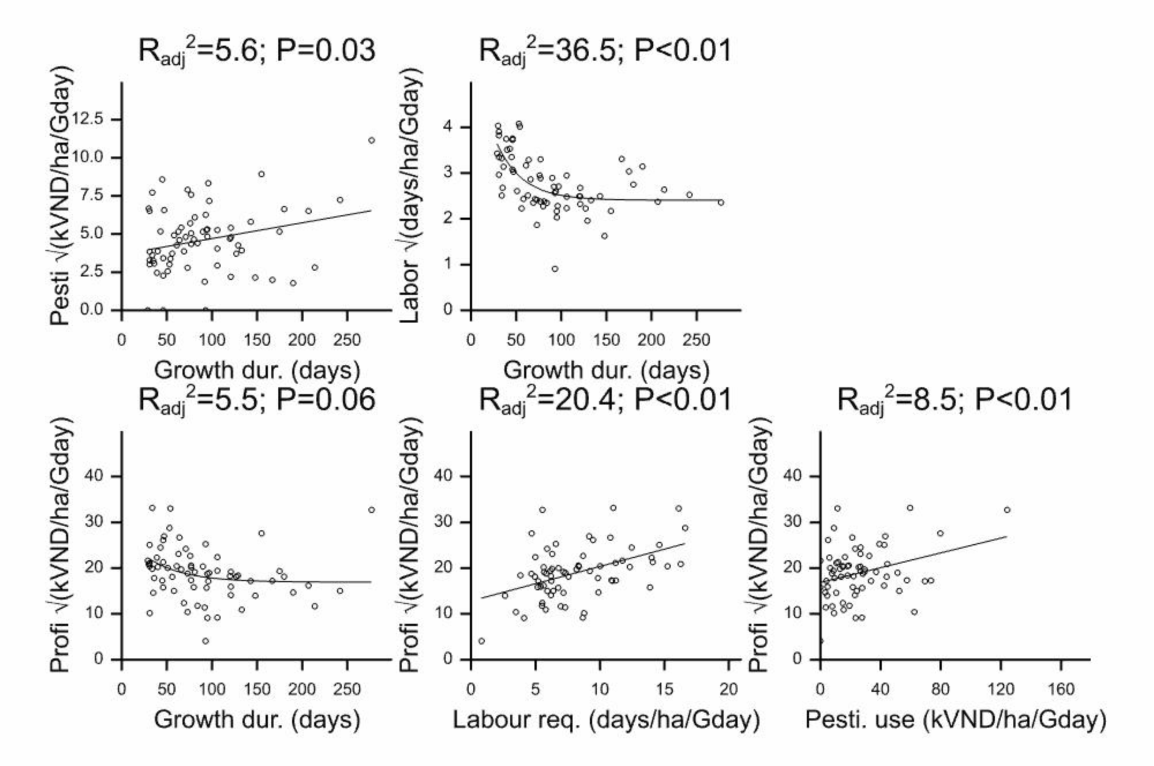

Figure 6. Regressions between profit, labour requirement, pesticide use and crop growth duration of the 68 planting periods (R_{adj}^2 = percentage variance accounted for).

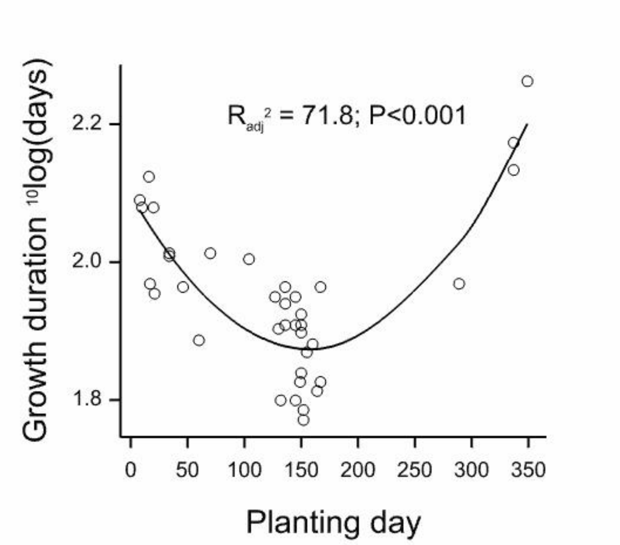

Figure 7. Regression between planting date and growth duration of wax gourd (n = 38; R_{adj}^2 = percentage variance accounted for).

percentage of labour input for land preparation, planting and harvesting was 53 for radish and 33 for broccoli.

The variables profit and labour requirement were calculated per hectare per day. The average landholding in the RRD is 700 m^2/capita and the average size of a household was

Table 4: Duration of growth, profit, labour requirement, cost of pesticide use and perishability class of vegetables cultivated in the Red River Delta, Vietnam, for each planting period (n = number of data sets per planting period; total n = 360; kVND = thousand Vietnamese Dong; Gday = growing day in the field; 2006: 1 U$ = 20 kVND).

Family Species	Crop (planted in month-month)	Planting period	Growth duration (days)			Profit (kVDN/ha/Gday)		Labour required (day/ha/Gday)		Pesticide use (kVND/ha/Gday)		Perishability (Table 3)
			n	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Amaranthaceae												
Amaranthus tricolor	Amaranth 1-12	1/1-31/12	2	31	0	416.7	51.4	15.2	0.4	14.8	5.8	4
Basellaceae												
Basella alba	Ceylon spinach 2-3	1/2-31/3	2	190	53	215.5	50.2	9.9	2.5	3.2	1.9	4
Chenopodiaceae												
Spinacia oleracea	Spinach 9-2	1/9-28/2	1	29		467.4		11.7		0.0		5
Compositae												
Chrysanthemum coronarium	Garland chrysanthemum 9-2	1/9-28/2	5	40	2	410.2	42.3	12.3	1.2	15.0	5.2	5
Lactuca sativa	Lettuce 5	1/5-31/5	1	31		445.9		11.2		10.8		5
Lactuca sativa	Lettuce 9-2	1/9-28/2	2	36	5	317.4	106.7	9.8	1.4	9.4	9.4	5
Convolvulaceae												
Ipomoea aquatica	Kang kong 2-8	1/2-31/8	2	148	56	195.4	78.4	2.6	1.2	4.6	4.6	4
Cruciferae												
Brassica juncea	Indian mustard 4-8	1/4-31/8	9	31	0	628.9	45.8	14.6	1.8	42.5	10.5	5
Brassica juncea	Indian mustard 9-3	1/9-31/3	6	30	1	436.7	83.2	16.3	1.7	44.6	11.3	5
Brassica juncea var. *rugosa*	Wrapped heart mustard 4-8	1/4-31/8	4	51	5	400.7	140.1	6.8	1.6	6.6	2.0	3
Brassica juncea var. *rugosa*	Wrapped heart mustard 9-1	1/9-31/1	11	58	5	225.5	92.7	5.9	0.9	24.2	4.4	3
Brassica oleracea var. *italica*	Broccoli 9-10	1/9-10/10	2	71	5	586.7	0.1	5.9	0.4	23.1	10.5	3
Brassica oleracea var. *italica*	Broccoli 10-12	11/10-5/12	1	96		294.2		5.2		69.5		3
Brassica oleracea var. *capitata*	Cabbage 8-9	20/8-30/9	3	63	7	533.7	106.0	6.3	1.0	26.7	11.8	3
Brassica oleracea var. *capitata*	Cabbage 10-1	1/10-5/1	5	84	7	138.5	37.8	5.5	1.4	19.3	6.1	3
Brassica oleracea var. *botrytis*	Cauliflower 9-10	1/9-10/10	2	76	1	514.4	64.3	8.7	3.2	32.5	1.1	3
Brassica oleracea var. *botrytis*	Cauliflower 10-12	11/10-5/12	11	95	3	52.1	41.3	4.1	0.3	19.9	4.7	3
Brassica oleracea var. *gongylodes*	Kohlrabi 7-9	10/7-15/9	7	56	3	327.8	92.1	5.0	0.6	13.8	5.0	3
Brassica oleracea var. *gongylodes*	Kohlrabi 9-2	16/9-25/2	70	69	1	153.2	14.4	5.5	0.4	15.0	1.2	3
Brassica oleracea var. *alboglabra*	Chinese kale 4-10	1/4 -30/10	1	47		726.5		9.2		43.2		4
Brassica oleracea var. *alboglabra*	Chinese kale 11-3	1/11-30/3	1	34		1099.7		11.0		59.7		4

Family Species	Crop (planted in month-month)	Planting period	Growth duration (days)			Profit (kVDN/ha/Gday)		Labour required (day/ha/Gday)		Pesticide use (kVND/ha/Gday)		Perishability (Table 3)
			n	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Brassica rapa ssp. *pekinensis*	Chinese cabbage 9	1/9-30/9	1	73		108.3		3.5		62.5		4
Brassica rapa var. *parachinensis*	Green choy sum 4-8	1/4-31/8	13	34	2	394.1	68.9	6.3	1.1	13.1	3.8	5
Brassica rapa var. *parachinensis*	Green choy sum 9-3	1/9-31/3	4	31	4	103.3	27.7	8.8	1.9	9.1	2.5	5
Brassica rapa ssp. *chinensis*	Green pakchoi 8-2	20/8-19/2	8	43	4	600.1	84.2	12.5	1.2	26.7	4.7	4
Raphanus sativus	Radish 3	1/3-31/3	2	46	4	682.7	55.0	9.5	1.1	5.2	1.5	3
Raphanus sativus	Radish 8-9	20/8-20/9	3	35	4	213.5	47.2	7.2	1.6	10.6	10.6	3
Cucurbitaceae												
Benincasa hispida	Wax gourd 2-3	1/2-31/3	5	95	5	352.0	83.2	4.7	0.4	28.2	8.4	2
Benincasa hispida	Wax gourd 4-6	1/4-30/6	23	77	2	407.8	40.2	5.6	0.5	25.5	5.2	2
Benincasa hispida	Wax gourd 10	1/10-30/10	1	93		16.5		0.8		0.0		2
Benincasa hispida	Wax gourd 12-1	20/12-31/1	9	127	9	329.0	67.9	5.0	0.7	13.8	0.8	2
Citrullus lanatus	Water melon 2-3	10/2-31/3	2	77	4	423.0	46.0	8.3	0.4	18.9	1.0	2
Citrullus lanatus	Water melon 8-9	20/8-20/9	2	64	10	711.9	222.0	10.8	2.1	21.2	1.4	2
Cucumis melo	Chinese melon 2-4	7/2-10/4	6	97	6	360.0	59.3	7.3	0.8	51.4	25.9	4
Cucumis melo cv. group Inodorus	Pear shaped melon 2-3	20/2-30/3	1	81		366.6		5.7		37.1		3
Cucumis sativus	Cucumber 1-4	25/1-5/4	9	90	5	414.1	58.3	8.4	1.1	26.6	4.7	4
Cucumis sativus	Cucumber 6	1/6-30/6	1	92		130.0		7.3		3.5		4
Cucumis sativus	Cucumber 9	1/9-20/9	2	77	1	301.5	81.6	10.9	2.6	57.6	23.7	4
Langenaria siceraria	Bottle gourd 3-6	1/3-5/6	5	120	9	332.7	14.3	6.2	0.7	22.1	5.4	3
Momordica charantia	Bitter gourd 2-3	15/2-31/3	3	207	23	261.9	7.7	5.6	0.4	42.4	10.4	3
Momordica charantia	Bitter gourd 4-6	1/4-30/6	2	143	8	295.2	29.6	6.2	1.7	33.6	3.4	3
Leguminosae												
Phaseolus vulgaris	French bean 9-12	1/9-31/12	12	121	7	367.3	36.7	7.2	0.4	29.3	5.2	3
Pisum sativum	Snow pea 11-12	20/11-5/12	1	93		638.5	0.0	6.6		39.2	0.0	3
Vigna unguiculata spp. *sesquipedalis*	Yard long bean 2-3	20/2-31/3	4	106	12	84.2	27.4	8.7	2.3	27.7	14.7	3
Vigna unguiculata spp. *sesquipedalis*	Yard long bean 4-8	1/4-31/8	8	94	5	246.5	38.6	6.8	0.6	27.8	8.5	3
Liliaceae												
Allium ampeloprasum var. *porrum*	Leek 3-6	1/3-30/6	3	66	5	389.4	170.6	8.2	1.9	29.4	28.4	3
Allium ampeloprasum var. *porrum*	Leek 8-2	20/8-28/2	2	61	0	417.8	6.3	10.0	0.2	18.1	13.6	3

Family Species	Crop (planted in month-month)	Planting period	Growth duration (days) n	 Mean	 SE	Profit (kVDN/ha/Gday) Mean	 SE	Labour required (day/ha/Gday) Mean	 SE	Pesticide use (kVND/ha/Gday) Mean	 SE	Perishability (Table 3)
Allium cepa var. *ascalonicum*	Shallot (clove) 9	10/9-30/9	1	106		377.5		6.2		8.7		1
Allium cepa var. *ascalonicum*	Shallot (clove + leaves) 9-1	1/9-21/1	3	73	3	354.2	5.6	5.8	1.4	7.8	4.0	3
Allium fistulosum	Welsh onion 1-12	1/1-31/12	2	39	8	496.5	84.9	14.0	1.0	6.0	6.0	4
Allium sativum	Garlic 9	10/9-25/9	1	121		254.6		5.4		4.8		1
Malvaceae												
Corchorus olitorius	Tossa jute 2-3	1/2-31/3	2	167	46	296.6	71.6	10.9	1.7	4.0	4.0	4
Poaceae												
Zea mays var. *rugosa*	Sweet corn 4-9	1/4-30/9	5	80	4	250.4	59.1	5.2	0.5	21.6	6.3	3
Solanaceae												
Capsicum annuum	Chili 8 -9	20/8-30/9	1	121		198.8		6.2		23.0		3
Capsicum annuum	Sweet pepper 1	15/1-31/1	1	155		761.6		4.7		79.8		3
Capsicum annuum	Sweet pepper 8-9	20/8-30/9	1	277		1071.0		5.5		124.2		3
Solanum lycopersicum	Tomato 8-2	20/8-15/2	13	129	12	338.4	137.8	3.8	0.4	18.2	6.5	3
Solanum melongena	Eggplant 2-3	1/2-31/3	3	242	16	225.6	28.4	6.4	0.5	52.4	11.6	3
Solanum melongena	Eggplant 5-6	20/5-30/6	3	133	22	119.0	46.3	5.8	1.3	15.4	7.0	3
Solanum melongena	Eggplant 10	1/10-30/10	1	214		135.8		7.0		7.9		3
Solanum undatum	Pickle 2-3	1/2-31/3	4	180	15	328.7	22.1	7.6	0.3	44.0	8.5	3
Solanum undatum	Pickle 6	1/6-30/6	1	175		374.6		9.2		26.7		3
Umbelliferae												
Apium graveolens	Celery 9-4	1/9-30/4	3	45	1	298.5	175.9	11.2	0.5	73.6	53.9	3
Coriandrum sativum	Coriander 4-8	1/4-31/8	9	54	2	1092.3	95.6	16.1	0.3	11.4	1.8	5
Coriandrum sativum	Coriander 9-3	1/9-31/3	10	53	2	828.0	59.1	16.6	0.3	9.0	1.6	5
Foeniculum vulgare	Fennel 4-8	1/4-31/8	7	46	3	454.1	46.3	14.1	0.6	11.7	3.5	4
Foeniculum vulgare	Fennel 9-3	1/9-31/3	7	46	3	249.1	47.4	13.9	0.5	0.0	0.0	4
		Average		91		390.8		8.1		25.7		

3.81 capita/household in 2006 (General Statistic Office (GSO), 2009), so that each household owned 2700 m^2 of land on average. If a family in the rural areas of the RRD grows vegetables year-round on 1000 m^2, with an average profit of 390 kVND/ha/Gday (Table 4), vegetable production in the RRD on 1000 m^2 can bring an income of 1200 kVND/month/household. With an average labour requirement of 8.1 day/ha/Gday, this means a labour input of 0.8 day/1000 m^2/Gday. A family with two adults can easily meet this requirement and the income from vegetable production would be considerably above the average income of 670 kVND/capita/month in the RRD in 2006. It should be noted, however, that 670 kVND is an average. In general the income per capita in urban areas is double that of rural areas.

Variables characterising vegetable production: profit, labour requirement and the costs of pesticides used, were calculated in kVND per hectare per growing day. In this way it is possible to compare the profit, labour requirement and the costs of pesticides used for different crops, independent of the growth duration of the crops. With the small landholding of 700 m^2/capita (General Statistic Office (GSO), 2007), farmers grow vegetable crops intensively in the RRD. Therefore, with these variables, the duration of vegetable cropping systems can be counted in days, enabling the design of year-round cropping systems based on planting date and crop growth duration. The calculation differed from calculations of previous research in which the variables were calculated per ha per year or per ha per crop (Dogliotti *et al*., 2003; Jansen *et al*., 1996), limiting the comparison between crops at the same unit of time.

The range of variation in the variables, and consequently the low percentage of the data that fitted the significant regressions, reflect the enormous diversity in vegetable crops and cropping conditions in the RRD (Huong *et al*., 2013), but is also indicative of the opportunities to design new, innovative cropping systems.

The growth duration of crops can be significantly related to planting date, as shown with wax gourd. Apparently higher temperatures result in faster development, coupled with a higher radiation, this results in a shorter growing period (Norman *et al*., 1984).

After a multidisciplinary analysis of factors currently influencing vegetable production in the RRD, it was concluded that especially the small landholdings and the extremely small plots form a barrier to development of vegetable production, because they result in small amounts of product, limiting effective marketing (Huong *et al*., 2013). A potential pathway to sustainable development would be the development of permanent vegetable production systems, with producers operating in producer's organisations, with production and marketing integrated in a vegetable value chain. The present study shows that based on current production and profit levels, permanent vegetable production has the potential to be profitable, while increased labour demand could likely be fulfilled by the family household. Using the present data set with a newly developed model for designing permanent vegetable production systems, it was shown that, using various production scenarios, such as high profitability, low labour demand and high crop biodiversity, permanent vegetable production appeared to be a realistic option for the development of the vegetable production sector in the RRD (Huong *et al*., 201x).

5. Conclusions

The majority of vegetables grown in the RRD provided a profit between 100 and 400 kVND/ha/Gday, required a labour input from 3 to 9 day/ha/Gday and had a growth duration between 30 and 120 days. The costs of pesticide use ranged mostly between 0 and 40 kVND/ha/Gday. Most products were classified as having a transport and shelf life of up to four days. The presence of data sets with negative profit, illustrates the risks in vegetable production.

In general, crops with a high profit and short growth duration required more labour per growing day. The data show that permanent vegetable production has the potential to contribute to poverty alleviation in rural areas by substantially increasing household income.

The growth duration of crops grown year-round may be influenced by the planting date. Planting in the hot summer season may result in a shorter growing period.

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Annex 1. Details of methodology to assess the duration of growth of the crop based on course data in the VEGSYS data set.

To be able to calculate the duration of growth of the crops in case the planting date and the last harvest date were recorded as months only (e.g. as 'January'), in decreasing order the following rules were applied:

Planting date:

i) Based on the date of first application of urea (N) or single super phosphate (P). Median and Standard Error (SE) of the duration from planting date to the date of the first application of N or P were calculated from the sheets with complete records of those dates. The planting date was defined as based on the number of days before the first N or P application with the lowest SE (Table A1).

ii) In case, in the month of planting, the first application of N or P was recorded as month and the first time of other activities was recorded as date, the planting date was defined as the date at the middle of the period from the first of the month to the day before the first recorded activity, but at least five days before the first application of N.

iii) In case the first time of all activities was recorded as month or as date after the month of planting, the planting date was defined as the date of the middle of the month of planting.

Harvest date:

i) When with multiple harvests the last harvest was recorded as month, the last harvesting date was defined as the date of the middle of the period from the last recorded harvest date to the end of the month.

ii) In case harvests were recorded as months only, the last harvest date was defined as the middle of the month, but at least 5 days after the last pesticide application.

Table A1. Planting dates (**bold** numbers) defined as the number of days to the first nitrogen (N) or phosphate (P) application (lowest SE chosen) for five crops of VEGSYS project data (VEGSYS, 2005).

Crop, planting period (m-m)	Days to the first N application			Days to the first P application		
	n	Median	SE	n	Median	SE
Cauliflower 10-12	8	**11**	2.4	4	0	4.7
French bean 9-12	2	**13**	2.5			
Kohlrabi 9-2	50	**9**	0.6	37	7	0.9
Wax gourd 4-6	9	21	3.6	8	**8**	2.6
Wrapped heart mustard 4-8	3	**18**	3.8			

Chapter 4

PermVeg: a model to design crop sequences for permanent vegetable production systems in the Red River Delta, Vietnam

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Abstract

The constraints in current vegetable production systems in the Red River Delta, Vietnam, in which vegetables are rotated with flooded rice, called for the design of alternative systems of permanent vegetable production. The practical model, PermVeg, was developed to generate vegetable crop sequences, as based on a set of rules and restrictions. Next to the traditional production system, alternative, permanent vegetable production systems were designed based on the following five scenarios: (i) increased profit, (ii) reduced labour requirement, (iii) decreased costs of pesticide use, (iv) improved crop biodiversity, and (v) selected crops with low perishable products. The latter system was especially intended for rural areas with long transport lines to city markets. The new systems were evaluated for profitability, labour requirement and costs of pesticide use.

PermVeg showed that theoretically all selected crop sequences in the different alternative systems increased farmers' income compared to the traditional system. The system with the highest profitability increased profit per hectare per day by a factor of three as compared to the traditional system. Labour requirement in days per hectare per day in a crop sequence also increased in all systems. Except for the system with low costs of pesticide use, permanent vegetable production systems had higher pesticide costs than the traditional, vegetable – flooded rice crop sequence. Given the model outcomes, permanent vegetable production systems can be an option to improve farmers' income, to provide labour opportunities, and, in the case of the high crop biodiversity system, to contribute to the development of sustainable production systems.

The PermVeg model can act as a practical tool to rapidly explore crop sequence options, to help farmers' decision making.

Keywords: Red River Delta, Vietnam, modelling, permanent vegetable production, vegetable production systems

1. Introduction

During the last decades the objective of agricultural activities has changed from increasing productivity per unit area towards the development of more sustainable production systems (Struik and Bonciarelli, 1997; van Ittersum and Rabbinge, 1997). Sustainable agriculture can be defined as agriculture in which a set of objectives in contrasting domains such as production, economics, environment, landscape and equity are satisfied (Dogliotti *et al*., 2003). Characteristics of sustainable agriculture include maximizing the use of natural processes, recycling nutrients, minimizing inputs, maximizing resource use efficiency, and durable use of critical resources, such as land, water, energy and phosphate (Struik and Bonciarelli, 1997).

Field vegetable production in tropical Asia is a key activity to ensure food security, quality of diet, trade development and income generation (Johnson *et al*., 2009). This also holds for the Red River Delta (RRD) in Vietnam. The RRD comprises 21% of the vegetable production area of Vietnam and produced 26% of the country's total vegetable products during 2007-2009 (General Statistics Office (GSO), unpublished data). However, vegetables are mainly rotated with flooded rice. This crop system has disadvantages. E.g., the soil structure is negatively affected by the wet puddling during rice cultivation, creating less favourable conditions for vegetable production (Kleinhenz *et al*., 1997). In addition, labour demand for vegetable production in this system is high due to the compacted soil after rice production, the construction of raised beds for vegetable production and the subsequent flattening of raised beds for flooded rice cultivation. Because vegetables are mainly grown in the cool season and rice is grown in the hot season, the system also induces seasonal supply and price fluctuations of vegetables (An *et al*., 2003). The system yields less income for farmers than permanent vegetable production systems (Anh *et al*., 2006). On a limited scale there are permanent vegetable production systems in the RRD too. However, in these systems, vegetables in the same botanical family e.g. *Brassicaceae*, may be grown continuously, causing accumulation of family-specific soil-borne pests and diseases (Anh *et al*., 2005a; 2006).

Negative effects of the present vegetable production systems in the RRD, as mentioned above, called for the design of vegetable production systems, which ameliorate soil conditions, allow year-round production, aim to reduce the need for pesticide use and improve farmers' income. In this design process, we first conducted a multi-disciplinary analysis of current vegetable production in the RRD, covering climate, soils, socio-economic, agronomic and marketing conditions (Huong *et al*., 2013a). The development of permanent vegetable production systems came out as a potential pathway to sustainable development, with producers co-operating in producer organizations and aiming for the integration of production with marketing in a vegetable value chain.

As the next step in this approach we investigated the potential of permanent vegetable production in terms of profitability and labour demand. From an analysis of 360 data sets of the current production of 42 different vegetable crops in the RRD, it was concluded that permanent vegetable production has the potential to significantly increase household income, while increased labour demand can be absorbed within the family (Huong *et al*., 2013b).

In the trend towards more sustainable production systems, models have been used to design new field vegetable production systems, which reduce soil erosion, maintain or improve physical and biological soil fertility, and increase farm income, e.g., the model ROTAT (Dogliotti *et al*., 2003; 2004). ROTAT, however, designs crop sequences in closed annual crop rotations. This model therefore is less suitable to design vegetable crop sequences for the RRD, where many vegetable crops are cultivated several times per year, in many different sequence configurations, without a certain closed rotation pattern (Huong *et al*., 2013a, b).

It was our aim to make a practical model for the design of crop sequences independent of the starting date of the crop sequence during the year, in which a crop can be grown several times a year, taking into account all potential planting dates of a crop as defined by crop planting periods, with planning of the sequence in days and on day number rather than months and month number and with the results of crop sequences evaluated in units or values averaged per day in the sequence, to enable comparison of sequences independent of the length of the sequence.

The model should be easy to operate and present results that can be used directly to support the learning and decision making process of advisers and farmers.

In the present paper requirements of permanent vegetable production systems are formulated and a program to generate the vegetable crop sequences fulfilling these requirements is described.

Objective

The aim of the present work is to develop a model with which crop sequences can be designed for permanent vegetable production systems. The systems should: (i) improve soil conditions by reducing soil compaction because of puddling with flooded rice (So and Ringrose-Voase, 2000; Everaarts *et al*., 2006); (ii) provide opportunities to increase farmers' income; (iii) reduce labour requirements; (iv) allow low pesticide use; (v) limit (soil-borne) pest and disease incidence by increasing biodiversity, and (vi) provide an opportunity for crop production at some distance from markets by producing low perishable products.

2. Materials and methods

2.1. Alternative systems

We defined five scenarios comprising rules for the development of alternative permanent vegetable production systems as likely improvements to the present traditional system of vegetable production in rotation with flooded rice (Huong *et al*., 2013a). A system, therefore, comprises the sequences designed based on the rules of a scenario.

(i). The high profitability scenario for the '**Profitability'** system. This scenario aims to maximize income from vegetable production by selecting crops with a high profitability. Poverty is still endemic in many rural areas of Vietnam (Minot *et al*., 2006). Although the RRD is the economic centre of northern Vietnam (Huong *et al*., 2013a), the official poverty rate in the RRD is still around 9% (General Statistics Office (GSO), 2007). Data collected on the profitability of vegetable production showed that vegetable production can raise family income (Huong *et al*., 2013b).

(ii). The low labour requirement scenario for the '**Labour'** system. Crops grown in this scenario have a low labour requirement. There may be many reasons for wanting a vegetable production system with low labour requirements. E.g., the farm work has to be carried out by the wife only, as the husband commutes daily to a city job and the children go to school. Some villages in the RRD specialize in handicraft production, or in the production of other materials for income, limiting labour availability. However, the income from vegetable production is still needed. In other cases the family already focuses exclusively on agricultural production for income, but they still would like to expand with crops requiring low labour input.

(iii). The low costs of pesticide use scenario for the '**Pesticide'** system. Excessive pesticide use in vegetable production in the RRD is a major concern, both to the government

(Hoi *et al*., 2009a) and to the consumer (Hoi *et al*., 2009b). The aim of this scenario is to identify cropping sequences of crops requiring low levels of pesticide use. The data used on crop specific pesticide input were related to the costs of the pesticides used, as farmers sometimes had no good recollection of active ingredients or trade-marks used, but always were able to provide data on pesticide expenses (Huong *et al*., 2013b).

(iv). The high level of biodiversity scenario for the '**Biodiversity'** system. Soil-borne diseases can be controlled effectively through crop rotation. E.g., Fusarium wilt caused by *Fusarium oxysporum* is a common disease in the RRD (Oanh *et al*., 2004). In general, *Fusarium oxysporum* is host specific, but one forma specialis may infect several crops within a family (Gordon and Martyn, 1997). In this scenario, crops of one botanical family are only cultivated once in two years (i.e. once in a sequence). Different crop species take up nutrients from the soil differently (Mengel, 1997; White and Broadley, 2005). Therefore, a sequence with as many different families as possible will be a healthy system in both aspects: soil-borne disease control and efficiency of soil nutrient extraction.

(v). The low perishable product scenario for the '**Perishability'** system. Because of the lack of cool storage and transport facilities in locations far away from markets, farmers have to grow vegetables with products that have a low perishability: i.e., products that can be kept at ambient temperatures and transported across considerable distance before reaching the market. Crops with low perishable products are selected for this scenario.

2.2. PermVeg, a tool for generating crop sequences

With the objective to design permanent vegetable production systems for the RRD, we developed the PermVeg (*Perm*anent *Veg*etable production systems) model using Genstat 12 (Payne *et al*., 2009). The model combines crops from a defined list in order to generate all possible crop sequences within a given period of time, based on a number of selection criteria, or restrictions, controlled by users. The selection criteria and the restrictions eliminate in early stages those crop sequences that are undesirable. The selection criteria are based on agronomic and environmental objectives. Selection criteria can be at least one of the three important variables in vegetable production in the RRD: profitability, labour requirement and costs of pesticide use (Huong *et al*., 2013b). The restrictions are based on expert knowledge about planting time during the year, host species of pests and diseases common in the region, etc. The following restrictions need to be submitted to PermVeg:

2.2.1.Time period

Starting day: the day number at which the first crop in a sequence is planted.

Stopping day: the day number at which the last crop in a sequence preferably has to be harvested.

Stopping period: the number of days before and after the stopping day during which the harvest of the last crop in the sequence is acceptable.

Interval: the number of days between the harvest of a crop and the planting of the next crop.

2.2.2. Restriction on number of crop sequences and number of crops in a sequence

Maxnrsequences: in the algorithms all possible sequences are formed, which may go beyond computer capacity. To handle this, the maximum number of sequences can be set. When the number of sequences becomes higher than maxnrsequences, they are sorted according to the criteria in use and the least valuable sequences are removed from the calculations. The number of sequences saved for the next iteration is equal to maxnrsequences.

Maxprint: maximum number of sequences exported to EXCEL after each iteration. After each iteration the sequences are exported to an EXCEL file. Because it is of no use to export all the sequences a maximum can be set with Maxprint.

Maxnrcropsinseq: maximum numbers of crops in a sequence. Maxnrcropsinseq must be chosen high enough so that the length of all generated sequences will reach the stopping period.

2.3. Application: generating vegetable crop sequences for the RRD

We designed crop sequences for a period of two years. For the design process we used the planting period, crop growth duration, profitability, labour requirement and costs of pesticide use of 42 vegetable crops presently grown in the RRD (Huong *et al*., 2013b). The variables profitability and costs of pesticides were expressed in thousand Vietnamese Dong (kVND) per hectare (ha) per day (day) in the crop sequence. Labour requirement was expressed in day (8 hours) per hectare (ha) per day (day) in the crop sequence.

2.3.1. General restrictions

To prevent accumulation of host specific soil-borne diseases, there must be at least two crops of different botanical families between crops of the same family, except for amaranth (*Amaranthus tricolor)*. As far as we know, amaranth is not a host species of any soil-borne disease. Amaranth, therefore, was allowed to be grown successively, except in the system with the high level of biodiversity.

Sweet pepper (*Capsicum annuum*), fennel (*Foeniculum vulgare*) and coriander (*Coriandrum sativum*) were excluded from the list of crops submitted to PermVeg (Huong *et al*., 2013b). Sweet pepper is a new crop to the RRD and as yet hardly tested. It generates a high profit, but also requires high pesticide use. It would be dominant in all sequences whenever the selection criterion is profit. If the crop fails, or its price goes down, the crop sequences would all collapse. This is because the growth duration in the field is long: 155 days if planted in January and 277 days if planted in August and September. Because fennel and coriander are mainly used as herbs and are highly perishable, they are consumed less than other vegetables and need to be sold at the day of harvesting. They are sown several times on different parts of a plot, to prolong the harvesting period. Because of the limited areas needed by these crops, they were not submitted to the program.

2.3.2. Criteria of five permanent vegetable production systems and the traditional system

(i). **Profitability**. All vegetables were submitted to the computer program. Sequences were ranked according to profit. The sequence selected should have the highest profit among the sequences with the same number of crops.

(ii). **Labour**. All vegetables were submitted to the computer program. Sequences were ranked according to labour requirement. The sequences with profit below the median of the profit (345 kVND/ha/day) of the vegetable crops involved in the study were discarded. The sequence selected should have the lowest labour requirement among the sequences with the same number of crops.

(iii). **Pesticide**. All vegetables were submitted to the computer program. Sequences were ranked according to costs of pesticide use. The sequences with profit below the median of the profit of the vegetable crops involved in the study were discarded. The sequence selected should have the lowest costs of pesticide use among the sequences with the same number of crops.

(iv). **Biodiversity**. Crops of the same botanical family occurred only once in a sequence. All vegetables were submitted to the computer program. Sequences were ranked according to profit. The sequence selected should have the highest profit among the sequences with the same number of crops.

(v). **Perishability**. Only vegetables with products of low perishability (at least four days between harvest and selling, Huong *et al*., 2013b) were submitted to the computer program. The sequences were ranked according to profit. The sequence selected should have the highest profit among the sequences with the same number of crops.

(vi). In the traditional system (**'Traditional'**) the first rice crop is planted in February (day 36-46), with a growth duration in the field of 109 days. The second rice crop is planted in June – July (day 171-201), with a growth duration of 94 days. Values used for profitability, labour requirement and costs of pesticide use for rice (Table 1) are based on data collected for the Khang Dan rice variety in 2006 in the Vu Ban district, Nam Dinh Province (Tin, 2009). Growth duration in the field was not recorded, but was fixed on the typical growth duration of the Khang Dan variety. In this system vegetable sequences were calculated from starting day 270 of each year, until stopping day 30 of the next year, where the stopping period consisted of the 10 days interval before and after the stopping day.

Table 1. Duration of growth in the field, profit, labour requirement and cost of pesticide use of rice (2006: 1 € = 20 thousand Vietnamese Dong; kVND = thousand Vietnamese Dong; Gday = growing day in the field).

Crop (planted in month-month)	Planting period		Growth duration (days)		Profit (kVND/ha/Gday)		Labour required (day/ha/Gday)		Pesticide use (kVND/ha/Gday)	
		n	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rice (2)	5/2 -15/2	11	109	0	46.7	0.0	0.9	0.5	3.6	0.5
Rice (6-7)	20/6-20/7	11	94	0	62.0	3.4	1.4	0.0	6.2	0.9

2.3.3.The algorithm to select the optimum crop sequence for each system

In this study setting Maxnrcropsinseq = 25 was high enough. At the maximum number of crops in a sequence, the length of the sequence in days must exceed the number of days between starting day and stopping day. The starting date was May 1, 2007 (day 121). The stopping date was April 29, 2009 (day 850). The stopping period was assumed to be 10 days before and 10 days after stopping date. The length of each sequence therefore was between

720 and 740 days.

First the subset of the crops for which May 1 was in the planting period, and thus could be planted on May 1, was established. The number of crops in this subset was called $S1$. So the program started with $S1$ sequences of one crop. Each of the sequences was indexed with i_1 (i_1=1…$S1$) and consisted of crop numbers. Additional to each sequence the profitability, labour requirement and costs of pesticide use for the whole sequence were calculated and saved for each sequence of crops. Also the planting date of the following crop was saved, being the planting date of the last crop in the sequence added with the number of days of its growing period and 5 days, being the length of the interval between consecutive crops.

After $S1$ sequences of one crop were formed, for each sequence there was again a subset of crops that could be planted after the first crop, each satisfying the restrictions mentioned above. So each sequence i_1 with one crop was split into $s_{2,i1}$ new sequences of two crops:

$$S2 = \sum_{i1=1}^{S1} s_{2,i1}$$

For each of these $S2$ sequences again profitability, labour requirement and costs of pesticide use were saved as well as the planting date of the third crop. For each sequence there was again a subset of crops that could be planted after the second crop, each satisfying the restrictions mentioned above. So each sequence i_2 with two crops was split into $s_{3,i2}$ new sequences of three crops:

$$S3 = \sum_{i2=1}^{S2} s_{3,i2}$$

And so on until $S25$. However, each crop sequence with a harvest date of the last crop falling between 720 and 740 days without possibility to grow another crop before 740 days, was ended and evaluated for profitability, labour requirement and costs of pesticide use. Sequences shorter than 720 days, but without candidate crops that could be harvested before day 741 were discarded.

For each crop, the profit, the labour requirement and the costs of pesticide use were supplied to the algorithm in units per ha per growing day. To compare crop sequences, first the total quantity of profit, labour requirement and the costs of pesticide use were calculated per crop and summed for the whole sequence. The totals per sequence over the sum of growing days and interval days of the sequence, resulted in the profit, labour requirement and costs of pesticides use per ha per day for the crop sequence.

From the formed sequences the one that scored highest on the designated criterion, was chosen. For each iteration, the sequences with the last harvest date within the day 720-740, were exported to an EXCEL file. In addition to the sequences, the day number of the last harvest and the profitability, labour requirement and costs of pesticide use per day and per sequence were exported. The other sequences were used for the next iteration. To restrict the number of sequences Maxnrsequences was set to 25,000 and to reduce the output Maxprint was set to 100. The sequences saved in the calculations were selected according to profitability, labour requirement or costs of pesticide use.

The program reported per iteration: the number of candidate crops, the maximum number of crops per sequence, the actual number of crops per sequence which is equal to i after the i^{th} iteration and the number of sequences at the end of each iteration.

3. Results

3.1. Five permanent vegetable production systems and the traditional system

Following the design of the alternative systems based on the five scenarios and the traditional system, PermVeg generated a number of crop sequences for each system (crop names and planting periods are explained in Table 2):

Table 2. Crops in the model sequences (Huong *et al.*, 2013b).

Nr	***Family***, *Species*	Common name (planted in month-month)	Growth duration (days)
	Amaranthaceae		
1	*Amaranthus tricolor*	Amaranth (1-12)	31
	Basellaceae		
2	*Basella alba*	Ceylon spinach (2-3)	190
	Chenopodiaceae		
3	*Spinacia oleracea*	Spinach (9-2)	29
	Compositae		
4	*Chrysanthemum coronarium*	Garland chrysanthemum (9-2)	40
5	*Lactuca sativa*	Lettuce (5); (9-2)	31; 36

Nr	***Family***, *Species*	Common name (planted in month-month)	Growth duration (days)
	Convolvulaceae		
6	*Ipomoea aquatica*	Kang kong (2-8)	148
	Cruciferae		
7	*Brassica juncea*	Indian mustard (4-8)	31
8	*Brassica juncea* var. *rugosa*	Wrapped heart mustard (4-8)	51
9	*Brassica oleracea* var. *italica*	Broccoli (9-10)	71
10	*Brassica oleracea* var. *capitata*	Cabbage (8-9)	63
11	*Brassica oleracea* var. *botrytis*	Cauliflower (9-10)	76
12	*Brassica oleracea* var. *gongylodes*	Kohlrabi (7-9)	56
13	*Brassica oleracea* var. *alboglabra*	Chinese kale (4-10); (11-3)	47; 34
14	*Brassica rapa* var. *parachinensis*	Green choy sum (4-8); (9-3)	34, 31
15	*Brassica rapa* ssp. *chinensis*	Green pakchoi (8-2)	43
16	*Raphanus sativus*	Radish (3); (8-9)	46, 35
	Cucurbitaceae		
17	*Benincasa hispida*	Wax gourd (2-3);(4-6); (10); (12-1)	95; 77; 93; 127
18	*Citrullus lanatus*	Water melon (2-3); (8-9)	77; 64
19	*Cucumis melo* cv. group *Inodorus*	Pear shaped melon (2-3)	81
20	*Cucumis sativus*	Cucumber (6)	92
21	*Langenaria siceraria*	Bottle gourd (3-6)	120
22	*Momordica charantia*	Bitter gourd (2-3); (4-6)	207; 143
	Leguminosae		
23	*Phaseolus vulgaris*	French bean (9-12)	121
24	*Pisum sativum*	Snow pea (11-12)	93
	Liliaceae		
25	*Allium ampeloprasum* var. *porrum*	Leek (3-6); (8-2)	66; 61
26	*Allium cepa* var. *cepa*	Onion (9)	106
27	*Allium cepa* var. *ascalonicum*	Shallot _clove (9)	106
28	*Allium cepa* var. *ascalonicum*	Shallot _clove + leaves (9-1)	73
29	*Allium fistulosum*	Welsh onion (1-12)	39
	Malvaceae		
30	*Corchorus olitorius*	Tossa jute (2-3)	167
	Poaceae		
31	*Zea mays* var. *rugosa*	Sweet corn (4-9)	80
32	*Oryza sativa*	Rice (1-2); (6-7)	109; 94
	Solanaceae		
33	*Solanum lycopersicum*	Tomato (8-2)	129
34	*Solanum melongena*	Eggplant (2-3); (10)	242; 214
35	*Solanum undatum*	Pickle (2-3); (6)	180; 175
	Umbelliferae		
36	*Apium graveolens*	Celery (9-4)	45

(i). **Profitability**. PermVeg exported sequences comprising 5-18 crops for the profitability system. The sequences with the highest profit among sequences with the same number of crops were selected (Table 3). Crops with a high profitability, such as Chinese kale (*Brassica oleracea* var. *alboglabra*), grown as well as in April- October as in November – March, water melon (*Citrullus lanatus*) grown in August – September, and snow pea (*Pisum sativum*) occurred dominantly in the selected sequences. Profit of the sequences increased when the number of crops increased and reached the maximum value when there were 17 crops in the sequence. Labour requirement increased and costs of pesticide use decreased when the number of crops in the sequences increased.

(ii). **Labour**. PermVeg exported sequences comprising 6-13 crops for the labour system. The sequences with the lowest amount of labour required among sequences with the same number of crops were selected (Table 4). Crops with a low labour requirement occurred dominantly in the selected sequences, such as green choy sum (*Brassica rapa* var. *parachinensis*) grown in April – August, tomato (*Solanum lycopersicum*) and wax gourd (*Benincasa hispida*) grown in April – June. The profit of the selected sequences did not vary much. Labour requirement increased when the number of crops in the selected sequences increased (except for the sequence with six crops). The selected sequence with seven crops required the lowest amount of labour. The costs of pesticide use decreased when the number of crops in the sequences increased.

(iii). **Pesticide**. PermVeg exported sequences comprising 6-18 crops for the pesticide system. The sequences with the lowest costs of pesticide use among sequences with the same number of crops were selected (Table 5). Crops with low pesticide requirement occurred dominantly in the selected sequences, such as Welsh onion (*Allium fistulosum*) and spinach (*Spinacia oleracea*). The profit of the selected sequences varied by not more than 8%. The labour requirement increased when the number of crops in the selected sequences increased. The costs of pesticide use decreased when the number of crops in the sequences increased and reached the minimum value when there were 15 or 16 crops in the sequence, then increased slightly when the number of crops in the sequences increased.

(iv). **Biodiversity**. PermVeg exported sequences comprising 5-10 crops for the biodiversity system. The sequences with the required biodiversity and with the highest

Table 3. **Profitability**. Characteristics of the sequences with the highest profit among sequences with the same number of crops.

Sequence	Nr crops	Length (days)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	5	740	308	7.2	27.2
b	6	723	394	7.1	32.6
c	7	726	447	6.8	30.9
d	8	726	475	7.0	30.9
e	9	721	496	8.6	28.1
f	10	727	522	8.9	32.1
g	11	736	549	9.1	33.6
h	12	739	574	8.3	30.7
i	13	720	586	9.0	26.8
j	14	739	598	9.3	27.9
k	15	737	605	9.9	25.7
l	16	726	607	9.9	24.9
m	17	727	608	10.3	23.3
n	18	738	563	11.0	22.6

a. Indian mustard (4-8)-pickle (6)-snow pea (11-12)-bitter gourd (2-3)-eggplant (10)

b. Indian mustard (4-8)-pickle (6)-snow pea (11-12)-bitter gourd (2-3)-broccoli (9-10)-French bean (9-12)

c. Bottle gourd (3-6)-cauliflower (9-10)-snow pea (11-12)-pickle (2-3)-water melon (8-9)-Chinese kale (11-3)-tomato (8-2)

d. Chinese kale (4-10)-sweet corn (4-9)-water melon (8-9)-Snow pea (11-12)-pickle (2-3)-water melon (8-9)-Chinese kale (11-3)-tomato (8-2)

e. Indian mustard (4-8)-pickle (6)-snow pea (11-12)-water melon (2-3)-Chinese kale (4-10)-Welsh onion (1-12)-water melon (8-9)-Chinese kale (11-3)-French bean (9-12)

f. Indian mustard (4-8)-pickle (6)-snow pea (11-12)-Chinese kale (11-3)-celery (9-4)-Welsh onion (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-leek (8-2)

g. Indian mustard (4-8)-pickle (6)-snow pea (11-12)-Chinese kale (11-3)-celery (9-4)-Welsh onion (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-Chinese kale (11-3)-amaranth (1-12)

h. Chinese kale (4-10)-sweet corn (4-9)-water melon (8-9)-snow pea (11-12)-Chinese kale (11-3)-leek (3-6)-amaranth (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-Chinese kale (11-3)-amaranth (1-12)

i. Chinese kale (4-10)-leek (3-6)-water melon (8-9)-Chinese kale (11-3)-Welsh onion (1-12)-spinach (9-2)-Chinese kale (11-3)-leek (3-6)-amaranth (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-radish (3)

j. Chinese kale (4-10)-leek (3-6)-water melon (8-9)-Chinese kale (11-3)-leek (8-2)-spinach (9-2)-Chinese kale (11-3)-lettuce (5)-Welsh onion (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-Chinese kale (11-3)-amaranth (1-12)

k. Lettuce (5)-Chinese kale (4-10)-Welsh onion (1-12)-water melon (8-9)-Chinese kale (11-3)-garland chrysanthemum (9-2)-Welsh onion (1-12)-Chinese kale (11-3)-lettuce (5)-Welsh onion (1-12)-Chinese kale (4-10)-water melon (8-9)-snow pea (11-12)-Chinese kale (11-3)-amaranth (1-12)

l. Chinese kale (4-10)-leek (3-6)-water melon (8-9)-Chinese kale (11-3)-Welsh onion (1-12)- spinach (9-2)-Chinese kale (11-3)-Welsh onion (1-12)-lettuce (5)-Chinese kale (4-10)-water melon (8-9)-spinach (9-2)-Chinese kale (11-3)- amaranth (1-12)- spinach (9-2)-Chinese kale (11-3)

m. Lettuce (5)-Chinese kale (4-10)-Welsh onion (1-12)-water melon (8-9)-Chinese kale (11-3)-Welsh onion (1-12)- spinach (9-2)-Chinese kale (11-3)-amaranth (1-12)-lettuce (5)-Chinese kale (4-10)-water melon (8-9)-spinach (9-2)-Chinese kale (11-3)- amaranth (1-12)-spinach (9-2)-Chinese kale (11-3)

n. Lettuce (5)-Chinese kale (4-10)-Welsh onion (1-12)-water melon (8-9)-Chinese kale (11-3)-amaranth (1-12)-spinach (9-2)-Chinese kale (11-3)-amaranth (1-12)-lettuce (5)-Indian mustard (4-8)-amaranth (1-12)-water melon (8-9)-Chinese kale (11-3)-amaranth (1-12)-spinach (9-2)-amaranth (1-12)- Indian mustard (4-8)

Table 4. **Labour**. Characteristics of the sequences with the lowest labour requirement among sequences with the same number of crops.

Sequence	Nr crops	Length (days)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	6	720	364	4.9	26.6
b	7	722	351	4.2	16.4
c	8	736	347	4.4	16.8
d	9	735	347	4.6	18.0
e	10	737	353	4.8	13.3
f	11	734	353	5.2	13.0
g	12	736	355	5.8	12.7
h	13	740	349	6.1	12.8

a. Chinese kale (4-10)-kang kong (2-8)-snow pea (11-12)-bitter gourd (2-3)-broccoli (9-10)-tomato (8-2)

b. Wax gourd (4-6)-kohlrabi (7-9)-onion (9)-tomato (8-2)-Chinese kale (4-10)-kang kong (2-8)-tomato (8-2)

c. Green choy sum (4-8)-wax gourd (4-6)-tomato (8-2)-shallot_clove + leaves (9-1)-Chinese kale (11-3)-wax gourd (4-6)-kang kong (2-8)-tomato (8-2)

d. Green choy sum (4-8)-wax gourd (4-6)-tomato (8-2)-Chinese kale (11-3)-spinach (9-2)-pear shaped melon (2-3)-kang kong (2-8)-tomato (8-2)-green choy sum (4-8)

e. Wrapped heart mustard (4-8)-wax gourd (4-6)-onion (9)-Chinese kale (11-3)-spinach (9-2)-kang kong (2-8)-Chinese kale (4-10)-wax gourd (10)-shallot_clove + leaves (9-1)-green choy sum (4-8)

f. Wrapped heart mustard (4-8)-wax gourd (4-6)-onion (9)-Chinese kale (11-3)-spinach (9-2)-kang kong (2-8)-Chinese kale (4-10)-wax gourd (10)-lettuce (9-2)-spinach (9-2)-green choy sum (4-8)

g. Green choy sum (4-8)-wax gourd (4-6)-tomato (8-2)-Chinese kale (11-3)-spinach (9-2)-kang kong (2-8)-green choy sum (4-8)-spinach (9-2)-shallot_clove + leaves (9-1)-amaranth (1-12)-spinach (9-2)-green choy sum (4-8)

h. Green choy sum (4-8)-wax gourd (4-6)-tomato (8-2)-Chinese kale (11-3)-spinach (9-2)-kang kong (2-8)-green choy sum (4-8)-spinach (9-2)-lettuce (9-2)-amaranth (1-12)-spinach (9-2)-lettuce (9-2)-green choy sum (4-8)

profitability among sequences with the same number of crops were selected (Table 6). Profit and labour requirement of the sequences increased when the number of crops increased and reached the maximum value when there were nine crops in the sequence. The costs of pesticide use varied among the selected sequences, but did not follow the pattern of the previous systems.

(v) **Perishability**. PermVeg exported sequences comprising 5-12 crops for the perishability system. The sequences with the required low perishability and with highest profitability among sequences with the same number of crops were selected (Table 7). Snow pea, radish (*Raphanus sativus*) grown in March, water melon grown in August – September and celery (*Apium graveolens*) occurred dominantly in the selected sequences. Profit increased when the number of crops increased and reached the maximum value when there were 10 crops in the sequence. Labour requirement increased when the number of crops in the sequences increased. The costs of pesticide use did not vary much, except for the low value of the sequence with nine crops.

(vi). **Traditional**. With the two rice crops fixed in time, PermVeg exported vegetable crop sequences comprising 1-4 crops for the period from day 270 of each year to five days before day 46 of the following year. The sequences with the highest profitability among sequences with the same number of vegetable crops for that period were selected. The selected vegetable sequences were rotated with flooded rice planted in June-July and rice planted in February (Table 8). Profit increased when the number of crops in the sequences increased and reached the maximum value when there were 10 crops in the sequence. Labour requirement increased when the number of crops in the sequences increased. The costs of pesticide use were lowest when there were 12 crops in the sequence.

3.2. Comparison of the permanent vegetable production systems with the traditional system

Profit, labour requirement and costs of pesticide use of the permanent vegetable production systems were compared with the traditional system. The profit of all the sequences of the permanent vegetable production systems was higher than that of the **Traditional** system (Figure 1). With the higher number of crops per sequence, the **Profitability** system had the highest profit. Except for the sequence with 10 crops in the **Labour** system, the labour requirement of all the sequences of the permanent vegetable systems was higher than that of the traditional system. The **Labour** system needed the lowest amount of labour of the alternative systems. In general the amount of labour needed increased with an increase in the number of crops in a sequence. The costs of pesticide use of the sequences in the **Pesticide** system with 10 to 18 crops, were lower than those of the traditional system. The costs of pesticide use of the selected sequences of the other four alternative permanent vegetable production systems were higher than those of the traditional system. The costs of pesticide use tended to decrease with an increase in the number of crops in a sequence.

4. Discussion

As a practical tool for the design of cropping sequences for vegetable production systems for an intensive vegetable production area, PermVeg has new features in comparison with the ROTAT model (Dogliotti *et al*., 2003). PermVeg generates crop sequences without closed rotation requirements, with the length of sequences counted in days, while the sequence can

Table 5. **Pesticide**. Characteristics of the sequences with the lowest cost of pesticide use among sequences with the same number of crops.

Sequence	Nr crops	Length (days)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	6	737	349	7.0	15.2
b	7	740	355	6.1	12.4
c	8	731	354	7.2	10.4
d	9	739	356	8.1	8.7
e	10	732	366	8.1	6.4
f	11	732	376	8.7	5.9
g	12	730	371	9.1	5.5
h	13	729	368	7.2	5.2
i	14	738	374	9.6	4.8
j	15	731	372	8.4	4.6
k	16	727	349	8.6	4.6
l	17	740	352	9.6	4.9
m	18	740	379	9.7	5.4

a. Bottle gourd (3-6)-broccoli (9-10)-French bean (9-12)-tossa jute (2-3)-shallot_clove (9)-wax gourd (12-1)
b. Wrapped heart mustard (4-8)-wax gourd (4-6)-onion (9)-Chinese kale (11-3)-tossa jute (2-3)-kang kong (2-8)-wax gourd (12-1)
c. Lettuce (5)-Welsh onion (1-12)-Chinese kale (4-10)-water melon (8-9)-shallot_clove + leaves (9-1)-tossa jute (2-3)-kang kong (2-8)-wax gourd (12-1)
d. Welsh onion (1-12)-wrapped heart mustard (4-8)- amaranth (1-12)-shallot_clove (9)-green pakchoi (8-2)-spinach (9-2)-tossa jute (2-3)-shallot_clove (9)-wax gourd (12-1)
e. Lettuce (5)-wrapped heart mustard (4-8)-Welsh onion (1-12)-water melon (8-9)-spinach (9-2)-Welsh onion (1-12)-tossa jute (2-3)-kang kong (2-8)-shallot_clove + leaves (9-1)-radish (3)
f. Lettuce (5)-wrapped heart mustard (4-8)-Welsh onion (1-12)-water melon (8-9)-spinach (9-2)-Welsh onion (1-12)-tossa jute (2-3)-kang kong (2-8)-Welsh onion (1-12)- spinach (9-2)-radish (3)
g. Welsh onion (1-12)-wrapped heart mustard (4-8)-amaranth (1-12)-shallot_clove (9)-spinach (9-2)-tossa jute (2-3)-Welsh onion (1-12)-spinach (9-2)-lettuce (9-2)-shallot_clove + leaves (9-1)-spinach (9-2)-radish (3)
h. Lettuce (5)-wrapped heart mustard (4-8)-Welsh onion (1-12)-spinach (9-2)-lettuce (9-2)-shallot_clove + leaves (9-1)-spinach (9-2)-radish (3)-Welsh onion (1-12)-kang kong (2-8)-spinach (9-2)-shallot_clove + leaves (9-1)-radish (3)
i. Lettuce (5)-wrapped heart mustard (4-8)-Welsh onion (1-12)-spinach (9-2)-lettuce (9-2)-Welsh onion (1-12)-spinach (9-2)-tossa jute (2-3)-Welsh onion (1-12)-spinach (9-2)-lettuce (9-2)-shallot_clove + leaves (9-1)-spinach (9-2)-radish (3)
j. Lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-spinach (9-2)-Welsh onion (1-12)-green choy sum (9-3)-spinach (9-2)-Welsh onion (1-12)-radish (3)-kang kong (2-8)-spinach (9-2)-Welsh onion (1-12)-lettuce (9-2)-spinach (9-2)-radish (3)
k. Lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-spinach (9-2)-Welsh onion (1-12)-lettuce (9-2)-spinach (9-2)-Welsh onion (1-12)-radish (3)-lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-wax gourd (10)-Welsh onion (1-12)-spinach (9-2)-green choy sum (9-3)
l. Lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-spinach (9-2)-Welsh onion (1-12)-green choy sum (9-3)-spinach (9-2)-Welsh onion (1-12)-radish (3)-lettuce (5)-cucumber (6)-spinach (9-2)-Welsh onion (1-12)-green choy sum (9-3)-spinach (9-2)-lettuce (9-2)-Welsh onion (1-12)
m. Lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-spinach (9-2)-Welsh onion (1-12)-green choy sum (9-3)-spinach (9-2)-Welsh onion (1-12)-radish (3)-lettuce (5)-Welsh onion (1-12)-wrapped heart mustard (4-8)-spinach (9-2)-lettuce (9-2)-green choy sum (9-3)-spinach (9-2)-lettuce (9-2)-Welsh onion (1-12)

Table 6. **Biodiversity**. Characteristics of the sequences with the required biodiversity and with the highest profit among sequences with the same number of crops.

Sequence	Nr crops	Length (days)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	5	729	290	5.3	27.9
b	6	734	322	8.0	15.5
c	7	736	412	8.1	19.7
d	8	724	424	9.1	16.9
e	9	725	446	9.5	19.7
f	10	720	424	8.7	20.0

a. Kang kong (2-8)-French bean (9-12)-eggplant (2-3)-broccoli (9-10)-wax gourd (12-1)
b. Bottle gourd (3-6)-cauliflower (9-10)-snow pea (11-12)-tossa jute (2-3)-Welsh onion (1-12)-eggplant (10)
c. Lettuce (5)-pickle (6)-snow pea (11-12)-ceylon spinach (2-3)-onion (9)-Chinese kale (11-3)-water melon (2-3)
d. Amaranth (1-12)-pickle (6)-snow pea (11-12)-tossa jute (2-3)-water melon (8-9)-shallot_clove + leaves (9-1)-garland chrysanthemum (9-2)-radish (3)
e. Lettuce (5)-pickle (6)-snow pea (11-12)-tossa jute (2-3)-water melon (8-9)-Chinese kale (11-3)-leek (8-2)-spinach (9-2)-amaranth (1-12)
f. Lettuce (5)-Chinese kale (4-10)-amaranth (1-12)-celery (9-4)-spinach (9-2)-snow pea (11-12)-tossa jute (2-3)-water melon (8-9)-tomato (8-2)-Welsh onion (1-12)

Table 7. **Perishability.** Characteristics of the sequences with required low perishability and with the highest profit among sequences with the same number of crops.

Sequence	Nr crops	Length (days)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	5	740	295	6.2	27.8
b	6	721	385	5.7	29.9
c	7	720	450	7.2	28.0
d	8	720	461	7.7	28.3
e	9	723	459	6.9	24.9
f	10	736	470	7.1	28.1
g	11	725	460	7.2	27.8
h	12	727	437	8.6	26.2

a. Bitter gourd (4-6)-cabbage (8-9)-snow pea (11-12)-bitter gourd (2-3)-eggplant (10)
b. Bottle gourd (3-6)-cauliflower (9-10)-snow pea (11-12)-bitter gourd (2-3)-broccoli (9-10)-tomato (8-2)
c. Bitter gourd (4-6)-cabbage (8-9)-snow pea (11-12)-water melon (2-3)-pickle (6)-snow pea (11-12)-radish (3)
d. Wrapped heart mustard (4-8)-leek (3-6)-water melon (8-9)-French bean (9-12)-pickle (2-3)-water melon (8-9)-snow pea (11-12)-radish (3)
e. Bottle gourd (3-6)-cauliflower (9-10)-snow pea (11-12)-leek (3-6)-wax gourd (4-6)-wrapped heart mustard (4-8)-leek (8-2)-snow pea (11-12)-radish (3)
f. Wrapped heart mustard (4-8)-sweet corn (4-9)-water melon (8-9)-snow pea (11-12)-radish (3)-celery (9-4)-wax gourd (4-6)-cauliflower (9-10)-snow pea (11-12)-leek (3-6)
g. Wrapped heart mustard (4-8)-sweet corn (4-9)-water melon (8-9)-snow pea (11-12)-radish (3)-celery (9-4)-wax gourd (4-6)-radish (8-9)-celery (9-4)-snow pea (11-12)-radish (3)
h. Wrapped heart mustard (4-8)-leek (3-6)-water melon (8-9)-celery (9-4)-leek (8-2)-radish (3)-celery (9-4)-leek (3-6)-water melon (8-9)-celery (9-4)-shallot_clove + leaves (9-1)-radish (3)

Table 8. **Traditional**. Characteristics of the sequences with the highest profit among sequences with the same number of crops, starting at day 171. Vegetables sequences were started at day 270 and ended before day 46 of the following year.

Sequence*	Nr crops	Length (day)	Profit (kVND/ha/day)	Labour required (day/ha/day)	Pesticide use (kVND/ha/day)
a	6	704	157	3.1	12.8
b	8	704	196	3.2	9.1
c	10	704	239	4.7	10.9
d	12	711	180	5.2	7.8

a. Rice (6-7)-French bean (9-12)-rice (2)-rice (6-7)-French bean (9-12)-rice (2)
b. Rice (6-7)-broccoli (9-10)-garland chrysanthemum (9-2)-rice (2)-rice (6-7)-broccoli (9-10)-garland chrysanthemum (9-2)-rice (2)
c. Rice (6-7)-Welsh onion (1-12)-Chinese kale (11-3)-garland chrysanthemum (9-2)-rice (2)-rice (6-7)-Welsh onion (1-12)-Chinese kale (11-3)-garland chrysanthemum (9-2)-rice (2)
d. Rice (6-7)-spinach (9-2)-Indian mustard (4-8)-amaranth (1-12)-spinach (9-2)-rice (2)-rice (6-7)-spinach (9-2)-Indian mustard (4-8)- amaranth (1-12)-spinach (9-2)-rice (2)

start at any day of the year. PermVeg, therefore, is a suitable program to design crop sequences for the RRD, or other regions, where vegetable crops can be grown continuously.

The model was used to design the treatments for a field experiment starting on May 1, 2007. A comparison of model outcomes for the five alternative production systems with starting dates Jan. 1, Apr. 1, Jul. 1 and Oct. 1, showed similar patterns in results, but differences between outcomes of different planting dates were observed. The first crop of a sequence, selected on its planting period during the year, influences the further crop options in the sequence. Different systems therefore, should be compared with the same planting date. The model outcomes are based on data of vegetable production in the RRD collected in a certain period of time (Huong *et al*., 2013b). As yields and prices, and consequently profits, in field vegetable production do vary, modelling with different data as presently used, may result in different outcomes of the model. Also extreme risks in vegetable production, such as the complete loss of a crop, are not taken into account in the model. Vegetable production always faces risks due to weather, pests and diseases and price-induced risks (Midmore and Jansen, 2003; Fransisco and Ali, 2006). Crops with a high profit margin can even pose more risks to farmers (Laborte *et al*., 2007).

The **Profitability** system tended to have a higher profit, a higher labour requirement and lower costs of pesticide use when the number of crops in the sequence increased. This was because vegetable crops in the RRD tended to have a higher profit, a higher labour requirement and a lower pesticide use when their growth duration decreased (Huong *et al*., 2013b). However, this trend was not always obvious in the other systems.

Safe, i.e. sustainable, vegetable production policy has been implemented by the

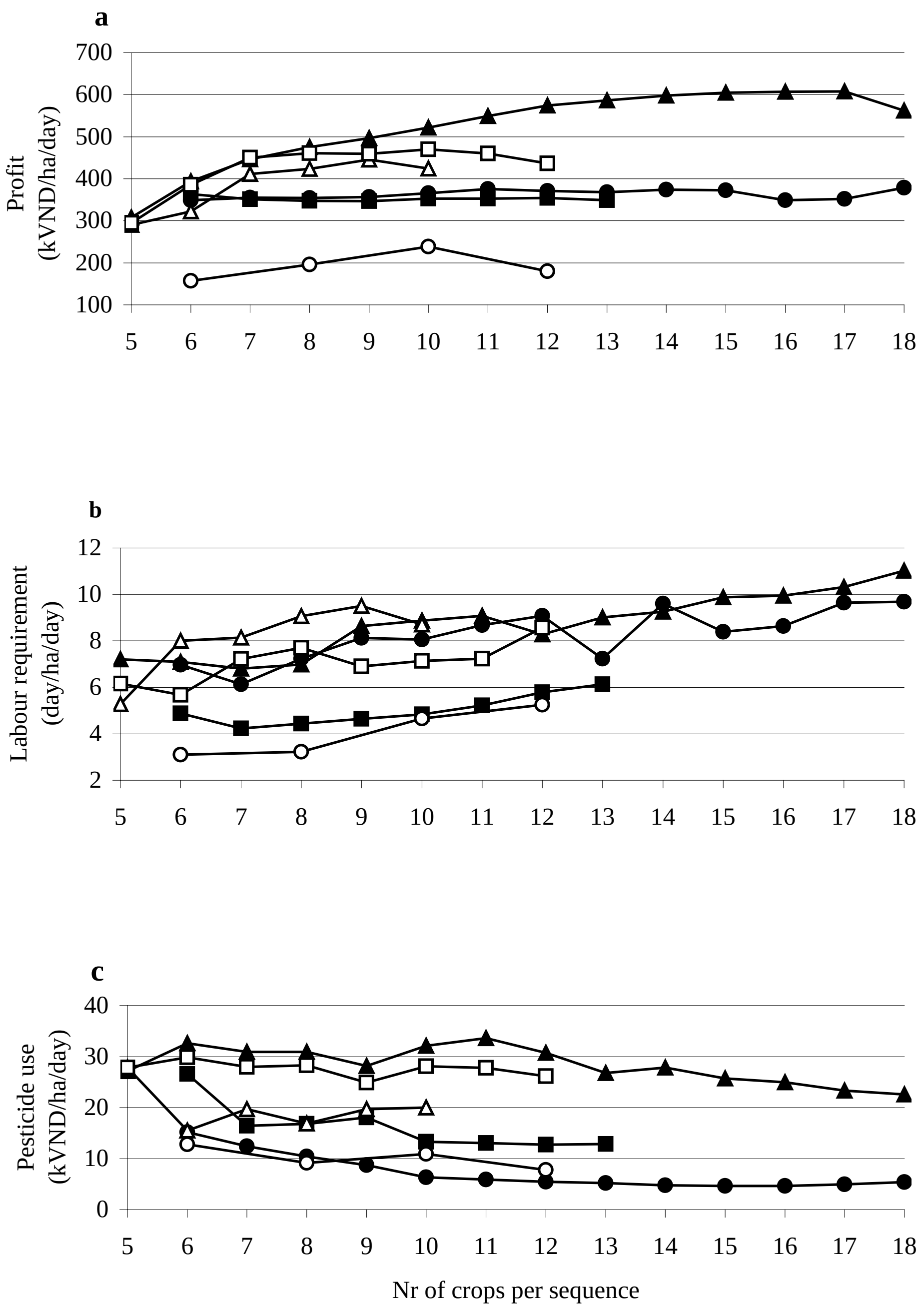

Figure 1: Profitability (**a**), labour requirement (**b**) and costs of pesticide use (**c**) of the six systems: **Profitability** (▲), **Labour** (■), **Pesticide** (●), **Biodiversity** (Δ), **Perishability** (□) and **Traditional** (○).

Ministry of Agriculture and Rural Development (MARD) since 1995 (Moustier *et al.*, 2006; Mergenthaler *et al.*, 2009). Although all alternative permanent vegetable production systems have a proper crop sequence in terms of crop rotation, the **Biodiversity** system was specifically designed with the aim of reducing pesticide use by increasing biodiversity in the cropping sequence. The system could be used to promote sustainable vegetable production systems as recommended by the government. The **Pesticide** system selects for crops with low costs of pesticide use, but as such has no direct effect on pesticide use per crop.

With an average per capita landholding in the RRD of 700 m^2 and 3.81 capita per household (General Statistics Office (GSO), 2007), the farm size of a family of four, would be 2,700 m^2. When vegetables are grown permanently on 1,000 m^2, the labour requirement with permanent vegetable production runs up to a maximum of about one day per day in the field (10 days per hectare per day, Figure 1). This is likely to be easily fulfilled by available labour within the household.

Although the alternative vegetable production systems designed always required more labour per hectare than the **Traditional** system, the income per labour day of selected sequences of **Profitability**, **Labour** and **Perishability** systems was higher than that of the **Traditional** system. E.g., the sequence of 12 crops in the **Profitability** system and the sequence of seven crops in the **Labour** system had a labour-day income of 69.4 kVND and 83.0 kVND, respectively, whereas the sequences of the **Traditional** system had the highest labour-day income of 60.7 kVND with a sequence of eight crops. Permanent vegetable production systems, therefore, potentially may generate a higher profit per unit of area and a higher profit per unit of labour.

In theory the diversity of vegetable products offered on the markets could be reduced if the outcomes of the PermVeg model would be rigorously applied. The selected sequences of **Profit**, **Labour**, **Pesticide**, **Biodiversity**, **Perishability** and **Traditional** systems comprised 54, 41, 49, 62, 46 and 21% of total candidate vegetable crops, respectively. All selected sequences together comprised 90% of the total number of candidate vegetable crops (Huong *et al*., 2013b). Because of the selection criteria, crops such as yard long bean (*Vigna sinensis*) and garlic (*Allium sativum*) were absent in any of the selected sequences of the six systems. However, if as a consequence of the outcomes of the PermVeg model work, certain crops would be grown less, while demand is still there, then prices of these crops are likely to rise and crops will become more attractive to produce. Therefore, in practice, market demand can be expected to make corrections. For reasons of tradition, or other reasons, a crop can be more dominant in one location than in another location (Anh *et al*., 2005a, b; Anh *et al*., 2006). Different subsets of crops, therefore, can be submitted to the PermVeg model to design cropping systems for different locations. When different subsets of crops are submitted for different locations, the potential negative effects on diversity of vegetable products for sale in the RRD can be reduced.

The performance of crops in crop sequences according to the five scenarios was tested in a two-year field experiment and compared with the performance of a traditional system of vegetable – flooded rice rotation (Huong *et al*., 201X). The PermVeg model reasonably well established crop growth duration, length of crop sequences and labour requirement, making it a useful tool for designing crop sequences for well-defined scenarios. Yield level, product price, costs of pesticide use, or a combination of these factors, influenced the profitability of individual crops in the experiment (Huong *et al*., 201X), and profitability and costs of pesticide use of the crop sequences were poorly predicted. The results indicate the sensitivity of the PermVeg model to varying yield levels, product prices and costs of pesticide use.

However, the results also showed that at local product prices, the **Profitability** and **Labour** system were more profitable than the **Traditional** system, while at city wholesale market prices *all* systems, apart from the **Perishability** system, were more profitable than the **Traditional** system, illustrating the potential of permanent vegetable production.

5. Application of the PermVeg model

The PermVeg model is primarily a single criteria crop sequence optimization model, although in the optimization it makes use of multiple restrictions, such as the general restriction of at least two crops of different botanical families between crops of the same family, and specific restrictions such as a minimum profit level, only one botanical family in a sequence or product perishability classes. The model was designed for practical application. It should be able to run easily and quickly on the laptop of an agricultural adviser, who in a discussion with farmers, together, wants to explore novel vegetable crop sequences. The outcome of the model is such that results are simple, clear and can be directly discussed with farmers in a situation of decision making. The model can start at any day of the year, making it possible to explore new crop sequence options when present crop sequences are not performing as expected or changing conditions need to be addressed.

With an average family landholding in the RRD of only 2,700 m^2 and average plot size of not more than 400 m^2, in a rather static socio-economic setting (Huong *et al*., 2013a), the choice of crops to produce - and its associated labour requirements - is likely to be a major decision to be made by the farmer in his farming operations.

The PermVeg model can not only help to explore potential crop sequence options for the whole RRD, but the program can also be used for exploration of options for vegetable production systems in a limited region. Stakeholders' objectives, restrictions on number and type of crops, as e.g. based on tradition or market potential, real or default data on yields, costs, prices and labour requirement, as based on experts' or farmers' knowledge, can be submitted to the PermVeg model to generate potential cropping sequences for a certain region.

As such the PermVeg model can act as a tool to rapidly explore crop sequence options, as based on farmers' supplied data and preferences, to help farmers' decision making.

6. Conclusions

The PermVeg model was designed to generate crop sequences for permanent vegetable production systems in the RRD. The model was able to successfully generate crop sequences based on a set of selection criteria and rules.

Based on the current data set collected in the RRD all five alternative permanent vegetable production systems generated higher incomes than the traditional system.

The PermVeg model can be used as a tool to generate crop sequences for discussion, learning and support of decision making by vegetable farmers in the RRD and elsewhere with comparable production conditions.

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Chapter 5

Performance of permanent vegetable production systems in the Red River Delta, Vietnam

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Abstract

The model PermVeg was developed to design crop sequences for permanent vegetable production systems for the Red River Delta, Vietnam. From May 2007 to May 2009 a field experiment was carried out, with the objectives to test the performance of permanent vegetable production systems and to compare the model outcomes with the results of the field experiment. The production systems tested were five systems designed according to the scenarios of (i) high profitability, (ii) low labour requirement, (iii) low costs of pesticide use, (iv) high level of crop biodiversity, and (v) low perishable products, respectively.

The five systems were compared with the traditional vegetable production system in which vegetables were rotated with flooded rice. At local prices, only the high profitability and low labour requirement systems yielded significantly higher profits than the traditional system. At city whole-sale market prices, profits of all permanent vegetable production systems were significantly higher than that of the traditional system, except for the low perishability system. Permanent vegetable production systems required more labour than the traditional system. Labour day incomes of permanent vegetable production systems generally were not higher than those of the traditional system. The labour day income increased only with the low labour requirement system at city whole-sale market prices. Permanent vegetable production systems required more insecticide and fungicide use than the traditional system.

The model outcomes correlated reasonably well with the labour requirement and the length in days of production systems in the field. The model poorly predicted profits and costs of pesticide use.

We concluded that permanent vegetable production systems can yield higher profits than the traditional system, and can contribute to enhancing employment opportunities and increasing household income.

Given the comparatively high pesticide requirement in the permanent vegetable production systems, further research on effective pest and disease control in vegetable production is required to reduce pesticide use.

*Keywords***:** Permanent field vegetable production systems, field vegetables, profit, labour requirement, labour day income, cost of pesticide use, Red River Delta, Vietnam

1. Introduction

Field vegetable production in South East Asia plays a major role in food supply, quality of the diet, income improvement and trade development (Johnson *et al*., 2009). Vegetables provide essential micro-nutrients and fibres for a balanced diet. As income and educational levels have increased, consumers have become more aware of the role of vegetables in a healthy diet. Indeed, daily consumption of vegetables per capita in many South East Asian countries has increased over the last 15 years: e.g., in Vietnam, from 120 g/person per day in 1990-1992 to 230 g/person per day in 2005-2007 and in Laos from 60 g/person per day in 1990-1992 to 340 g/person per day in 2005-2007 (FAOSTAT, 2010). In Vietnam, Laos, and Cambodia vegetable production yields a higher income for farmers than cereal production (Ali, 2008). Besides increasing income for farmers, vegetable production in South East Asia stimulates trade as well. During 2000-2005 Thailand exported hundreds of million US dollars of vegetable products per year (Johnson *et al*., 2009).

In the Red River Delta (RRD), Vietnam, vegetables are mainly grown in a rotation with two consecutive flooded rice crops per year (Huong *et al*., 2013a). This vegetable production system in the RRD has disadvantages, e.g., seasonality of production and prices (Thuy *et al*., 2002; An *et al*., 2003), poor soil conditions for vegetables and high labour requirement for land preparation (Everaarts *et al*., 2006). There also are year-round vegetable production systems in the RRD. In these systems, crops of the same plant family, e.g., *Brassicaceae*, may be grown continuously (Anh *et al*., 2005; 2006), potentially increasing the incidence of family-specific pests and diseases.

The disadvantages of the present vegetable production systems called for the design of innovative permanent vegetable production systems for the RRD (Huong *et al*., 201X). The model PermVeg was developed to generate the crop sequences for new permanent vegetable production systems for the RRD, as based on the data of profit, labour requirement and costs of pesticide use of 42 different vegetable crops commercially produced in the RRD (Huong *et al*., 2013b). Crop sequences for permanent vegetable production systems were designed based on the pre-requisites and restrictions imposed by five scenarios: (i) high profitability, (ii) low labour requirement, (iii) low costs of pesticide use, (iv) high level of crop biodiversity, and (v) low perishable products, respectively (Huong *et al*., 201X). Taking into account the pre-requisites and restrictions of a certain scenario, the PermVeg model selects crops for a crop sequence according to the required crop planting time, as mostly related to the seasonal variation in temperature, and crop growth duration, with a five day interval between crops. PermVeg generates crop sequences and calculates the length of the total crop sequence in days. The profit, labour requirement and costs of pesticide use of each crop sequence are calculated per hectare per day (Huong *et al*., 201X).

A two-year long field experiment was carried out to test the performance of the five newly designed permanent vegetable production systems in comparison with the traditional vegetable and flooded rice system, and to compare the data used in the modelling and the results of the model calculations with those from the field experiment.

2. Materials and methods

2.1. Location, climate and soil of the experimental site

The field experiment for testing the performance of the designed permanent vegetable production systems was carried out from May 2007 to May 2009 at Son Du village, Nguyen Khe commune, Dong Anh district, Hanoi Province (21^o 10’ N, 105^o 49’ E), about 17 km northeast of Hanoi. The field had a history of vegetable cultivation in rotation with two consecutive flooded rice crops a year since at least 1989 (as based on local people’s memory).

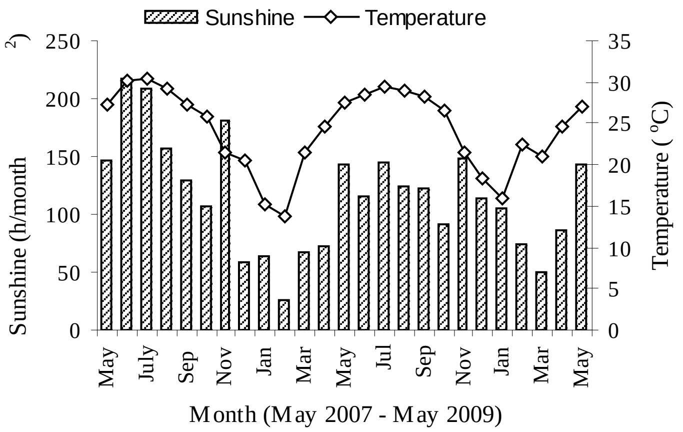
The climate at the experimental site is a tropical monsoon climate, with a hot and wet season from May to September, a cool and dry season from October to January and a cool and humid season February to April (Huong *et al*., 2013a). The weather conditions during the experiment are presented in Figure 1. January and February 2008 were very cold. Exceptionally high rainfall in the period October 30 to November 5 2008 caused temporary flooding of the experimental field.

The soil at the experimental site is a sandy loam with a pH of 6.1 and low organic carbon content (Table 1).

2.2. Crop sequences

Crop sequences for the vegetable production systems, covering a period of approximately two years, were generated with the PermVeg model (Huong *et al*., 201X).

The permanent vegetable production systems tested, as based on the five scenarios, (i) high profitability, (ii) low labour requirement, (iii) low costs of pesticide use, (iv) high level



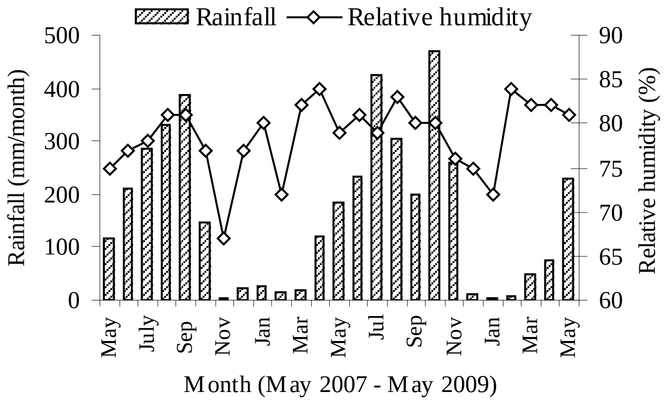


Figure 1. Monthly total sunshine, mean temperature, total rainfall and mean relative humidity in Hanoi (Lang Ha Meteo Station), May 2007 - May 2009.

Table 1. Soil properties of the experimental site (0-20 cm of raised bed).

Texture (%)	Sand	49
	Silt	42
	Clay	9
pH H_2O		6.1
Organic carbon (%)		1.03
N total (%)		0.11
P total (%)		0.04
K total (%)		0.17
P available (mg/100g soil)		28.0
K available (mg/100g soil)		6.79
CEC (meq/100g soil)		9.15

of crop biodiversity, and (v) low perishable products, were the following (Table 2):

Table 2. Crop sequences of vegetable production systems generated by the PermVeg model.

Profitability: Welsh onion (*Allium fistulosum*) - Chinese kale (*Brassica oleracea* var. *alboglabra*) - Amaranth (*Amaranthus tricolor*) - Water melon (*Citrullus lanatus*) - Chinese kale - Spinach (*Spinacia oleracea*) - Tomato (*Solanum lycopersicum*) - Chinese kale - Welsh onion - Water melon - Snow pea (*Pisum sativum*) - Chinese kale - Amaranth.
Labour: Sweet corn (*Zea mays* var. *rugosa*) - Kohlrabi (*Brassica oleracea* var. *gongylodes*) - Onion (*Allium cepa* var. *cepa*) - Tomato - Wax gourd (*Benincasa hispida*) - Kohlrabi - Sweet corn - Tomato.
Pesticide: Amaranth - Chinese kale - Welsh onion - Water melon - Green pakchoi (*Brassica rapa* ssp. *chinensis*) - Welsh onion - Spinach - Radish (*Raphanus sativus*) - Welsh onion - Tossa jute (*Corchorus olitorius*) -Spinach - Welsh onion - Green choy sum (*Brassica rapa* var. *parachinensis*) - Amaranth.
Biodiversity: Chinese kale - Tossa jute - Garland chrysanthemum (*Chrysanthemum coronarium*) - Tomato - Welsh onion - Amaranth - Water melon - Spinach - Snow pea - Celery (*Apium graveolens*).
Perishability: Wrapped heart mustard (*Brassica juncea* var. *rugosa*) - Leek (*Allium ampeloprasum* var. *porrum*) - Water melon - Tomato - Celery - Leek - Kohlrabi - Water melon - Tomato - Radish.
Traditional: Rice (*Oryza sativa*) - Chinese kale - Welsh onion - Spinach - Rice - Rice - Chinese kale - Welsh onion - Spinach - Rice.

Profitability system: the crop sequence with the highest profitability per hectare per day was selected;

Labour system: the crop sequence with the lowest labour requirement per hectare per day was selected;

Pesticide system: the crop sequence with the lowest cost of pesticide use per hectare per day was selected;

Biodiversity system: crops of one botanical family are permitted to be grown only once in the crop sequence, the crop sequence with the highest profitability per hectare per day was selected;

Perishability system: only crops with products of low perishability (at least four days between harvest and selling) are selected, the crop sequence with the highest profitability per hectare per day was selected.

The traditional vegetable flooded rice system acted as reference:

Traditional system: the crop sequence (including two consecutive crops of flooded rice per year in the hot season) with the highest profitability per hectare per day was selected.

The sequences in Table 2 were based on a preliminary database. Upon later refinement of the data base, the model results of these crop sequences for length of crop sequence, profit, labour requirement and costs of pesticide use were recalculated using the final database (Huong *et al*., 2013b) (Table 3).

Table 3. Model results for the crop sequences of Table 2 as based on the data of Huong *et al*. (2013b) (kVND = thousand Vietnamese Dong).

System	Length (days)	Profit (kVND/ha/day)	Labour requirement (day/ha/day)	Costs of pesticide use (kVND/ha/day)
Profitability	741	561	8.7	25
Labour	748	333	4.5	18
Pesticide	739	433	10.8	10
Biodiversity	729	422	8.8	20
Perishability	761	412	6.6	21
Traditional	704	222	4.4	9

The cold period in 2008 caused a delay in planting and the temporary flooding in the same year caused some crops to fail. Subsequent crop choice had to take account of the season and the time left to the next scheduled crop. Therefore some crops grown in the field differed from the crops in the designed systems.

2.3. Experimental design and crop production

The experiment was set up in a randomised complete block design with six treatments and four replications. The six treatments were the consecutive cultivation of the crops of the permanent vegetable production systems: Profitability, Labour, Pesticide, Biodiversity and Perishability, and of those of the Traditional system (Table 2).

There were twenty-four plots. Each plot measured 10.50 m by 11.95 m, consisting of eight raised beds of 10.0 m long, 1.1 m wide and 0.2 m high, with 0.4 m wide furrows between beds. Data were calculated using a net plot size of 8.0 m by 9.0 m, comprising six beds and furrows.

At the establishment of the experimental field, the whole field was ploughed using buffalo traction. In the first three months of the experiment, before sowing or planting crops, the beds in the permanent vegetable production systems were ploughed using buffalo traction, followed by soil tillage with a hand held hoe. After that period soil tillage for crop sowing or planting was done by hand only, using a hoe.

In the Traditional system, the rice fields were ploughed and puddled before rice planting using buffalo traction. After harvest of the rice, the fields were ploughed using buffalo traction, followed by construction of the raised beds and tillage for vegetable sowing or planting by hand, using a hoe. For vegetables grown after vegetables in this system, soil tillage for sowing or planting was similar to that in the permanent vegetable production systems.

Fertilizers and manure were applied according to the recommendations by the Soils and Fertilizer Institute, the Vegetable and Fruit Research Institute and the Field Crops Research Institute of Vietnam. For crops without fertilizer recommendations by these institutes, fertilizers and manure were applied according to common local farmers' practice. Manure and fertilizers were mostly applied before planting. Nitrogen and potassium were applied also during the growing period. The latter was based on the crop stand. In most crops rice husk was applied as mulch. Pests and diseases were identified and treated using pesticides available at the location. Weeds were removed by hand.

Crop products were graded according to local standards in Class 1 and Class 2. Only wax gourd fruits were graded in Class 1, Class 2 and Class 3. Class 1 includes produce with good appearance, without damage of insects, diseases or cracking. An individual product should reach certain weight, depending on the product. For sweet corn the grain should cover the whole cob. Class 2 are the remaining produce. For wax gourd, Class 2 includes fruits with light green skin or abnormal shape. Class 3 of wax gourd fruits are fruits damaged by diseases.

2.4. Data measurement and analysis

The performance of the crops was evaluated using the variables profit, potential profit, labour requirement, labour day income, potential labour day income, costs of pesticide use, amount of active ingredient of insecticides and fungicides per hectare per day or per kg of product. Profit of each crop was calculated from gross return and production costs in thousand Vietnamese Dong (kVND) per hectare per growing day (Gday) in the field (kVND/ha/Gday). Gross return was calculated from the yield and the local price of the product as sold to middle men or at the local market. Production costs included the costs of seeds or seedlings, fertilizers, pesticides, other materials such as mulching materials, frames, plastic for shelters, costs of soil tillage (if applicable) and costs of rice threshing. Labour costs were not included in the production costs.

The potential profit is defined as the profit a farmer can achieve by selling his products directly at the Hanoi Long Bien wholesale market, about 30 km from the experimental site. The product prices at the wholesale market are generally considerably higher than those at the local market or the prices paid by middle men. As product prices were not always available at the Long Bien market, the available data of Long Bien market prices (after subtraction of 300 VND/kg of product for costs of transport), y, and local prices, x, were used to establish a prediction equation of Long Bien market prices. The variance of Long Bien market prices increased with rising price levels, and was assumed to be inversely normally distributed:

$$y = 1.31x + 1771 \ (n = 28; \% \text{ variance accounted for} = 64, P<0.05).$$

Rice is only sold in cities after processing and no correction was made for potential profit.

Labour requirement was calculated from labour recorded for all activities of crop management and expressed in days per hectare per growing day in the field (day/ha/Gday). From May to September 2007, the labour was recorded based on labour spent on individual crops in the four replications together. From October 2007 to May 2009, the labour was recorded based on individual plots. Soil tillage by buffalo traction and rice threshing were not included in labour.

Farmers' income per day of labour is based on 8 hours labour per day (Lday) (kVND/Lday).

Variables for evaluation of pesticide use of each crop were the costs of pesticides use (kVND/ha/Gday) and active ingredient (ai) in gram per ha per growing day in the field (g/ha/Gday) or in gram per kg of product (g/kg). Yield of sweet corn and kohlrabi was measured as the number of cobs and tubers, respectively. These two crops were excluded when calculating active ingredients per kg of product.

The results for vegetable production systems were calculated as averaged over the period from the day of planting of the first crop to the last day of harvesting of the last crop. The second spinach crops in the Pesticide and Biodiversity systems and the second water melon crop in the Perishability system failed due to flooding of the experimental field. The data of these crops were excluded from the calculations because of the exceptionality of floods in this region.

Statistical analysis of differences between systems was performed by analysis of variance using Genstat 12 (Payne *et al*., 2009). As all four plots of one treatment received the same amount of pesticides, statistical analysis of differences in pesticide use among systems was not possible.

Correlation between model values (Table 3), crop data (Huong *et al*., 2013b) and field experiment values was established by linear regression through the origin of model values or crop data on values of the field experiment. r^2 was calculated as the corrected sum of squares of the dependent variable (*SSy*) minus the sum of squares of residuals (*SSe*) over the corrected sum of squares of the dependent variable (*SSy*):

$$r^2 = (SSy - SSe)/SSy.$$

3. Results

3.1. Performance of the crops in the six systems

3.1.1. Profitability system

In general the products of the Profitability system belonged to Class 1 (Table 4). There were large variations in profit, labour requirement, costs of pesticide use and amounts of insecticides and fungicides used.

The profit of the first Welsh onion crop, planted in May 2007, was negative due to a low product price. The profit of snow pea was low because of a low yield due to diseases. The profits of the second Welsh onion crop and green choy sum were the highest as a result of very high product prices. Chinese kale and Welsh onion had high labour requirements because much labour had to be spent on weed control. In addition Welsh onion required extra labour for harvesting and cleaning the product. Green choy sum was planted instead of water melon, because the growth period left for water melon after the Welsh onion crop was too short. Chinese kale had to be treated with a high amount of insecticides, whereas the second Welsh onion crop and snow pea had to be treated with high amounts of fungicides.

3.1.2. Labour system

Sweet corn and wax gourd yielded extreme values of profits in the Labour system (Table 5). Sweet corn with a low yield of Class 1 and a low price, yielded a negative profit, while wax gourd yielded a very high profit because of a good product price.

Sweet corn, onion and wax gourd were treated with considerably more insecticides and/or fungicides than the other crops in the system.

In January - February 2008, the temperature was too low for the production of tomato seedlings. While waiting for seedlings, the crop interval between onion and tomato increased

Table 4. Performance of the crops in the Profitability system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)	Yield Class 2 (Mg/ha)	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Welsh onion (01-05-07)	48	9.2	0.0	-51.5	17.1	6.6	0.0	34.0
Chinese kale (28-06-07)	45	6.9	2.3	150.9	15.1	76.6	66.8	35.9
Amaranth (21-08-07)	19	5.5	0.0	572.9	10.7	0.0	0.0	0.0
Water melon (15-09-07)	73	10.6	3.9	160.4	6.6	32.9	1.3	35.8
Chinese kale (04-12-07)	47	15.2	2.1	482.7	8.0	40.3	3.4	0.0
Spinach (21-01-08)	47	26.2	0.0	293.2	8.0	18.8	0.0	14.0
Tomato (15-03-08)	93	18.4	0.0	132.1	7.6	32.2	3.2	31.9
Chinese kale (03-07-08)	43	7.8	0.0	516.3	17.9	38.2	2.0	26.3
Welsh onion (28-08-08)	51	8.9	0.0	1202.6	19.7	18.8	0.0	91.4
Green choy sum (20-10-08)	40	5.8	0.0	1279.6	7.8	15.9	0.2	3.4
Snow pea (08-12-08)	115	1.4	0.2	41.7	8.6	44.3	4.8	75.1
Chinese kale (08-04-09)	37	13.7	0.0	654.6	12.8	54.7	33.9	0.0

Table 5. Performance of the crops in the Labour system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)[2]	Yield Class 2 (Mg/ha)[2]	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Sweet corn (01-05-07)	65	15.5	19.6	-206.4	8.1	63.8	267.1	74.8
Kohlrabi (16-07-07)	53	34.0	19.0	117.5	8.9	51.1	7.6	53.4
Onion (22-09-07)	115	31.7	3.7	303.6	7.8	39.7	5.9	103.7
Tomato (11-03-08)	97	23.4	0.0	142.9	8.0	30.7	6.1	30.6
Wax gourd (07-07-08)[1]	65	17.1	16.3	1764.3	14.1	112.7	4.4	161.9
Kohlrabi (19-09-08)[2]	49	26.7	10.0	509.5	8.5	81.3	1.3	47.5
Garland chrysanthe. (15-11-08)	39	21.4	0.0	49.3	7.6	0.0	0.0	0.0
Tomato (03-01-09)	123	30.7	2.8	170.9	4.0	23.0	2.0	88.8

[1] Yield Class 3 Wax gourd: 3.8 Mg/ha. [2] Sweet corn 1000 cob/ha; Kohlrabi 1000 tuber/ha.

from 5 days to 56 days. This delayed the planting time of the following crops. Garland chrysanthemum was planted in November instead of sweet corn in September.

3.1.3. Pesticide system

Spinach yielded only low or negative profits in the Pesticide system (Table 6). The first spinach crop had a low yield, while the second crop failed completely due to the flooding in October-November 2008. The spinach re-sown thereafter yielded a negative profit because of a low product price.

Despite the intention of low costs of pesticide use in this system, costs of pesticide use were relatively high. Only tossa jute in this system did not require pesticides at all. Spinach required no pesticides in the survey data (Huong *et al*., 2013b), but it had to be treated with pesticides in the field experiment. Welsh onion required high amounts of fungicides.

Welsh onion planted in January 2008 required the lowest amount of labour in comparison with Welsh onion crops planted in other periods. Because of the cold weather in January and February 2008, no weed control was necessary in this otherwise labour intensive crop.

3.1.4. Biodiversity system

Following the outcome of the modelling based on the preliminary database, tossa jute was sown in June, be it that the preferred sowing period in practice is February-March. Because of the end of the preferred consumption season, the final harvest of the tossa jute was in September, leaving a growth duration in the field of only 95 days (Table 7) instead of the 167 days as designed originally. The following crops, garland chrysanthemum, tomato, Welsh onion, amaranth and water melon, were then planted earlier than scheduled. After an extra waiting time of 15 days, spinach was sown but the weather was still not suitable. The crop failed and was re-sown. Due to the flooding the re-sown spinach crop also failed. The third attempted spinach crop yielded a negative profit due to the combination of a low yield and a low product price. Snow pea also yielded a negative profit, because of yield loss due to diseases.

The largest amount of insecticides was used in Chinese kale, partly due to application errors. Tomato and water melon were treated with high amounts of fungicides.

Table 6. Performance of the crops in the Pesticide system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)	Yield Class 2 (Mg/ha)	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Amaranth (02-05-07)	27	10.3	0.0	215.0	11.3	14.8	0.1	0.0
Chinese kale (15-06-07)	43	7.9	1.1	650.2	15.1	64.9	36.6	74.1
Welsh onion (02-08-07)	43	12.0	0.0	185.8	12.7	43.1	0.0	65.2
Water melon (20-09-07)	81	11.6	3.9	195.1	5.7	41.1	1.5	65.6
Green pakchoi (15-12-07)	32	18.7	0.0	587.7	8.3	59.8	17.3	0.0
Welsh onion (18-01-08)	61	19.9	0.0	311.3	7.8	23.5	0.0	161.7
Spinach (23-03-08)	31	3.8	0.0	70.1	12.3	28.3	0.6	9.0
Radish (03-05-08)	26	22.2	0.0	294.4	10.0	47.1	17.2	3.1
Welsh onion (05-06-08)	48	6.8	0.0	507.0	16.2	57.0	5.0	55.8
Tossa jute (27-07-08)	75	21.9	0.0	371.2	7.8	0.0	0.0	0.0
Spinach (16-10-08)[1]	21	0.0	0.0	-528.0	9.1	1.9	0.0	1.1
Spinach (22-11-08)	45	7.3	2.0	-95.1	7.7	17.3	0.0	5.7
Welsh onion (10-01-09)	68	6.0	0.0	131.3	14.4	32.0	5.0	119.6
Green choy sum (22-03-09)	31	12.2	0.0	268.4	12.4	66.7	19.6	4.8
Amaranth (24-04-09)	33	1.8	0.0	299.2	10.4	4.8	6.1	0.0

[1]Failed due to flood

Table 7. Performance of the crops in the Biodiversity system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)	Yield Class 2 (Mg/ha)	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Chinese kale (01-05-07)	33	7.7	0.0	139.2	21.4	51.9	131.9	48.9
Tossa jute (08-06-07)	95	31.5	0.0	409.4	7.0	2.7	7.6	0.0
Garland chrysanthe. (17-09-07)	39	5.3	0.0	456.7	9.3	0.0	0.0	0.0
Tomato (12-11-07)	125	57.3	0.0	32.1	5.5	40.2	15.9	145.0
Welsh onion (22-03-08)	48	14.5	0.0	353.2	18.2	43.2	1.1	43.6
Amaranth (14-05-08)	27	7.6	0.0	145.4	8.7	17.7	28.0	0.0
Water melon (24-06-08)	57	13.7	2.4	160.6	8.2	56.2	5.1	128.4
Spinach (10-09-08)	21	0.0	0.0	-498.6	11.4	2.8	0.0	1.7
Spinach (08-10-08)[1]	29	0.0	0.0	-287.9	5.8	1.4	0.0	0.8
Spinach (22-11-08)	46	6.1	2.2	-112.7	9.5	16.9	0.0	5.6
Snow pea (09-01-09)	109	0.7	0.3	-51.2	8.2	38.0	9.5	14.3

[1]Failed due to flood

3.1.5. Perishability system

Leek, water melon and one tomato crop in the Perishability system yielded negative or low profits (Table 8). Due to diseases leek failed twice to reach a good yield level. Water melon failed completely because of the flood. The tomato crop planted in November 2007 yielded a low profit because of low prices.

Leek, kohlrabi and tomato had to be treated with high amounts of fungicides, whereas wrapped heart mustard needed a high amount of insecticides. In 2008 leek was treated with rather expensive fungicides, so that the costs of pesticide use were high.

3.1.6. Traditional system

Three crops of rice in the Traditional system yielded a low profit (Table 9). The rice planted in March 2008 yielded a higher profit because of a high price. All rice crops had a low labour requirement and three of the four crops had low costs of pesticide use. Although the total duration for vegetables grown in this system was shorter than that for rice, vegetables yielded two thirds of the profit of this system. Shallot was planted instead of Welsh onion, because after the flood seedlings of the Welsh onion variety for the cool season were not available. The price for shallot was low, however, resulting in a negative profit.

3.2. Comparison of the six systems

Profits significantly varied among the six systems (Table 10). The Profitability system had the highest profit. At local prices only the Profitability and Labour systems had higher profits than the Traditional system. The profit of the Perishability system was considerably lower than that of the Traditional system, mainly caused by crop failure (leek) and crop loss (water melon) because of the flood. At potential prices, however, all systems except the Perishability system, yielded a higher profit than the Traditional system.

As compared to the Traditional system, the total labour requirement increased with all permanent vegetable production systems. Labour day income with local product prices, however, did only slightly increase in the case of the Labour system and decreased significantly with the Biodiversity and Perishability systems. Potential labour day income increased considerably with the low labour requirement system and for the other systems was

Table 8. Performance of the crops in the Perishability system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)	Yield Class 2 (Mg/ha)	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Wrapped heart mustard (02-05-07)	47	12.4	0.0	148.8	10.5	29.5	237.4	0.0
Leek (26-06-07)	64	0.7	3.0	-343.1	8.8	48.0	0.0	61.1
Water melon (31-08-07)	59	7.8	4.0	98.6	7.6	45.0	2.2	25.5
Tomato (10-11-07)	127	56.0	0.0	27.2	5.2	39.5	15.7	142.7
Celery (21-03-08)	46	14.2	0.0	554.1	11.8	19.5	1.0	11.9
Leek (12-05-08)	76	2.3	0.0	-69.5	12.0	102.8	0.0	42.6
Kohlrabi (08-08-08)	59	9.6	38.4	135.7	9.2	56.2	1.7	67.0
Water melon (18-10-08)[1]	19	0.0	0.0	-519.0	4.8	0.0	0.0	0.0
Tomato (15-11-08)	146	25.5	11.8	216.6	4.3	19.6	0.2	90.4
Radish (10-04-09)	33	11.8	0.0	363.4	11.7	29.9	9.0	0.0

[1]Failed due to flood

Table 9. Performance of the crops in the Traditional system (2007-2009; kVND = thousand Vietnamese Dong; Gday = growing day).

Crop (planting date: day-month-year)	Growth duration (days)	Yield Class 1 (Mg/ha)	Yield Class 2 (Mg/ha)	Profit (kVND/ha/Gday)	Labour (day/ha/Gday)	Costs of pesticide use (kVND/ha/Gday)	Insecticide (ai) (g/ha/Gday)	Fungicide (ai) (g/ha/Gday)
Rice (25-06-07)	90	5.1	0.0	51.5	3.2	2.2	0.0	0.0
Chinese kale (01-10-07)	39	21.5	0.0	1629.7	11.2	48.5	4.5	0.0
Welsh onion (27-11-07)	52	10.1	0.0	102.4	12.4	18.4	0.0	52.1
Spinach (19-01-08)	46	23.8	0.0	230.6	9.3	19.2	0.0	14.3
Rice (12-03-08)	99	6.7	0.0	241.5	2.1	18.3	14.6	4.0
Rice (02-07-08)	84	5.0	0.0	87.4	2.5	7.1	18.1	0.0
Chinese kale (06-10-08)	44	2.3	1.1	245.2	12.5	74.5	0.1	25.8
Shallot (27-11-08)[1]	54	10.8	2.2	-215.9	10.8	7.7	0.0	64.9
Rice (16-02-09)	105	5.4	0.0	39.9	1.6	2.3	2.3	0.0

[1](clove+leaves; *Allium cepa* var. *ascalonicum*)

Table 10. Effect of the different vegetable production systems on profit at local prices, potential profit at city wholesale market prices, labour requirement, labour day (Lday = 8h/day) income at local prices and potential labour day income at city whole-sale market prices (kVND = thousand Vietnamese Dong).

System	Profit (kVND/ha/day)	Potential profit (kVND/ha/day)	Labour requirement (day/ha/day)	Labour day income (kVND/Lday)	Potential labour day income (kVND/Lday)
Profitability	321[e]	797[c]	9.7[f]	33[bc]	83[a]
Labour	277[de]	877[c]	6.5[b]	42[c]	135[b]
Pesticide	238[cd]	763[c]	8.9[e]	27[b]	85[a]
Biodiversity	102[ab]	545[b]	7.6[d]	13[a]	71[a]
Perishability	89[a]	504[ab]	7.0[c]	13[a]	72[a]
Traditional	168[bc]	406[a]	5.0[a]	34[bc]	82[a]
LSD (P=0.05)	71	132	0.3	10	18
Significance	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001

Means with common letter are not significantly different at $P \leq 0.05$

equal to the traditional system.

The costs of pesticide use of each permanent vegetable production system were higher than those of the Traditional system (Table 11), which was due to the nature of the crops grown. In general vegetable crops are more susceptible to pests and diseases than rice. The costs of pesticide use of the Labour system were the highest since the highest amounts of insecticides and fungicides were applied. Also the Perishability system had high costs of pesticide use.

Insecticide use per kilogram of product in the permanent vegetable production systems compared mostly favourably to the Traditional system (Table 11). Fungicide use per kilogram of product in all permanent vegetable production systems was higher as compared to the Traditional system (Table 11).

3.3. Performance of the PermVeg model

There was reasonable agreement between the model data for crop systems labour requirements and the data obtained in the field experiment (Figure 2). The same applied to the length of the crop sequences. The model data on profit and cost of pesticide use of crop systems correlated poorly with those from the field experiment (r^2 could not be calculated because $SSy<SSe$ and r^2=0.20, respectively).

Table 11. Effect of the different vegetable production systems on costs of pesticide use and use of insecticides and fungicides (ai = active ingredient; kVND = thousand Vietnamese Dong).

System	Costs of pesticide use	Insecticide (ai)		Fungicide (ai)	
	(kVND/ha/day)	(g/ha/day)	(g/kg product)	(g/ha/day)	(g/kg product)
Profitability	30	7.3	0.04	32.3	0.17
Labour	39	26.7	0.01	63.0	0.24
Pesticide	29	5.4	0.02	43.3	0.19
Biodiversity	24	12.6	0.06	42.6	0.21
Perishability	38	18.5	0.09	60.0	0.27
Traditional	15	4.8	0.04	11.9	0.09

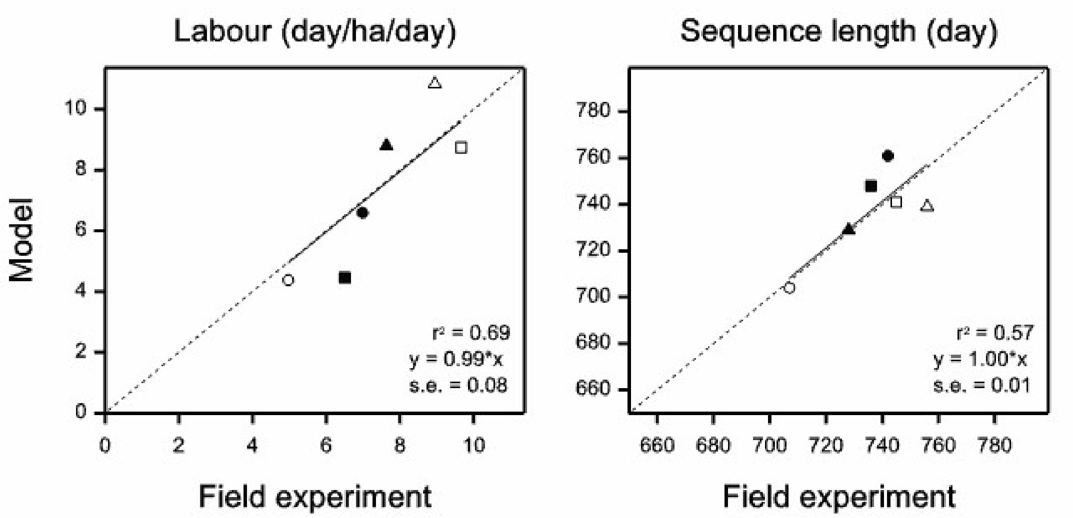


Figure 2. Regression through the origin of the model outcome data on the data of the field experiment at system level (**Profitability** (□), **Labour** (■), **Pesticide** (Δ), **Perishability** (●), **Biodiversity** (▲) and **Traditional** (○)).

Correlation between data on crop labour requirement from the database and from the field experiment was not particularly strong, but data on crop growth duration correlated quite well, except for one outlier (Figure 3). The outlier concerned tossa jute, as explained under Biodiversity.

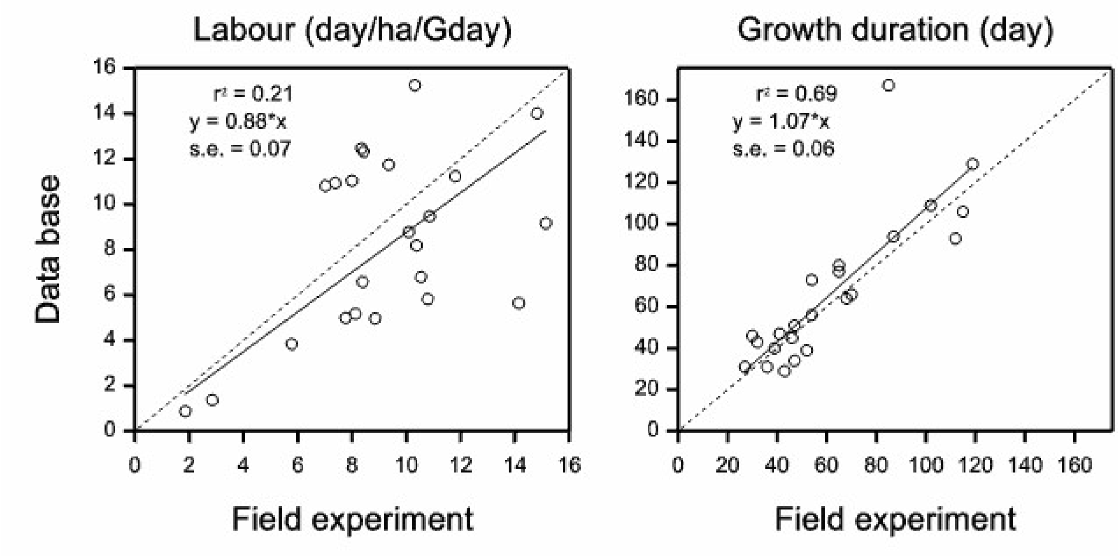


Figure 3. Regression through the origin of the database data on labour requirement and crop growth duration on the data of the field experiment at crop level.

4. Discussion

4.1. Systems

4.1.1. Profitability system

The objective of reaching a high profitability in vegetable production was indeed achieved in the permanent vegetable production system Profitability. The profit of the Profitability system at local prices was 1.9 times higher than that of the Traditional system. This result is consistent with Lu *et al*. (2010), who found that the profit of a permanent vegetable production system was 1.8 times higher than that of a vegetable-rice system. When products would be directly sold at city wholesale market prices, the profitability would be even higher.

4.1.2. Labour system

In line with the model predictions the labour system had the lowest labour requirement of the permanent vegetable production systems tested and it was slightly higher than in the traditional system. Since high profits were obtained in the labour system, the labour-day income was the highest of all systems studied, including the traditional system. The labour system is thus an attractive option for vegetable production when few labour is available.

4.1.3. Pesticide system

Among the permanent vegetable production systems, the costs of pesticide use in the Pesticide system were not conclusively low. Although a crop sequence with the lowest cost of pesticide use was selected from the data base, it is the actual need for control of pests and diseases and the price of the pesticides used, that determine the costs of pesticide use. In this case, especially the comparatively high use of fungicides contributed to the costs of pesticide use. Apparently it is difficult to select for low costs of pesticide use based on historical records.

4.1.4. Biodiversity system

The aim of the Biodiversity system was to increase crop biodiversity by allowing only one crop of a botanical family in the two-year sequence, with the underlying aim to prevent build-up of pest and disease incidence in subsequent crops. Amongst others due to crop failures, the system did not perform well in terms of profitability, although potential profitability was higher. No clear effect was found of the Biodiversity system on insecticide or fungicide use. To clearly identify and confirm an effect, long term testing of this system may be required.

4.1.5. Perishability system

When evaluated in terms of profitability the Perishability system scored negatively, or neutral, in comparison with the Traditional system. The costs of pesticide use were high with this system. Based on the present results it is difficult to recommend the Perishability system for crop production in rural areas.

4.1.6. Traditional system

The Traditional system acted as reference for the permanent vegetable production systems. Its profitability can likely be considerably increased by direct marketing at a city wholesale market.

4.2. PermVeg model performance

The PermVeg model data correlated reasonably well with the field experiment data for labour requirement and sequence length of the crop systems. Especially crop growth durations as measured in the field experiment correlated well with the data of the PermVeg data base. This confirms that the model is a useful tool to design crop sequences.

The data of the PermVeg model for profit did not relate well to those of the field experiment. Profit is subject to product price variability, both within and between years, influencing profitability. In addition, the model aims at a maximum presence of crops in the field, assuming only five day intervals between crops. The model assumes also that all crops will be productive. In the field experiment the profitability was lower because intervals between crops often exceeded five days and some crops failed completely.

The model also did not correlate well for costs of pesticide use. Types and prices of pesticides in the data base, as provided by RRD farmers, may have differed from those used in the field experiment. There are many different types of pesticides, with varying prices, used in the RRD. About 150 new types of pesticides were registered each year during the period of 2001-2007 (Hoi *et al*., 2009).

4.3. Profitability of individual crops

The results in Tables 4 – 9 show considerable variation in the profitability of individual crops. As many crops were grown only once or twice in the experiment, no analysis of factors determining profits for these crops could be made. For crops that were grown five to eight times, regression analysis of profit on yield, local price, production costs or costs of pesticides, showed that the profitability of individual crops was dependent on different factors. For spinach no significant relations were found. For Chinese kale profitability was significantly positively related to yield level ($P<0.05$). Profit of Welsh onion was significantly related to local price ($P<0.01$). Profit of tomato was positively influenced by local price ($P<0.05$) and negatively influenced by costs of pesticide use ($P<0.01$). It appears that for individual crops yield level, product price, costs of pesticide use, or a combination of these factors, may have a significant effect on profitability, illustrating the variability in vegetable production and marketing performance.

4.4. Labour

All permanent vegetable production systems required more labour than the Traditional system. This finding is in line with that of Lu *et al*. (2010), who found that a permanent vegetable production system required 1.47 times more labour than a vegetable-rice rotation system. As such, permanent vegetable production systems increase employment opportunities in rural and peri-urban areas.

Although labour requirement in permanent vegetable production systems was higher, labour day income did not necessarily increase and in case of low profitability, it even decreased. Nevertheless, potential labour-day income of all permanent vegetable production systems was at least equal to that of the Traditional system. With equal labour day incomes between systems, all extra labour, when supplied from the household itself, helps to increase household income. In case labour has to be hired, household income will only increase when day wages paid are lower than the labour day income derived from permanent vegetable production systems. In the present research only the Labour system increased potential labour day income, confirming the defined low labour requirement scenario of this system.

4.5. Pesticide use

Permanent vegetable production systems had higher costs of pesticide use than the Traditional system. This result is again consistent with those of Lu *et al*. (2010), who found that costs of pesticide use of a permanent vegetable production system were 2.5 times higher than those of a vegetable-rice rotation system. Vegetable crops require more pesticides than rice (Huang *et al*., 2003). For the Red River Delta, Linh (2001) found that costs of pesticide use of vegetable crops in the cool season (about 4 months), were 8-10 times higher than those for rice in the remaining time of the year. In addition, in the tropics crops can be grown year-round and pests and diseases can flourish year-round as well (Ewel, 1986).

Since vegetables are necessary for a healthy and balanced diet, since vegetable production improves farmers' income (Dinham, 2003) and since there is an increasing demand for vegetables by the growing populations of the big cities, year-round vegetable production is likely to become essential for the RRD. More research should therefore be initiated with the aim to reduce undesirable effects of pesticide use on the environment and human health.

Practical methods to reduce pesticide use are using disease-resistant vegetable varieties and rotating host species with species that are not hosts to common diseases, using film-coated seeds for seedling insect control, using biological pesticides (Finch and Collier, 2000), good water management to reduce soil borne disease incidence and balanced nutrition for vegetable crops.

Under the humid tropical environment, the use of plastic shelters (Arya *et al*., 2001; Ha, 2008) can be an option to reduce crop disease infection, especially in the heavy rainfall season.

4.6. Risks in crop production and marketing

At local prices profits of some permanent vegetable production systems did not significantly differ from that of the Traditional system or were even lower than that of the Traditional system. This was mainly because in these systems crops failed due to adverse weather conditions or diseases, i.e. production risks. Sometimes low prices, a marketing risk, played a role.

Due to the sensitive nature of the vegetable crops, both physically and in terms of pest and disease susceptibility, production risks in vegetable cultivation have frequently been emphasised (Ali, 2008; Francisco and Ali, 2006; Midmore and Jansen, 2003). The risks with production in the field may be higher during the off-season than during the main production season, whereas marketing risks, i.e. low prices, often occur during the peak supply season (An *et al*., 2003; Ali, 2008).

4.7. Marketing

A considerable difference was found between profit with selling locally and potential profit with selling at a city wholesale market. The method of selling the product, therefore, plays an important role for the income of vegetable growers. However, the small landholdings of farmers (Huong *et al*., 2013a), resulting in small product volumes, represent a problem in marketing their products. One option to improve the marketing of vegetable products for small farmers, is for farmers to work together in cooperatives to improve the efficiency of marketing (Moustier *et al*., 2006). In addition, marketing through direct contracts between growers and traders (Moustier *et al*., 2006), instead of relying on contacts with local middle men, can help growers to better plan production and harvest, in order to secure higher and more stable prices.

5. Conclusion

The model scenarios of high profitability and low labour requirements were confirmed by the results of the field experiment. Both systems of permanent vegetable production can improve farmers' income in the RRD, generate employment for rural and peri-urban areas and contribute to year-round regional supply of vegetables for the growing urban population of the RRD. However, family household income will mostly only improve if the additional labour required can be supplied by the family household itself or can be hired at day wages lower than the labour day income derived from permanent vegetable production. Realising a higher product price by developing new marketing systems, is important to increase the profitability of vegetable production.

Pesticide use increases with permanent vegetable production systems. Research on effective pest and disease control is required to reduce pesticide use and to decrease the risk of pesticide residues for farmers, the environment and consumers.

The PermVeg model can be used to design crop sequences and estimate labour requirements for permanent vegetable production systems.

Acknowledgements

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Chapter 6

Vegetable production after flooded rice improves soil properties in the Red River Delta, Vietnam

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Sumitted to Pedosphere

Abstract

Vegetable production in South East Asia often is in rotation with flooded rice. The puddling of the soil with flooded rice production may result in unfavourable soil conditions for the subsequent production of dry land crops. To establish whether permanent vegetable production results in better soil conditions for vegetables, the effects on soil properties after flooded rice of five different permanent vegetable production systems, and of a system of vegetable production in rotation with flooded rice, were studied in a two-year long field experiment.

Bulk density at 0.05 – 0.10 m decreased significantly with permanent vegetable production as well as with vegetable production in rotation with flooded rice. The decrease in bulk density was related to the number of crops cultivated, suggesting that frequency of soil tillage had a major effect on bulk density. The data imply that buffalo assisted ploughing after flooded rice production, in combination with construction of raised beds, may reduce or totally eliminate negative effects of puddling on soil structure. Bulk density at 0.15 – 0.20 m was not or hardly influenced.

Soil acidity decreased in all systems. The decrease was proportional to the amount of lime applied. Organic carbon content positively related to the amount of dry manure applied. The increase in available phosphorus and total phosphorus positively correlated with the amount of phosphorus applied.

The significant decrease in bulk density and acidity and the increase in organic carbon and phosphorus content, after only two years, show that soil conditions after flooded rice can improve in a rather short time under intensive vegetable production.

Key words: Bulk density, soil fertility, soil improvement, vegetable production, Red River Delta, Vietnam

1. Introduction

Population growth, improved living standards and urbanisation in South East Asia increase the demand for vegetables (Johnson *et al*., 2009). Consequently, farmers enlarge, or intensify, their production of vegetables. Often vegetables are produced in a rotation with flooded rice. The rice crop traditionally being grown to assure the availability of staple food for the household.

Questions have been raised about the suitability of the soil for the production of vegetable crops after flooded rice cultivation (So and Ringrose-Voase, 2000; Everaarts *et al*., 2006). The breakdown of soil structure during wet land preparation, puddling, may result in soil physical constraints and a limited water holding capacity for the succeeding dry land crop (So and Ringrose-Voase, 2000; Kukal and Aggarwal, 2003a). Puddling may also result in a compacted layer below the puddling zone, affecting rooting (Kukal and Aggarwal, 2003b).

It is known that long term vegetable production, and vegetable production systems, can influence soil chemical and soil physical properties (Wells *et al*., 2000; Cao *et al*. 2004; Shao-Wen Huang *et al*., 2006), but little is known concerning the effect of vegetable production on soil properties immediately after flooded rice cultivation.

The increased demand for vegetables in the Red River Delta (RRD), Vietnam (Huong *et al*., 2013) and the question whether soil conditions for vegetables would improve under permanent vegetable production, resulted in the setup of a field experiment in which permanent vegetable production was investigated as an alternative to the rotation of vegetables with flooded rice (Huong *et al*., 201X). On a location with a long-term history of vegetable production in rotation with flooded rice, vegetables were cultivated during two years in five different permanent vegetable production systems and in the traditional system in which vegetables are rotated with two flooded rice crops per year.

For soil conditions, special interest was in the question whether permanent vegetable production improves soil physical conditions as compared to vegetable production in rotation with flooded rice, where soil compaction may occur because of puddling.

In this paper we report the effect of vegetable production after flooded rice cultivation on soil physical and soil chemical properties.

2. Materials and methods

2.1. Location, climate and soil of the experimental site

The experiment was carried out from May 2007 to May 2009 at Son Du village, Nguyen Khe commune, Dong Anh district, Hanoi Province, Vietnam (21^o 10' N, 105^o 49' E) (Huong *et al.*, 201X). The experimental field had a history of vegetable cultivation in rotation with two consecutive flooded rice crops a year since at least 1989 (as based on local people's memory).

The local climate is a tropical monsoon climate. Average monthly temperatures during the experiment varied from 13 to 30 ^oC (Figure 1). Rainfall in the October 30 to November 5 period in 2008 was exceptionally high, causing flooding of the experimental field.

The soil at the experimental site is a sandy loam soil (Haplic Acrisol, FAO-UNESCO classification), with 49% sand, 42% loam and 9% clay (Huong *et al.*, 201X). Two profile pits (1.2 m deep) dug at the experimental field at the end of the experiment showed a compacted layer between 0.18 and 0.25 m.

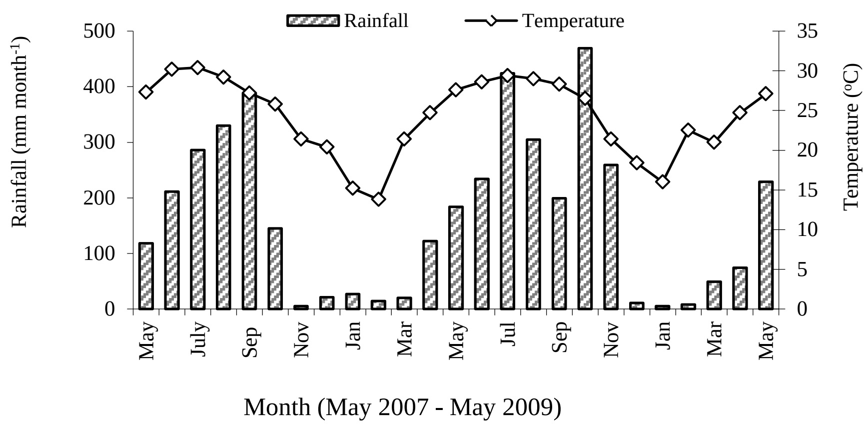

Figure 1. Monthly total rainfall and mean temperature in Hanoi (Lang Ha Meteo Station), May 2007 - May 2009.

2.2. Experimental design, crops, fertiliser application and soil tillage

The experiment was set up as a randomised complete block design with four replications. Plot size was 8.0 x 9.0 m^2, comprising six raised beds (8.0 x 1.1 m^2, 0.2 m high), with 0.4 m wide furrows in between.

The six treatments were the production of vegetables in five different, two-year long permanent vegetable production systems and in one system in which the production of vegetable crops was rotated with two flooded rice crops per year (Table 1). The permanent vegetable production systems tested were designed according to five scenarios (Huong *et al*., 201X). They had the following characteristics:

(i) **Profitability**: the crop sequence aiming for the highest net profit;

(ii) **Labour**: the crop sequence aiming for the lowest labour requirement;

(iii) **Pesticide**: the crop sequence aiming for the lowest cost of pesticide use;

(iv) **Biodiversity**: crops of one botanical family grown only once in a two-year crop sequence;

(v) **Perishability**: only crops with products of low perishability (at least four days allowed between harvest and selling);

(vi) **Traditional**: vegetables in rotation with two crops of flooded rice per year (common local practice).

Table 1. Crops and crop sequences of the permanent vegetable production systems and of the traditional system tested in the field experiment (Huong *et al.*, 201X).

Profitability: Welsh onion (*Allium fistulosum*) – Chinese kale (*Brassica oleracea* var. *alboglabra*) – Amaranth (*Amaranthus tricolor*) – Water melon (*Citrullus lanatus*) – Chinese kale – Spinach (*Spinacia oleracea*) – Tomato (*Solanum lycopersicum*) – Chinese kale – Welsh onion – Green choy sum (*Brassica rapa* var. *parachinensis*) – Snow pea (*Pisum sativum*) – Chinese kale.
Labour: Sweet corn (*Zea mays* var. *rugosa*) – Kohlrabi (*Brassica oleracea* var. *gongylodes*) – Onion (*Allium cepa* var. *cepa*) – Tomato – Wax gourd (*Benincasa hispida*) – Kohlrabi – Garland chrysanthemum (*Chrysanthemum coronarium*) – Tomato.
Pesticide: Amaranth – Chinese kale – Welsh onion – Water melon – Green pakchoi (*Brassica rapa* ssp. *chinensis*) – Welsh onion – Spinach – Radish (*Raphanus sativus*) – Welsh onion – Tossa jute (*Corchorus olitorius*) – Spinach – Spinach – Welsh onion – Green choy sum – Amaranth.
Biodiversity: Chinese kale – Tossa jute – Garland chrysanthemum – Tomato – Welsh onion – Amaranth – Water melon – Spinach[1] – Spinach – Spinach – Snow pea.
Perishability: Wrapped heart mustard (*Brassica juncea* var. *rugosa*) – Leek (*Allium ampeloprasum* var. *porrum*) – Water melon – Tomato – Celery (*Apium graveolens*) – Leek - Kohlrabi – Water melon – Tomato – Radish.
Traditional: Rice (*Oryza sativa*) – Chinese kale – Welsh onion – Spinach – Rice – Rice – Chinese kale – Shallot (*Allium cepa* var. *ascalonicum*) – Rice.

[1]The first two crops of spinach in the Biodiversity system failed.

The total number of crops cultivated and the total amount of nutrients, organic manure, lime and rice husk applied differed among systems (Table 2). The different systems required the production of different crops, with different fertiliser recommendations, making the comparison between treatments a comparison between systems. Rice husk was applied as a mulch.

Table 2. Total number of crops cultivated and total amount of fertilisers, organic manure, lime and rice husk applied.

System	Crops	Fertiliser (kg/ha)			Organic manure	Lime	Rice husk
		N	P	K	(dry, Mg/ha)	(Mg/ha)	(Mg/ha)
Profitability	12	1242	354	374	38.9	4.8	30.6
Labour	8	878	354	434	45.4	3.2	13.9
Pesticide	15	1172	352	293	42.4	4.8	43.4
Biodiversity	11	899	310	286	38.2	4.3	25.1
Perishability	10	842	421	575	38.3	3.8	7.2
Traditional	9	752	247	625	36.9	4.8	22.3

At the establishment of the experimental field, the whole field was ploughed using buffalo traction. In the first three months of the experiment the beds in the permanent vegetable production systems were ploughed using buffalo traction before sowing or planting crops, followed by soil tillage with a hand held hoe. After that period soil tillage for crop sowing or planting was done by hand only, using a hoe.

In the Traditional system, the plots with rice were ploughed and puddled before planting, using buffalo traction. After harvest of the rice, the fields were ploughed using buffalo traction, followed by construction of the raised beds and tillage for sowing or planting by hand, using a hoe. For vegetables grown after vegetables in this system, soil tillage for sowing or planting was similar to that in the permanent vegetable production systems.

Depth of soil tillage with ploughing using buffalo traction was approximately 0.15 m. Depth of soil tillage with hand held hoe was 0.18 to 0.20 m.

2.3. Soil sampling and soil analysis

2.3.1. Physical soil fertility

Soil samples for bulk density analysis were taken with a standard 53 mm diameter ring at depths of 0.05 - 0.10 and 0.15 - 0.20 m below soil surface in the centre of each of five adjacent beds per plot. The first samples were taken at 23 May 2007, approximately three weeks after planting of the first crops, because of late arrival of equipment. Subsequent sampling in each system was shortly after the harvest of a crop at approximately 6, 12 and 18 months after planting of the first crop. The final sampling was after the harvest of the last crop in each system.

Soil samples were dried at 105 ^{o}C for 4 h, placed in a desiccator at room temperature and weighted with a precision of 0.0001 g. Drying continued until constant weight. Samples were analysed at the Soils and Fertiliser Institute, Hanoi. Many of the rings of the third sampling time were incompletely filled and/or contained high amounts of non-decomposed organic material. Therefore the data of this sampling were not taken into account.

2.3.2. Chemical soil fertility

For chemical analysis, on each plot seven soil core samples were taken at equal distance along the diagonal of each of the six beds of a plot to a depth of 0.2 m, resulting in 42 samples per plot. Samples per plot were mixed and one subsample per plot was taken, air-dried, sieved over 2 mm and analysed for pH-H_20 (10 g of air-dry soil shaken in 25 ml of distilled water for 10 min, after 30 min the solution was stirred again and pH-H_2O was measured by a pH meter), organic carbon (OC, %, Walkley-Black, Nelson and Sommers, 1996), nitrogen (Total N (Kjeldahl), %, Bremner, 1996), phosphorus (P-total, %, determined by a two acid decomposition, 1 g soil with 5 ml concentrated sulphuric acid incubation during 4-6 hours followed by an addition of 0.5 ml per concentrated chloric acid digestion at 200 °C; P-available, mg/100g, Bray-II, Kuo, 1996), potassium (K-total, %, K-available, mg/100g, Helmke and Sparks, 1996) and Cation Exchange Capacity (CEC, meq/100g, determined by 1M NH_4Ac, pH 7, followed by desorption of NH_4^+ by 1M KCl, Sumner and Miller, 1996). Samples were analysed at the Soils and Fertiliser Institute, Hanoi.

The first sampling was done for the whole experimental field at 30 April 2007, after field preparation, shortly before the planting of the first crops. Subsequent time of sampling was the same as for bulk density.

2.4. Statistical analysis

For each system, the trend in physical or chemical parameters was assessed with linear regression, with the parameter y as response variate and number of days after the first observation (day number) as predictor ($y = \alpha + \beta x$). Analysis of variance was done on the slope of the regression line, β, to establish significant difference from zero (i.e. no effect) and to establish differences between systems.

With data for each parameter pooled, linear regression analysis was done with the parameter y as response variate and, depending on the parameter, either day number, accumulated amount of organic manure applied, accumulated amount of lime applied, accumulated amount of rice husk applied or accumulated number of crops already cultivated, as predictor. Statistical analysis was done using GenStat 12 (Payne *et al.*, 2009).

Lime application started only in the second half of the first year of the experiment. pH-H_2O data of the second sampling (approximately 6 months after planting of the first crop) were therefore not taken into account in the regression analysis of pH-H_20 on amount of accumulated lime applied. Data for organic carbon in one system, Profitability, were erratic and were omitted from analysis.

3. Results

3.1. Bulk density

In all systems bulk density at 0.05 – 0.10 m significantly ($P \leq 0.01$) decreased with time (Figure 2, Table 3). The Labour, Pesticide and Biodiversity systems showed the greatest decrease. Average bulk density at 0.05 – 0.10 m for the whole field at the start of the experiment was 1.43 g/cm^3. The average bulk density of the soil layer 0.05 – 0.10 m for the permanent vegetable production systems at final sampling was 1.30 g/cm^3.

Table 3. Slope (β × 10,000) of the regression line of bulk density and pH-H_2O on number of days after the first observation.

System	Bulk density (0.05-0.10 m)	pH-H_2O
Profitability	-1.2 bc	5.2 b
Labour	-2.1 ab	1.9 a
Pesticide	-2.5 a	2.2 a
Biodiversity	-2.6 a	5.6 bc
Perishability	-1.3 bc	7.7 c
Traditional	-0.9 c	5.5 bc
LSD (*P*=0.05)	0.9	2.3
Significance	*P*=0.003	*P*<0.001

Means with common letter are not significantly different at $P \leq 0.05$

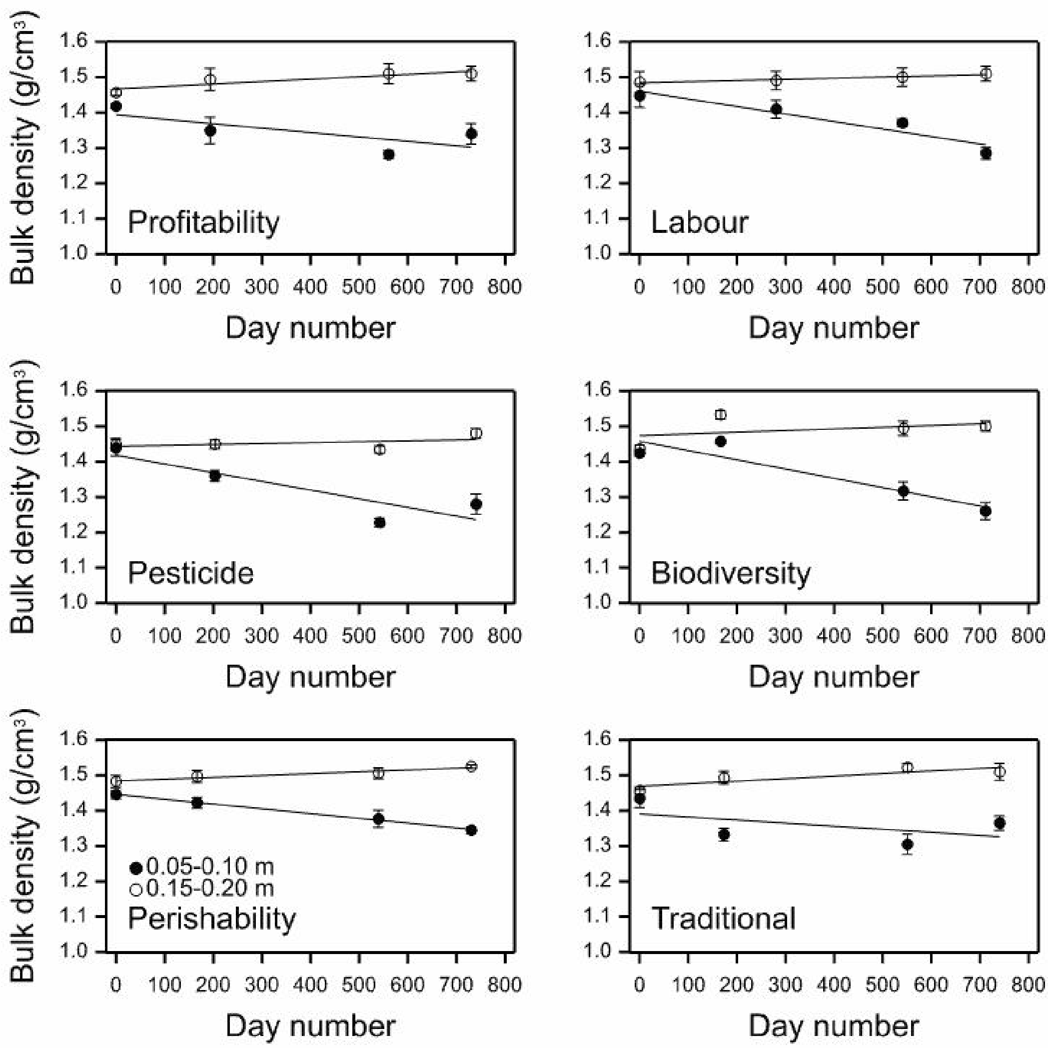

Figure 2. Change of bulk density with time in the six vegetable production systems (standard error sometimes within symbol).

The slope of the regression lines of the bulk densities at 0.15 - 0.20 m did not differ significantly among systems. Only the slopes of the regression lines of the bulk density of the Profitability and the Traditional systems in this layer significantly differed from zero (P=0.03 and P=0.02, respectively), indicating a small but significant increase of bulk density with time.

When data for bulk density of all systems were pooled, the best correlation for the 0.05 - 0.10 m layer was found with number of crops cultivated (r^2=0.68) (Figure 3). Similar correlations for the bulk density of the 0.15 - 0.20 m layer yielded only low correlations ($r^2 \leq$ 0.28).

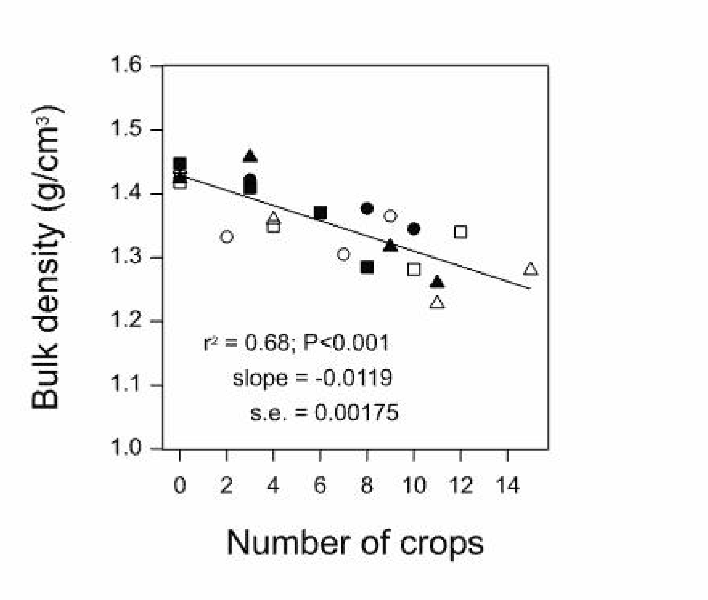

Figure 3. Bulk density in relation to the number of crops cultivated in the vegetable production systems Profitability (□), Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

3.2. pH-H_2O

The total amount of lime applied in the Traditional system was similar to that in the Profitability and Pesticide systems and higher than in the other systems (Table 2). In all systems pH-H_2O significantly ($P \leq 0.05$) increased with time (Figure 4). The increase in pH-H_2O was fastest with the Perishability system (Table 3). With all data for pH-H_2O pooled, the increase in pH-H_2O was significantly related to the amount of lime applied (Figure 5).

3.3. Organic carbon

The average soil organic carbon content at the start of the experiment was relatively low, 1.02 %. Soil organic carbon increased in all systems, but only significantly in the Labour (P=0.036) and Perishability (P<0.001) systems. For the five systems combined, soil organic carbon significantly increased with time (Figure 6). At the end of the experiment average soil organic carbon, as based on the five systems, amounted to 1.14 %. The increase in organic carbon was significantly related to the amount of dry manure applied (Figure 7).

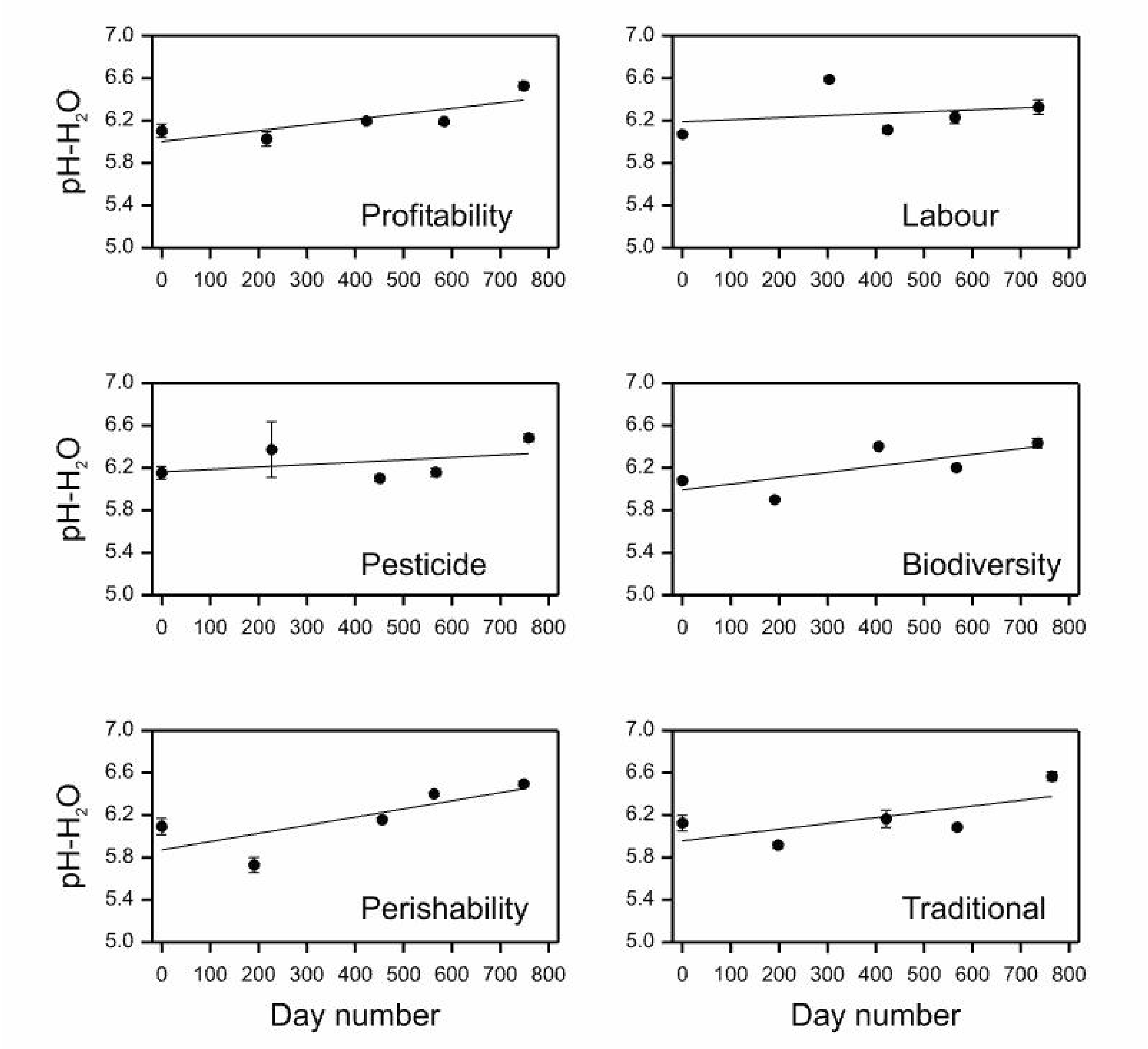

Figure 4. Increase in pH-H_2O with time in the six vegetable production systems (standard error sometimes within symbol).

3.4. Total nitrogen

Total nitrogen in the soil was not strongly influenced by the vegetable production systems (P=0.038). The slope of the regression lines of total nitrogen on time did not significantly differ from zero for the Labour, Pesticide, Perishability and Biodiversity systems. Total nitrogen decreased significantly in the Profitability (P=0.002) and in the Traditional system (P=0.001). Total nitrogen could not be related to the amount of nitrogen applied.

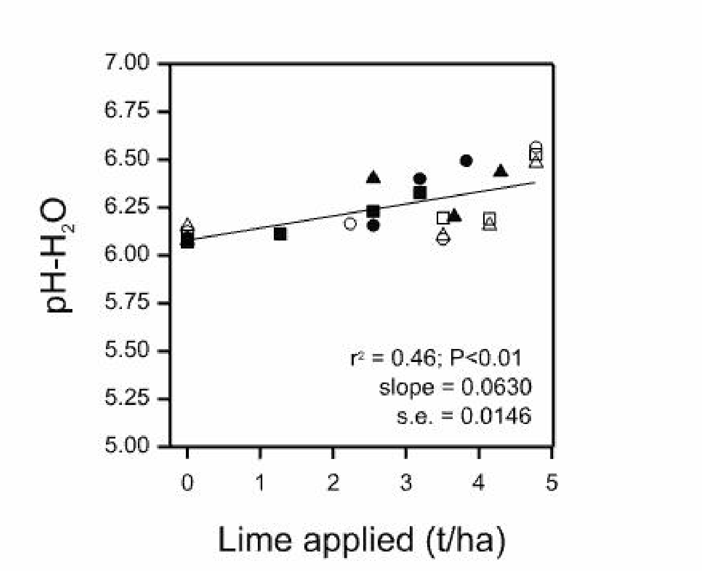

Figure 5. pH-H_2O in relation to the amount of lime applied in the vegetable production systems Profitability (□), Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

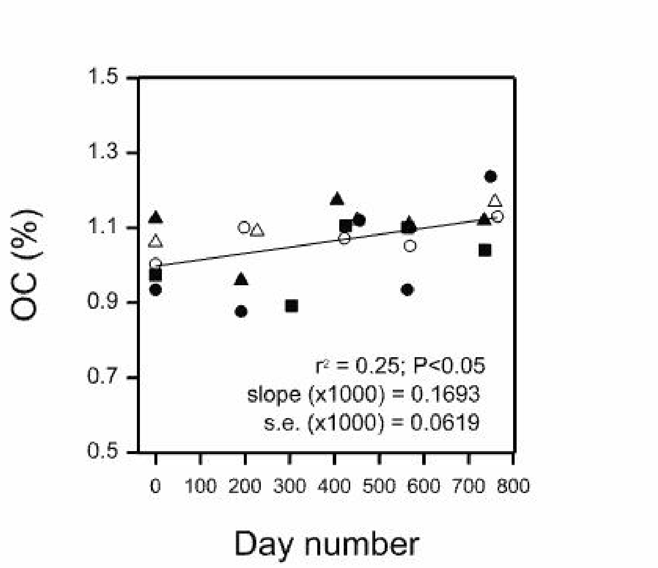

Figure 6. Increase in organic carbon with time in the vegetable production systems Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

3.5. Total phosphorus

No difference was found between the slopes of the regression lines of the different vegetable production systems for total phosphorus. Total phosphorus increased significantly ($P \leq 0.05$) in all systems, but the Profitability system. With data for all systems pooled, total phosphorus significantly increased with time (Figure 8) and was related to the amount of phosphorus applied (Figure 9).

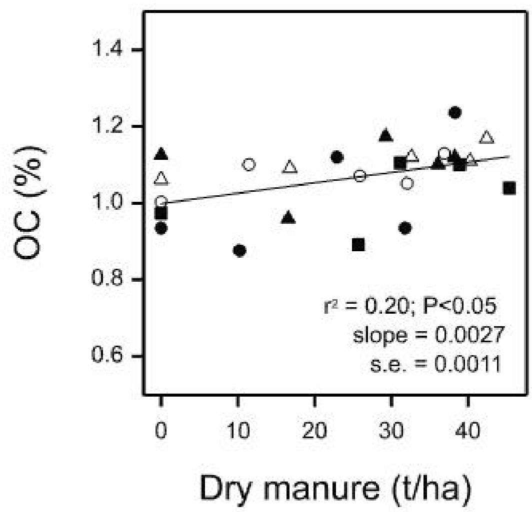

Figure 7. Organic carbon in relation to the amount of dry manure applied in the vegetable production systems Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

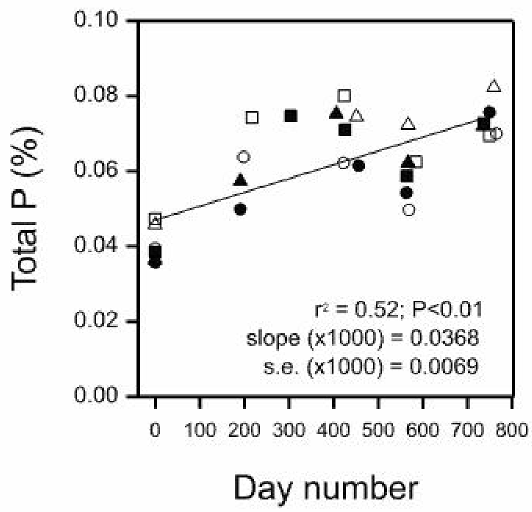

Figure 8. Increase in total phosphorus with time in the vegetable production systems Profitability (□), Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

3.6. Available phosphorus

The slopes of the regression lines for available phosphorus did not significantly differ among the vegetable production systems. Available phosphorus significantly increased in the Labour (P=0.03) and Perishability systems (P=0.02), but not in the other ones. Available phosphorus was significantly related to the amount of phosphorus applied (Figure 10).

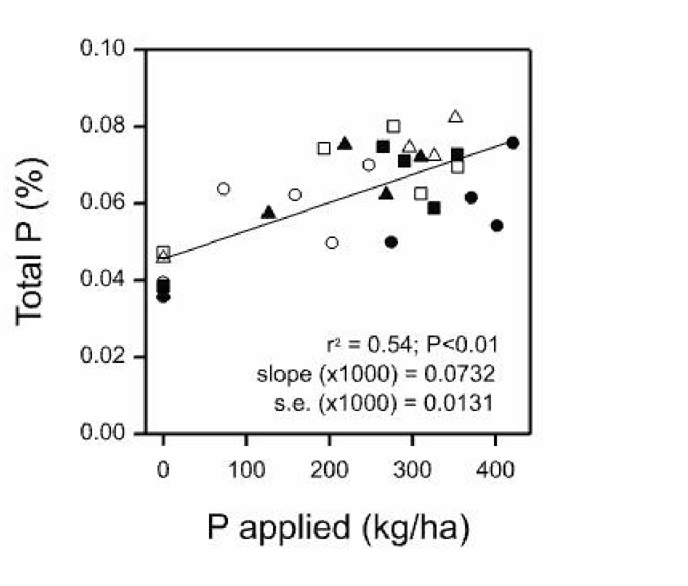

Figure 9. Total phosphorus in relation to the amount of phosphorus applied in the vegetable production systems Profitability (□), Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

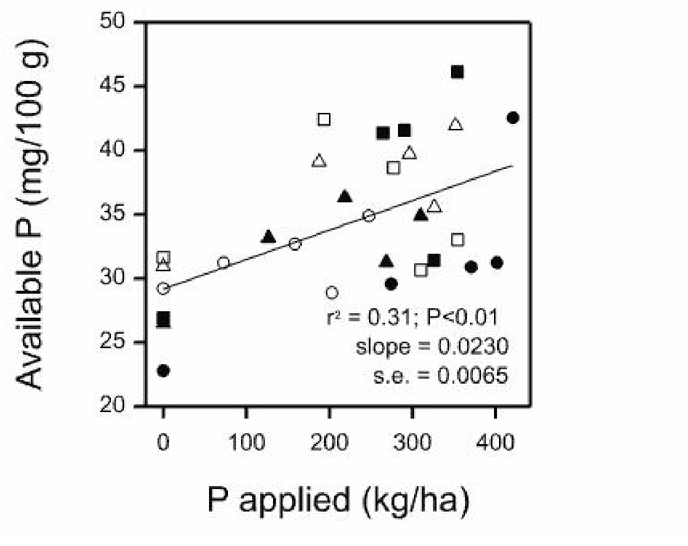

Figure 10. Available phosphorus in relation to the amount of phosphorus applied in the vegetable production systems Profitability (□), Labour (■), Pesticide (Δ), Biodiversity (▲), Perishability (●) and Traditional (○).

3.7. Total potassium

Total potassium in the soil was 0.17 % at the start of the experiment and it was 0.15 % at the end. There was no effect of the different systems on the slopes of the regressions lines of total potassium. The slopes of the individual regression lines did not significantly differ from zero, indicating no change in total potassium in the soil during the experiment in the different systems. When averaged over all systems, however, the slight decrease with time of total potassium was significant: P=0.017.

3.8. Available potassium

Averaged over all systems, available potassium ranged from 6.79 mg/100g at the start of the experiment to 12.84 mg/100g at the end. Available potassium was not strongly influenced by the systems (P=0.031). Available potassium increased with time in the Labour, Pesticide and Traditional systems. In the other systems available potassium was not influenced.

3.9. Cation Exchange Capacity

No effect of systems was found on Cation Exchange Capacity (CEC). When averaged over all systems and each time of sampling, CEC was 9.3 meq/100g soil.

4. Discussion

4.1. Physical soil fertility

The increase in bulk density of the soil layer 0.05 - 0.10 m at the final sampling date in the Profitability and Pesticide systems may be the result of the combination of heavy rainfall and an open crop stand in the final crops, causing soil compaction. The first, second and fourth sampling in the Traditional system was made in raised beds, but the final sampling was done in the compacted soil after the harvest of the rice, which explains the increase in bulk density of the soil layer 0.05 - 0.10 m at the final sampling.

The experimental field had a long history of vegetable cultivation in rotation with two crops of flooded rice a year. Bulk density of the soil layer 0.05 - 0.10 m decreased with time in all permanent vegetable production systems, with only small differences in the rate of decrease among systems. It is remarkable that such a positive and consistent effect on bulk density was reached in only two years.

The various positive effects of crop cultivation on bulk density, such as soil tillage, application of organic material and rooting of crops, cannot be separated. However, since the number of crops correlated best to the decrease in bulk density, frequency of soil tillage is likely to have had a major effect on bulk density.

Despite the repeated puddling in the Traditional system with the rice crops, bulk density also decreased with time in the Traditional system. Puddling is done to prepare the soil for flooded rice, creating a mud and a plough pan to retain the water. Puddling breaks down soil aggregates. The degree of breakdown will depend on the intensity of the puddling and on the structural stability of the soil. The effects of puddling on soil physical properties and on the growth and yield of post-rice crops have been studied (Kirchhof *et al*., 2000; Ringrose-Voase *et al*., 2000; Kukal and Aggarwal, 2003a,b), but not in combination with the construction of raised beds immediately after rice harvest. It may be the buffalo assisted ploughing and the subsequent construction of raised beds, with its associated intensive soil tillage that reduces the negative effects of puddling and restores soil structure. The presence of non-decomposed rice stubble and roots in the soil of the freshly made raised beds may contribute to restoration of soil structure. Apparently the soil of the experimental field had a high innate soil structural stability.

The data show that the effect of flooded rice in the rotation in terms of negative effects on soil structure may be less than previously anticipated (Huong *et al*., 2013). The data illustrate that at least in the upper soil layers, the quality of the soil in terms of bulk density can be improved with repeated good soil tillage.

The results also suggest that the soil tillage in the experiment was not sufficient at the deeper soil layers, as bulk density between 0.15 and 0.20 m did not decrease and sometimes even increased. The compacted layer observed in the soil of the experimental field between 0.18 and 0.25 m (see Materials and methods) implies that the potential rooting volume of the soil was limited. Although the highest concentration of roots of vegetables on raised beds may be found in the upper 0.20 m (Kleinhenz *et al*., 1997), a potential rooting depth confined to the layer 0-0.20 (-0.25) m, severely limits the development of a robust root system for the vegetable crops. The limited volume of the raised bed may hinder the efficient uptake of nutrients by limiting the potential for nutrient uptake to the soil volume of the raised bed only.

4.2. Chemical soil fertility

Generally a pH-H_2O of 6.0-7.0 is considered to be favourable for vegetable production, but soil properties under vegetable production may vary widely (Everaarts and de Putter, 2009). The initial average pH-H_2O of the experimental field was 6.1. Soil acidity decreased in all systems. At the end of the experiment the pH-H_2O averaged over all systems was 6.5. The increase was related to the amount of lime applied. On average pH-H_2O increased with 0.06 units for each ton of lime applied per hectare. Lime application consistently influenced soil acidity and showed that under the local conditions liming can be effective in raising the pH, even in only two years.

Application of manure appeared to be able to increase the organic carbon content of the soil. The increase from an average of 1.02 % at the start of the experiment to an average at the final sampling of 1.14 %, shows that soil improvement in terms of a rapid increase in organic matter is possible by the application of organic manure. Given the relatively low value for organic carbon at the start of the experiment, this may indicate that organic manure application in the past has been less than sufficient. The magnitude of the increase in the organic carbon content is in line with results found elsewhere, e.g. Powlson *et al*. (1987) and Hassink (1994).

In the two years of the experiment total nitrogen was not strongly influenced by the various vegetable production systems. Despite a high total amount of nitrogen applied, total soil nitrogen significantly decreased in the Profitability system. This could possibly be an indication of nitrogen leaching losses (Mai *et al*., 2010) and low fertiliser use efficiency (Nguyen *et al*., 2007), where crops significantly use soil nitrogen initially present. Research on crop nutrient uptake and nutrient removal with products is needed to establish the magnitude of potential nitrogen losses.

Total phosphorus increased in the Traditional system as well as in the other systems, except for the Profitability system. The initial average value of 0.04 % for all systems was increased considerably and related to the amount of phosphorus applied. Also available phosphorus increased with the amount of phosphorus applied. It is not known to what extent phosphorus is presently a limiting factor in vegetable production in the Red River Delta, but the results suggest that applying phosphorus might result in an increase in available phosphorus. The build-up in total phosphorus suggests that the amount of phosphorus applied was likely higher than the amount taken up and removed by crop products. The increase in total and available phosphorus warrants an investigation of current fertilizer recommendations, in order to avoid build-up of excess phosphorus in the soil (Shao-Wen Huang *et al*., 2006; Chan *et al*., 2007; Darilek *et al*., 2010) and mitigate potential environmental pollution.

Total potassium was not or was hardly influenced by the different systems in the experiment. The small decrease in total potassium during the two years of the experiment might be an indication that loss of potassium by leaching or by removal with crop products, was larger than the amount of potassium applied.

5. Conclusions

The decrease in bulk density and acidity, and increase in organic carbon, total phosphorus and available phosphorus, after only two years, show that soil conditions after a long history of two crops of flooded rice a year, can improve in a rather short time under permanent vegetable production. The increase in total phosphorus and available phosphorus indicates the need for evaluation of phosphorus fertiliser recommendations to avoid the build-up of excess phosphorus.

The decrease in bulk density, even when flooded rice is included in the production system, points to a high potential of restoring soil structural stability after puddling with repeated intensive soil tillage and raised bed construction.

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Chapter 7

General discussion

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1. Introduction

The objective of this study was to improve vegetable production systems in the Red River Delta (RRD), which can enhance soil quality for growing vegetables and increase income for farmers. Negative effects of the present vegetable production systems in the RRD, e.g., seasonality of production and prices, and poor soil conditions, were studied in Chapter 2. Data on profit, labour requirement and costs of pesticide use of 42 different vegetable crops commercially produced in the RRD were generated (Chapter 3). The model PermVeg was developed to generate crop sequences for new permanent vegetable production systems in the RRD (Chapter 4) based on the data from Chapter 3. A two-year field experiment was carried out to compare the designed permanent vegetable production systems with the traditional system in which vegetables are rotated with rice and to test performance of the PermVeg model in terms of profit, labour requirement and pesticide use (Chapter 5). We compared soil physical and chemical properties between the permanent vegetable production systems and the traditional system in Chapter 6. The current chapter aims to analyse the strengths, weaknesses, opportunities, and threats (SWOT analysis) of the model PermVeg and of permanent vegetable production systems in the RRD as designed by the model. Moreover, recommendations that may help farmers to improve their production and marketing of vegetables are presented.

2. SWOT Analyses

2.1. The PermVeg model

2.1.1. Strengths

In the thesis the PermVeg model is described. This newly developed model proved to be a useful tool to generate crop sequences for permanent vegetable production systems in the RRD (Chapter 4). Crop growth duration in the field, crop interval and length of crop sequences generated by the model were counted in days. The model therefore allows for making comparisons among the designed systems and between the designed systems and the traditional system independently from length of crop sequence (Chapter 5). This comparison was possible because of the criteria used to compare the systems, profit, labour requirement and pesticide use, were calculated per ha per day. Those criteria make the model innovative and different from other models, such as ROTAT. The latter calculates output and input per ha per year, corresponding to per ha per crop season (Dogliotti *et al*., 2003).

In addition, a crop sequence generated by PermVeg can start at any day of the year. This makes PermVeg a very useful tool to design crop systems for the Red River Delta (RRD). In the sub-tropical climate prevailing in the RRD, vegetables can be grown year-round (Chapter 1, Chapter 2). With the small acreage of agricultural land on average available per capita in the RRD of only 700 m^2/person (GSO, 2007), making maximum use of cultivation land is very important in this region.

2.1.2. Weaknesses

PermVeg is predominantly a single-objective model. If we want to take more than one objective into account, we have to formulate them as restrictions. E.g., when it generated crop sequences for low labour scenario (Chapter 4), the model sorted crop sequences according to labour requirement. To balance with profit, the model discarded the sequences with profit below the median of profit of vegetable crops in the defined list.

PermVeg cannot work as a farm design model. It generates a crop sequence based on a defined list of crops. It cannot prevent supply over demand. At the farm scale, to prevent over supply, farmers in a production area need to be able to predict the demand for their vegetable products in their target markets and to predict the supply by their competitors, so that they can make a proper farm planning. The PermVeg model cannot predict well the profit of vegetable crops in permanent vegetables systems either, because prices of vegetables vary within and between years (Chapter 5).

In the future, land may be concentrated in fewer farms via transferring land use rights as is the case in China (Huang *et al*., 2012). When non-farm labour markets are rapidly developing, farmers rent their land and work in the non-agricultural sector. This process will limit the availability of agricultural labour. In that case, farm planning can be designed using a mixed integer linear programming model, named Farm Images (Dogliotti *et al*., 2005; 2006) based on targets, e.g., farm income, and restrictions, e.g., market demand, labour availability.

2.1.3. Opportunities

PermVeg is a simple model which can easily be applied. Researchers and extension officers can understand and operate the model to generate all options of crop sequences for a defined scenario. Researchers or extension officers can support local farmers to choose the most suitable crop sequence of a permanent vegetable system for the location.

2.1.4. Threats

Growing crop sequences generated by PermVeg may result in less diversity of vegetable products. In Chapter 4, crops presented in the crop sequences generated by PermVeg ranged from 21% to 62% of the number of the crops in the list. However, the negative effect can be reduced. A crop can be more dominant in a location than the other due to tradition or specific market potential of the product (Anh *et al*., 2005; Anh *et al*., 2006). Therefore, the defined list of crops submitted to the model can differ from one location to another. This creates positive effects on diversity of vegetable products.

PermVeg does not take into account the negative impact of permanent vegetable production systems on the environment.

2.2. Permanent vegetable production systems: contribution of permanent vegetable production systems in the Red River Delta to livelihood and sustainability

2.2.1. Strengths

Improving farmers' income can be achieved by growing vegetables year-round. The permanent production system designed with the priority on profit (Profitability system (Chapter 4)) can yield a higher income than the Traditional system, in which vegetables are rotated with rice, in the RRD (Chapter 5). This is in line with Lu *et al*. (2010) and Kasem and Thaba (2011), who have found that year-round vegetable systems yielded more income per unit of land area than the income achieved from the systems in which vegetables were rotated with rice.

Permanent vegetable production systems can generate more employment opportunity for rural and peri-urban areas than the Traditional system does in the RRD. The Profitability system can generate twice as much employment as the Traditional system does without decreasing the income per labour day (Chapter 5). As Vietnam is an agricultural country, with the agricultural population constituting 63% of the total population in 2011 (FAOSTAT 2012), this can contribute to developing the economy in the rural and peri-urban areas and to narrowing the income gap between rural and urban areas.

Vegetable production in the RRD is the main supply of vegetables for the urban citizens in the region and ensures their vegetable security. As urban agriculture can only provide about 2.7% of the vegetable demand of the citizens (Anh *et al*., 2004), most of the vegetables traded in the Hanoi market are field vegetables grown in the RRD, the northern midland and highland, the central highland and China. Vegetables, which can be grown year-round or in summer in the RRD, come from peri-urban areas of Hanoi and the nearby provinces in the RRD (Hung Yen, Hai Duong and Ha Nam). Temperate vegetables come from the northern midland and highland (Bac Giang and Son La), central highland (Lam Dong) and China during summer (Chapter 2; An *et al*., 2003). Especially, highly perishable leafy vegetables mainly come from the peri-urban areas of Hanoi indicating an important role of vegetable production in the peri-urban area in supplying vegetables to the city. The flood during the period 29 October – 5 November 2008, which destroyed the vegetables crops grown in Hanoi and its nearby provinces, caused a dramatic increase in the price of vegetables in November 2008. This sharp increase in vegetable prices proved that the role of the RRD in the vegetable supply to Hanoi is important (Chapter 2). As vegetable production in the RRD is mainly to supply vegetables to the cities in the region, permanent vegetable production systems contribute to year-round supply from the region itself, benefiting traders and consumers.

The objective of improving soil conditions by growing vegetables in permanent vegetable production systems, was achieved. The decrease in bulk density and soil acidity and the increase in organic carbon and total and available phosphorus after only two years show that soil conditions can improve in a rather short time under intensive vegetable cultivation. Soil conditions also improved in the traditional system, in which vegetables are rotated with flooded rice. The data imply that buffalo assisted ploughing after flooded rice production, in combination with construction of raised beds, including the application of organic material, may reduce or totally eliminate negative effects of puddling on soil structure (Chapter 6).

Development of lowland vegetables year-round can contribute to soil protection in the highlands. If highlands with steep slopes are over-exploited for intensive vegetable production, they can degrade quickly because of soil erosion (Rerkasem, 2005). Cultivated land cannot control water flows as well as land under natural vegetation, because there are periods without crop cover or with only a small canopy whereas land under natural vegetation is covered by vegetation throughout the year.

2.2.2. Weaknesses

Permanent vegetable production systems around Hanoi have some weaknesses, including uncontrolled markets and prices, poor horticultural practices, high labour input, and small landholdings. These are discussed below.

2.2.2.1. Uncontrolled markets and prices

Prices of vegetables, especially in remote rural areas, which are far away from city markets, are determined by collectors or middle men. Farmers do not have direct contacts with markets. The difference between potential profits calculated as based on the price in a city whole sale market, and the profits calculated, as based on the price in the local market or the selling price to middle men, in Chapter 5 proves that middle men can earn a lot from farmers' produce. Fluctuating prices make it more risky to choose for permanent vegetable production systems, because of insecure income.

2.2.2.2. Poor horticultural practices

Poor horticultural practices reduce vegetable production in general, but especially on year-round vegetable production in permanent vegetable production systems, because of the abiotic and biotic stresses during the hot and wet season. Knowledge of farmers on vegetable crop ecology and pest and disease management is still limited. Moreover, poor horticultural practices enhance abiotic and biotic stress of vegetables crops. For example, poor water management causes Fe deficiency in dicotyledonous vegetable crops (Huong *et al*., 2011). Poor water management also causes more serious infections by soil-borne diseases. The pH is rather low at some locations in the RRD, e.g. in Dong Anh (pH H_2O of around 6.0), which can cause Ca and Mg deficiency but can also increase clubroot (*Plasmodiophora brassicae*) infection on cruciferous crops.

2.2.2.3. High labour input

As discussed above, high labour requirement in vegetable production can be considered as strength as it generates employment for farmers. However, it can also become a weakness for vegetable production. High labour requirement is a major constraint and a reason to limit the acreage under permanent vegetable systems. The situation is the same in other Asian countries such as Thailand (Kasem and Thapa, 2011). Improving labour productivity is necessary if we want to extend the acreage under permanent vegetable systems. Increasing mechanization in vegetable production, when plot size is increased by exchange plots or land accumulation, can improve labour productivity.

2.2.2.4. Small landholdings

When a lot of vegetables are produced by small landholders, their control of the marketing and the integration into a value chain of vegetable products will be more difficult. Small landholding farmers, who produce conventional vegetables, do not produce vegetables professionally in terms of planning, marketing and quality control, because of their small volumes (Chapter 2). In addition, on small farms it is difficult to apply mechanization, which helps to save labour. This limits the area of permanent vegetable production systems because vegetable production requires more labour than rice production (Chapter 2, Chapter 5).

Uncontrolled markets and prices are the weaknesses for which it is the most difficult to improve. As described above, small landholding farmers are unprofessional in production and marketing, especially the conventional vegetable farmers who have not participated in commercial cooperatives.

2.2.3. Opportunities

Permanent vegetable production systems have opportunities to be extended because of the climatic conditions, special vegetable programmes, the emergence of commercial cooperatives, the opportunities for marketing of vegetable products, the support from foreign countries and the large area suitable for permanent vegetable production systems. These opportunities are discussed below.

2.2.3.1. Climatic conditions

Climatic conditions in the RRD are conducive to permanent vegetable production systems. The RRD has a sub-tropical climate, in which temperate vegetables and tropical vegetables can be grown in winter and summer, respectively. In addition, there are vegetables which can be grown year-round in the RRD, e.g. the leafy vegetables amaranth (*Amaranthus tricolor*) and green choy sum (*Brassica rapa* var. *parachinensis*). These opportunities create a large diversity of vegetables in the RRD and many options to design permanent vegetable production systems. In Chapter 3, data sets of 42 vegetable crops were collected, but there are more than 42 vegetable crops grown in the RRD. We could not collect data for some vegetables, including pumpkin (*Cucurbita maxima*) and luffa (*Luffa aegyptiaca*). With the development of plant breeding programmes, the duration of the crop cycle of temperate vegetables grown in the RRD has been prolonged using heat-tolerant varieties. Therefore, temperate vegetables can be present for a long period in permanent vegetable production systems creating diversity of vegetable products in the hot season.

2.2.3.2. The "Safe vegetables programme"

After the reform in the framework of the policy "renovation" or "doi moi" in 1986, Vietnam's economy has developed quickly and income and education levels have increased. There was a rising demand on high quality food. To improve the quality of vegetables the Ministry of Agriculture and Rural Development implemented the "Safe vegetables" programme. The programme trained farmers to apply fertilizers and pesticides properly and to use non-polluted water for vegetable production (Moustier *et al*., 2006). The programme has achieved some good results as indicated by the fact that vegetable growers trained in the "Safe vegetables" programme performed better than untrained farmers in classifying toxicity of pesticides and in safe pesticide use (Hoi *et al*., 2009). The untrained farmers can learn from the trained farmers to scale up safe vegetable production in the area. Excellently trained farmers can work as extension workers in a farmer field school to extend the programme to other areas. Knowledge of the advanced farmers supports year-round vegetable production, especially for vegetables produced under harsh conditions, e.g. during the hot and rainy season.

2.2.3.3. Empowering commercial cooperatives

Commercial cooperatives have been successful in the peri-urban area of Hanoi, e.g. the Van Noi and the Van Tri cooperatives. The members participate in the cooperatives voluntarily and share profits of joint activities. Quality control is most developed in the Van Tri cooperative. The managing board is in charge of crop planning, quality inspection, management of retail stalls for safe vegetables, input supply, interface with authorities for IPM training and delivery of certificates for safe vegetables (Moustier *et al*., 2006). The cooperatives can be considered as a model to develop safe production and marketing for year-round vegetable production to improve income for vegetable farmers.

2.2.3.4. Marketing of vegetable products

Marketing vegetable products plays an important role in vegetable farmers' income; it also provides the opportunity of implementing permanent vegetable production systems, since vegetable prices affect the profit of vegetables produced commercially more than intensification of production does (Yanagisawa *et al*., 2001). In this study (Chapter 5), the profit of vegetables sold at a city wholesale market was considerably higher than that of vegetables sold at a local market or to middle men. However, the small landholdings of farmers (Chapter 2) result in small product volumes and thus represent a problem in marketing their produce. One option to improve the marketing of vegetable products for small landholding farmers is to let them participate in commercial cooperatives to improve the efficiency of marketing. The managing board of the cooperatives signs contracts to canteens of schools, companies, restaurants, hotels and supply companies to sell products produced by the members in the cooperatives. The Van Noi and the Van Tri cooperatives in the Dong Anh district of Hanoi also directly retail their produce through their retail stalls of "safe vegetables" (Moustier *et al*., 2006). Farmers in other Asian countries, e.g. China, also prefer to directly retail their produce themselves because this maximizes their profit (Huang *et al*., 2006).

2.2.3.5. Support from foreign countries

Although research on vegetables is younger than research on rice, with the opening policy, cooperative research programmes on vegetable production and marketing have been established. Examples are the following two projects funded by European countries: “Sustainable technologies for pest, disease and soil fertility management in smallholder vegetable production in China and Vietnam 2002-2005” and “Sustainable Development of Peri-urban Agriculture in South-East Asia 2002-2006”. Farmers in the peri-urban area around Hanoi have been trained to apply properly pesticides and fertilizers through safe vegetable production programmes. These support programmes enhance the implementation of permanent vegetable production systems in the RRD.

2.2.3.6. Potential areas for permanent vegetable production systems

The RRD required about 1.7 million Mg of vegetables excluding waste in the year 2010 for the population of about 20 million people in 2010 and with vegetable consumption of 230 g/day excluding waste. The total amount of vegetables equals to 2.1 – 2.6 million Mg net amount of product as waste is about 25-50% of the net amount. With a yield of vegetables of about 75 Mg/ha per year (average yield of Biodiversity, Pesticide and Profit systems in Chapter 5), the area of permanent vegetable production systems should comprise 30 – 45 million ha, about 3.8 – 5.7% of the agricultural land of the RRD. Assume that RRD supplies one third of the vegetable demand for the three central provinces Thanh Hoa, Nghe An, and Ha Tinh, then the total area of permanent vegetable systems should comprise 34 – 50 million ha, about 4.2 – 6.4% of the agricultural land of the RRD. This proportion of land area for permanent vegetable production systems does not influence the rice security for the region, because as calculations in Chapter 2 indicated, farmer households can use about 28% of their rice land for horticulture and still ensure rice security for the whole region.

2.2.4.Threats

In the permanent vegetable systems more N was applied than in the traditional system (Chapter 6). In addition, N use efficiency may be rather low (40%-60%) in vegetable production in the Red River Delta (Khai *et al*., 2007). The permanent vegetable systems may release more N to groundwater or surface water than the traditional system, through leaching into groundwater and running off into surface water due to drainage in rainy season or furrow irrigation. Mai *et al*. (2010, 2013) found higher N leaching in fields with year-round vegetable production than in fields with the cropping sequence of rice-rice-maize. Overuse of fertilizers N, P, K in vegetable production in the peri-urban area of Hanoi causing groundwater pollution has been warranted (Khai *et al*., 2007). Not only the mobile element N, which leaches or erodes easily into ground water, but also the immobile element P causes groundwater pollution in the Yangtze River Delta, China (Huang *et al*., 2006). This negative impact can be reduced by good cultural practices: proper fertilizer application rates, mulch, irrigation and drainage. However, there are also negative effects of scaling up in time (long-term vegetable production) and in space (many farmers producing according to the same system). These are discussed below.

2.2.4.1. Negative effects of scaling up in time

We did not take into account the negative effect of permanent vegetable production systems on accumulating soil-borne diseases and pests. Some soil-borne diseases, e.g., *Rhizoctonia solani,* causing damping off, infect most vegetable crops. Growing vegetables continuously results in accumulating this fungus population in the soil. Rice is not a host plant of the fungus, so during the rice growing season, the pathogen cannot multiply. Some pests, e.g. *Spodoptera litura,* attack most vegetables, but not rice. Growing vegetables continuously in permanent vegetable production systems may increase the population of insects. In addition, microbes are more diverse in paddy soil than in vegetable soil (Sun *et al*., 2011). Plant diseases decrease with increasing diversity of soil microbes (Schnitzer *et al*., 2011; Shen *et al*., 2008). It implies that plant diseases may be more serious in permanent vegetable production systems than in the traditional system, where vegetables are rotated with rice.

2.2.4.2. Negative effects of scaling up in space

If all farmers in a location grow a vegetable crop sequence only, it will produce large quantities of products. If the market of the products has not yet been established, vegetable production can be risky due to supply being greater than demand. Unsecure marketing conditions have been considered as the most important constraint for permanent vegetable production systems. Because there are no contracts between producers and traders, except for the small amount of “safe vegetables” traded through cooperatives and distribution companies (Son *et al*., 2006), producers depend on fluctuating, free market prices. Vegetable prices can change season by season (Chapter 5), but also day by day (Ketelaar and Kumar, 2012). In general, vegetable prices in the Hanoi market are low during December – January because of good weather conditions for vegetables grown in the peri-urban area of Hanoi and other provinces in the RRD (Chapter 2; Thuy *et al*., 2002). The production areas are larger than those in the hot season as well, because farmers grow vegetables after rice in the rice-rice-winter vegetables system. However, prices of vegetables are unpredictable (Chapter 5). They depend on production areas and weather conditions. In addition, farmers, who do not join cooperatives, grow what they can and what crops they have seen their neighbours produce and sell successfully. By nature, vegetables are highly perishable and, without cool storage, vegetables have to be sold as soon as possible after harvesting. In addition, vegetables, especially leafy vegetables can grow fast, so the price can change day by day. Therefore, if there is more supply than demand, prices of vegetables will be very low or the products cannot be sold at all (Chapter 2). To prevent or reduce the risk, farmers or a group of farmers have to determine market of each vegetable product before planning to grow any vegetable crop.

3. Conclusions and recommendations

PermVeg is a useful tool to generate crop sequences for permanent vegetable production systems in the RRD, which can help to improve farmers' income. Using PermVeg, we will not miss any promising crop sequences because PermVeg generates all options of crop sequences based on defined list of crops, objectives and restrictions. The list of crops should be defined based on growing conditions (notably temperature and rainfall) and markets of the products.

However, crop sequences cannot solve all problems of vegetable production in the RRD. It is necessary to be improved both in terms of production and marketing. Regarding the production aspects, the "safe vegetable production programme" should be extended in other provinces of the region rather than in Hanoi only. Improving knowledge on water management, nutrition management and pesticide use for vegetable farmers is necessary to create sustainable vegetable production in the RRD, and elsewhere in the country. Training programmes should help farmers to identify the problems and constraints in vegetable production, and to improve the situation. It is necessary to train farmers in keeping field records and field diaries. Farmers participating in commercial cooperatives voluntarily as described above is an option to strengthen the marketing capacity for their products. Research should be carried out on the market demand of some of the main vegetables, e.g., cabbage (*Brassica oleracea* var. *capitata*) and tomato (*Solanum lycopersicum*), so that farm planning can be done to prevent oversupply. This helps farmers to avoid the common phenomenon “good yield – bad price”.

To save labour in vegetable production and to extend opportunities for permanent vegetable production systems, the two following options are recommended: 1) exchange plots or accumulate land via transferring land use rights to have larger farms to facilitate mechanization; 2) keep growing vegetables in permanent vegetable systems with raised beds and furrows between them in the same place to save labour required for land preparation.

Growing vegetables in permanent vegetable production systems contributes to secure year-round vegetable supply for the cities of the region and improves farmers’ income. In commercial vegetable cooperatives, PermVeg is a useful tool to help farmers in selecting crop sequences and regular supplying vegetables to customers (hotels, restaurants, schools, factories and supply companies), supermarkets, or traditional markets.

In permanent vegetable production systems, using varieties resistant to pests and diseases should be a priority, especially during the hot and wet season. This prevents yield loss due to pests and diseases, and reduces pesticide use to protect human health and environment.

The sequences of crops with low costs of pesticide use or high level of biodiversity did not reduce pest and disease incidence dramatically (Chapter 4, Chapter 5). This implies that it is not easy to control pests and diseases by crop sequences with vegetable crops only. Future research should pay attention to the issue that year-round vegetable production systems may need to be rotated with other crops after a period of time, e.g. year-round vegetables should be rotated with rice after two years.

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Summary

Field vegetable production in the Red River Delta (RRD) plays an important role in food security and nutrition security for the region. In the RRD vegetable crops are mainly rotated with rice, with rice being grown twice during the hot season and vegetables being grown during the cool season. The rotation rice-rice-vegetables may result in unfavourable physical properties of the soil for vegetable growing. Moreover, it is hard to increase farmers' income via improving rice production, as the level of rice intensification is already high and the acreage can hardly be increased. In this study we designed and tested permanent vegetable production systems with the objectives to improve the income for farmers and to improve soil conditions for growing vegetables in the RRD.

The study consisted of four steps. In Step 1, we analyzed constraints and opportunities for year-round vegetable production in the RRD and provided recommendations to reduce these constraints. In Step 2, we set up a database with data on profit, labour requirement, costs of pesticide use and planting period of vegetable crops grown in the RRD. In Step 3, we developed a model, called PermVeg, to generate crop sequences for permanent vegetable production systems in the RRD, using the database set up in Step 2. In Step 4, we tested the performance of the designed systems in the field in terms of profit, labour requirements, pesticide use and soil improvement in comparison with the traditional system, in which vegetables were rotated with rice. The four steps are described in Chapters 2-6.

Chapter 2 provides an overview of vegetable production in the RRD with natural conditions and social-economic conditions influencing vegetable production. Pathways for sustainable development were analysed and formulated.

Given the sub-tropical climate, vegetables can be grown year-round in the RRD. However, during the hot and wet season, from May to September, temperatures are too high to grow temperate vegetables, whereas the heavy rainfall is conducive to pests and diseases. During the cool seasons, yield and production of temperate vegetables can reach a peak. Farmers may then be confronted with oversupply: vegetables have to be sold at low price or cannot be sold at all. Small landholding, poor marketing, large volatility of vegetable prices and the insecure market are major constraints. Moreover, lack of knowledge on horticultural practices among both researchers and farmers is limiting progress. Overuse of fertilizers and pesticides is common in vegetable production in the RRD. In Chapter 2, recommendations to reduce the constraints by improving cropping systems are formulated. Opportunities for

growing vegetables year-round in improved cropping systems are analysed as well. Permanent vegetable production systems are recommended as an option to improve vegetable production systems in the RRD. These systems can improve soil physical properties by eliminating the repeated wetting, puddling and drying of the soil, reduce labour costs because of eliminating the labour needed to create raised beds for vegetable growing and subsequent flattening after vegetable production. These systems can facilitate year-round vegetable supply for the RRD and nearby provinces, increasing the farmers' income.

In Chapter 3, we collected data on vegetables to set up a database for designing new vegetable cropping systems, to characterize the vegetable production in terms of profitability, labour requirement and pesticide use and to evaluate vegetable production for its potential to increase rural household income. In addition, the relation between planting date and crop growth duration of vegetable crops grown year-round was inspected as well. Data on growth duration in the field based on planting dates and harvesting dates, profit, labour requirement and costs of pesticide use of 42 vegetables crops belonging to 13 botanical families were collected. The variables were calculated per ha per growing day. Besides, the period of time suitable for planting, i.e. the planting period, for each vegetable crop was defined based on the collected planting dates, crop characteristics, climatic conditions and marketability of the vegetable products. The data were obtained from three sources: 1) the database of the project: 'Sustainable technologies for pest, disease and soil fertility management in small holder vegetable production in China and Vietnam", with the acronym 'VEGSYS', which ran from 2002 to 2005. The data were collected in 2002-2003; 2) interview data collected in 2006; and 3) the data obtained from the Field Crops Research Institute collected in 2006. The collected data were used as a database to design crop sequences of permanent vegetable production systems in Chapter 4.

In Chapter 3, the relations between profit, labour requirement, pesticide use, and growth duration in the field were analysed. In general, crops with high profit and short growth duration in the field required more labour per growing day. In addition, in this Chapter 3, we analysed the relation between crop duration and planting day to assess the effect of seasonal variation in temperature and radiation on crop duration in the field. We found that the growth duration of crops grown year-round might be influenced by their planting date. Planting in the hot summer season might shorten the growing period.

In Chapter 4, we developed the PermVeg model for generating crop sequences for permanent vegetable production systems for the RRD, using the database set up in Chapter 3.

The permanent vegetable production systems were designed with the objectives: to improve soil conditions for growing vegetables, to increase farmers' income, to reduce labour requirements, to reduce pesticide use, to limit pest and disease incidence by increasing biodiversity, and to provide an opportunity for crop production at some distance from markets by producing low perishable products. The model combined crops from the list defined in Chapter 3 and generated all possible crop sequences within a growing period of two years, based on selection criteria and restrictions. The selection criteria included profit, labour requirement and costs of pesticide use and were calculated per ha per growing day in Chapter 3. The restrictions could be set up by users, e.g., there must be at least two crops of different botanical families between crops of the same family, except for amaranth (*Amaranthus tricolor*). Permanent vegetable production systems were designed based on five scenarios: i) increasing profit; ii) reducing labour requirement; iii) decreasing costs of pesticide use; iv) maximizing crop diversity; and v) low perishable products, and the systems were named Profitability, Labour, Pesticide, Biodiversity and Perishability, respectively. The last scenario was intended for rural areas far away from city markets. In this Chapter 4, we compared theoretically profit, labour requirement and costs of pesticide use of the permanent vegetable production systems with those of the traditional system. We found that profit and labour requirement of all crop sequences of permanent vegetable systems were higher than those of the traditional system. The costs of pesticide use of crop sequences with 10-18 crops of the Pesticide system were lower than those of the traditional system while costs of pesticide use of all other sequences of permanent vegetable production systems were higher than those of the traditional system.

With the variables profit, labour requirement and pesticide use, calculated per ha per day in the sequence, PermVeg generates crop sequences with the length of sequences counted in days, and the sequence can start at any day of the year. PermVeg, therefore, is a suitable program to design crop sequences for the RRD, or other regions, where vegetable crops can be grown continuously.

In Chapter 5, the performance of the theoretically best crop sequence of each system generated by PermVeg was tested in a two-year field experiment during the period 2007 - 2009. The objectives of the study were to compare the performance of the five permanent vegetable production systems with the traditional system and to assess the performance of the PermVeg model in the field. With local prices, only profits of the Profitability and the Labour systems were higher than those of the traditional system. At city wholesale market prices, profits of all permanent vegetable production systems were higher than those of the traditional system. All permanent vegetable production systems required more labour than the traditional system. However, the Labour system required the lowest amount of labour among the permanent vegetable production systems tested. Income per labour day of permanent vegetable production systems was not higher than that of the traditional system at local prices. At city wholesale market prices, only the Labour system had an income per labour day that was higher than that of the traditional system. Permanent vegetable production systems applied more fungicides and insecticides than the traditional system. The predictions of the PermVeg model reasonably matched the field experiment data for labour requirement and length of crop sequences. In addition, crop growth durations as measured in the field correlated well with the data of the PermVeg database, which were set up in Chapter 3 and were used in Chapter 4 to design the permanent vegetable production systems. The predictions of the PermVeg model for profit and costs of pesticide use were not good.

In Chapter 6, we evaluated the soil physical and chemical properties of the permanent vegetable production systems compared with the traditional system. Soil physical and chemical properties were improved after the two-year experiment in permanent vegetable production systems and the traditional system. Soil physical property of bulk density improved after the two-year experiment in all systems. Bulk density at a depth of 0.05 – 0.10 m decreased in all permanent vegetable systems and the traditional system. The decrease in bulk density was related to the number of crops cultivated, suggesting that frequency of soil tillage had a major effect on bulk density. The decrease may also be affected by application of organic materials on the soil in the period of two years. Bulk density at 0.15 – 0.20 m was not or hardly influenced. Soil pH increased in all systems. The increase was related to the quantity of lime applied. Organic carbon content positively related to the quantity of manure applied. The increase in available phosphorus and total phosphorus positively correlated with the quantity of phosphorus applied. The increase in total phosphorus and available phosphorus implies that the quantity of phosphorus applied was higher than the quantity taken up by crops and removed by crop products and residues. Total soil nitrogen remained the same in all permanent vegetable production systems, while it decreased in the Traditional system and the Profitability system. Total potassium did not differ among the permanent vegetable production systems and the traditional system. The small decrease in total potassium during the two years of the experiment may indicate that the quantity of potassium leached and taken up by crops and removed by crop products and residues was higher than the quantity of

potassium applied.

The main conclusions on the model PermVeg and on permanent vegetable production systems in the RRD are: 1) PermVeg is a useful tool to design crop sequences for permanent vegetable production systems for the RRD or other regions, where vegetables are grown continuously. 2) Permanent vegetable production systems can improve farmer's income. 3) Vegetable cultivation influences positively the soil physical and chemical properties in both permanent vegetable production systems and the traditional system.

Samenvatting

Vollegrondsgroenteteelt in de Red River Delta (RRD) van Vietnam speelt een belangrijke rol in de voedsel- en voedingszekerheid in de regio. In de RRD worden groentegewassen voornamelijk geteeld in een vruchtwisseling met rijst, waarbij rijst tweemaal achter elkaar wordt geteeld tijdens het warme seizoen en de groenten worden verbouwd tijdens het koele seizoen. De rotatie rijst - rijst - groenten kan resulteren in fysische eigenschappen van de bodem die ongunstig zijn voor de groenteteelt. Bovendien is het moeilijk om het inkomen van boeren te verhogen via het verbeteren van de productie van rijst, omdat de rijstteelt al zo intensief is en het areaal nauwelijks nog kan worden uitgebreid. In deze studie werden permanente groenteteeltsystemen ontworpen en getest, met als belangrijkste doelstellingen het inkomen van de boer te verhogen en de bodemgesteldheid voor het verbouwen van groenten in de RRD te verbeteren.

De studie bestond uit vier stappen. In Stap 1 werden de mogelijkheden en beperkingen geanalyseerd voor jaar-rond productie van groenten in de RRD en werden aanbevelingen gedaan om de beperkingen te verminderen. In Stap 2 werd een databank opgezet met daarin de gegevens betreffende saldo, arbeidsbehoefte, kosten van het gebruik van pesticiden en perioden van planten of zaaien van groentegewassen die in de RRD worden geteeld. In Stap 3 werd een model ontwikkeld, genaamd PermVeg, dat gewassequenties kan genereren voor permanente groenteteeltsystemen in de RRD; hierbij werd gebruik gemaakt van de databank uit Stap 2. In Stap 4, werden de prestaties van de ontworpen systemen in een veldproef op locatie in de Red River Delta getest op de uitkomst betreffende saldo, arbeidsbehoefte, het gebruik van pesticiden en de bodemverbetering in vergelijking met het traditionele systeem, waarin groenten werden geteeld in een vruchtwisseling met rijst. De vier stappen worden beschreven in de Hoofdstukken 2-6.

Hoofdstuk 2 geeft een overzicht van de groenteteelt in de RRD en van de natuurlijke omstandigheden en de sociaaleconomische condities die van invloed zijn op de groenteteelt. Mogelijke ontwikkelingsrichtingen voor duurzame groenteteelt worden geduid en geanalyseerd.

Gezien het subtropisch klimaat, is het mogelijk jaar-rond groenten te verbouwen in de RRD. Echter, tijdens het warme en natte seizoen, van mei tot september, zijn de temperaturen te hoog om groenten uit de gematigde gebieden te telen, terwijl de zware regenval het vóórkomen van ziekten en plagen bevordert. Tijdens het koele seizoen kunnen zowel de

opbrengst per oppervlakte-eenheid als de totale productie van groenten uit de gematigde gebieden een piek te bereiken. Telers kunnen dan worden geconfronteerd met een overschot: groenten moeten worden verkocht tegen een lage prijs of kunnen helemaal niet worden verkocht. De kleine arealen per bedrijf, slechte marketing, grote volatiliteit van de prijzen van groenten en de onzekere markt zijn belangrijke beperkingen. Bovendien belemmert het gebrek aan kennis over praktische aspecten van de teelt bij zowel onderzoekers als boeren de vooruitgang. Overmatig gebruik van meststoffen en pesticiden komt algemeen voor in de vollegrondsgroenteteelt in de RRD. In dit hoofdstuk worden aanbevelingen gedaan om de limiterende factoren op te heffen middels verbeteringen in de teeltsystemen. Mogelijkheden voor de jaar-rond vollegrondsgroenteteelt via betere teeltsystemen worden geanalyseerd. Permanente vollegrondsgroenteteelt wordt aanbevolen als een optie om de productiesystemen van groenten in de RRD te verbeteren. Dergelijke systemen kunnen de bodemfysische eigenschappen verbeteren doordat niet langer de structuur van de bodem negatief wordt beïnvloed door herhaaldelijk de bij de natte rijstteelt horende bodembewerkingen uit te voeren. Permanente groenteteelt verlaagt aan de ene kant de arbeidsbehoefte omdat niet langer steeds opnieuw verhoogde bedden hoeven te worden aangelegd en weer te worden verwijderd na de groenteteelt. Aan de andere kant is groenteteelt op zich arbeidsintensiever dan rijstteelt. Deze productiesystemen kunnen tevens het hele jaar door groente leveren aan de bevolking van de RRD en de nabijgelegen provincies en daarmee het inkomen van de boeren verbeteren.

In Hoofdstuk 3 wordt beschreven hoe gegevens werden verzameld over groenten en hun teelt teneinde een databank op te zetten voor het ontwerpen van nieuwe groenteteeltsystemen, om de groenteteelt te karakteriseren in termen van winstgevendheid, arbeidsbehoefte en het gebruik van pesticiden en om vast te stellen in hoeverre de groenteteelt kan bijdragen aan het gezinsinkomen van de rurale bevolking. Daarnaast werd de relatie tussen plantdatum en groeiduur van groentegewassen gedurende het gehele jaar gekarakteriseerd. Gegevens werden verzameld over de groeiduur in het veld op basis van de gegevens omtrent de tijdstippen van planten en oogsten, saldi, arbeidsbehoefte en de kosten van het gebruik van pesticiden van 42 groentegewassen, behorend tot 13 botanische families. De variabelen werden berekend per ha per groeidag. Daarnaast werd de geschikte periode voor zaaien of planten, of te wel de plantperiode, voor elk groentegewas gedefinieerd op basis van de verzamelde plantdata, gewaseigenschappen, klimatologische omstandigheden en de potentiële verkoopbaarheid van de groenten. De gegevens werden verkregen uit drie bronnen:

1) de database van het project “Duurzame technologieën voor plagen, ziekten en bodemvruchtbaarheidsbeheer in de vollegronds groenteteelt van kleine boeren in China en Vietnam”, met het acroniem ' VEGSYS ', dat liep van 2002 tot 2005; de gegevens werden verzameld in 2002-2003; 2) interviewgegevens die in 2006 werden verzameld; en 3) de resultaten van datacollectie door het Field Crops Research Institute in 2006. De verzamelde gegevens werden in Hoofdstuk 4 gebruikt als een database om daarmee gewassequenties in permanente productiesystemen van vollegronds groenten te ontwerpen.

In Hoofdstuk 3 werden de relaties tussen saldo, arbeidsbehoefte, het gebruik van pesticiden, en de groeiduur in het veld geanalyseerd. In het algemeen hadden gewassen met een hoog saldo en een korte groeiperiode in het veld meer arbeid per dag nodig. Verder werd in Hoofdstuk 3 de relatie tussen gewasduur en planttijdstip geanalyseerd teneinde het effect van seizoensgebonden variatie in temperatuur en straling op gewasduur in het veld vast te stellen. De groeiduur van de gewassen die het hele jaar door geteeld werden, bleek te kunnen worden beïnvloed door hun plantdatum. Planten in de hete zomer zou de groeiperiode kunnen verkorten.

In Hoofdstuk 4 werd het PermVeg model ontwikkeld voor het genereren van gewassequenties voor permanente productiesystemen van vollegrondsgroenten voor de RRD, met behulp van de in Hoofdstuk 3 gegenereerde databank. De permanente productiesystemen van vollegrondsgroenten werden ontworpen met de doelstellingen: het verbeteren van de bodemgesteldheid voor het telen van groenten, het verhogen van inkomen van boeren, het verminderen van de arbeidsbehoefte, het verminderen van het gebruik van pesticiden, het beperken van het vóórkomen van ziekten en plagen door het vergroten van de biodiversiteit, en het bieden van mogelijkheden voor de groenteteelt op enige afstand van de markten door het produceren van producten met een grotere houdbaarheid. Het model combineerde gewassen uit de lijst die in Hoofdstuk 3 was opgesteld en genereerde alle mogelijke gewassequenties binnen een groeiperiode van twee jaar, op basis van opgelegde selectiecriteria en restricties. De selectiecriteria betroffen saldo, arbeidskosten en de kosten van het gebruik van pesticiden en werden berekend per ha per groeidag. De opgelegde restricties kunnen worden ingesteld door de gebruikers van het model; bijvoorbeeld: er moeten ten minste twee gewassen van verschillende botanische families tussen gewassen van dezelfde familie zitten, met uitzondering van amaranth (Amaranthus tricolor). Permanente productiesystemen voor vollegrondsgroenten werden ontworpen op basis van vijf scenario's: i) het verhogen van het saldo; ii) beperking van arbeidsbehoefte; iii) het verminderen van de kosten van het gebruik van pesticiden; iv) het maximaliseren van de diversiteit aan gewassen, en v) geringe bederfelijkheid van de producten. Deze systemen werden respectievelijk Winstgevendheid, Arbeid, Gewasbeschermingsmiddelen, Biodiversiteit en Bederfelijkheid genoemd. Het laatste scenario is bedoeld voor het platteland dat op grote afstand ligt van de stedelijke markten. In dit hoofdstuk werden op theoretisch wijze de winstgevendheid, arbeidsbehoefte en de kosten van het gebruik van pesticiden van de permanente productiesystemen van vollegrondsgroenten vergeleken met die van het traditionele systeem. De saldi en arbeidsbehoefte van alle gewassequenties van de permanente productiesystemen van vollegronds groenten bleken hoger te liggen dan die van het traditionele systeem. De kosten van het gebruik van pesticiden van gewassequenties met 10-18 gewassen van het systeem Gewasbeschermingsmiddelen waren lager dan die van het traditionele systeem terwijl de kosten van het gebruik van pesticiden van alle andere sequenties van permanente productiesystemen voor vollegrondsgroenten hoger waren die van het traditionele systeem.

Met de variabelen saldi, arbeidsbehoefte en het gebruik van pesticiden, berekend per ha per dag in de gewassequentie, genereert PermVeg gewassequenties, met de lengte van de sequenties berekend in dagen. De sequentie kan op elke dag van het jaar beginnen. PermVeg is daarom een geschikt programma om gewassequenties te ontwerpen voor de RRD, of voor andere gebieden waar groentegewassen continu kunnen worden geteeld.

In Hoofdstuk 5 werden de prestaties van de theoretisch beste gewassequenties van elk systeem zoals die door PermVeg werden gegenereerd, getest in een twee jaar durend veldexperiment dat uitgevoerd werd in de periode 2007-2009. Dit omvangrijke veldexperiment had als doel de prestaties van de vijf permanente productiesystemen van vollegrondsgroenten te vergelijken met het traditionele systeem en de prestaties van het PermVeg model in het veld te toetsen. Op basis van de lokale prijzen waren alleen de saldi van de scenario’s Winstgevendheid en Arbeid hoger dan die van het traditionele systeem. Op basis van prijzen van de groothandel in de stad, waren de saldi van alle permanente productiesystemen van vollegrondsgroenten hoger dan die van het traditionele systeem, met uitzondering van het Bederfelijkheidsysteem. Alle permanente productiesystemen van vollegrondsgroenten vereisten meer arbeid dan het traditionele systeem. Echter, het scenario Arbeid had de laagste arbeidsbehoefte van alle permanente productiesystemen van vollegrondsgroenten die werden getest. Inkomen per gewerkte dag van de permanente productiesystemen van vollegrondsgroenten was – bij lokale prijzen – niet hoger dan dat van het traditionele systeem. Indien er werd gerekend met prijzen van de groothandel in de stedelijke markten, dan had alleen het systeem Arbeid een inkomen per gewerkte dag dat hoger was dan dat van het traditionele systeem. In permanente productiesystemen van vollegrondsgroenten werden meer fungiciden en insecticiden toegediend dan in het traditionele systeem. De voorspellingen van het PermVeg model kwamen redelijk overeen met de gegevens van het meerjarige veldexperiment voor zover het de arbeidsbehoefte en de lengte van de gewassequenties betrof. Daarnaast bestond er een goed verband tussen de groeiduur van de gewassen zoals die in het veld werd gemeten en de gegevens van de PermVeg database die in Hoofdstuk 3 was opgezet en in Hoofdstuk 4 was gebruikt om permanente productiesystemen van vollegrondsgroenten te ontwerpen. De voorspellingen van het PermVeg model voor saldi en de kosten van het gebruik van pesticiden waren niet goed.

In Hoofdstuk 6 werden de bodemfysische en -chemische eigenschappen vergeleken van de permanente productiesystemen van vollegrondsgroenten ten opzichte van het traditionele systeem. Bodemfysische en -chemische eigenschappen waren reeds verbeterd na het tweejarige experiment in zowel de permanente productiesystemen van vollegrondsgroenten als in het traditionele systeem. De bodemfysische eigenschap volumegewicht verbeterde na het tweejarige experiment in alle systemen. Het volumegewicht op een diepte van 0,05-0,10 m nam in alle permanente vollegrondsgroentesystemen en in het traditionele systeem af. De afname in volumegewicht was gerelateerd aan het aantal geteelde gewassen. Dit suggereert dat de frequentie van grondbewerking een aanzienlijk effect had op het volumegewicht. De daling kan ook worden beïnvloed door de toediening van organisch materiaal aan de bodem gedurende de twee jaar van het veldexperiment. Het volumegewicht in de laag 0,15-0,20 m werd niet of nauwelijks beïnvloed. De pH van de bodem steeg in alle systemen. De toename was gerelateerd aan de hoeveelheid toegediende kalk. Het gehalte aan organische koolstof was positief gerelateerd aan de hoeveelheid mest. De toename van beschikbare fosfor en van totaal fosfor was positief gecorreleerd met de hoeveelheid toegediende fosfor. De toename van totaal fosfor en van beschikbare fosfor impliceert dat de hoeveelheid toegediende fosfor hoger was dan de hoeveelheid die tijdens de teelt werd opgenomen en via producten en oogstresten van de gewassen werd verwijderd. De totale hoeveelheid stikstof in de bodem bleef gelijk in alle permanente productiesystemen van vollegrondsgroenten, terwijl deze daalde in het traditionele systeem en in het systeem Winstgevendheid. Totaal bodemkalium verschilde niet tussen de permanente productiesystemen van vollegrondsgroenten en het traditionele systeem. De kleine daling van het gehalte aan totaal kalium gedurende de twee jaar van het experiment kan erop wijzen dat de hoeveelheid kalium die uitspoelde vermeerderd met het kalium dat door de gewassen werd opgenomen en via oogstproducten en gewasresten werd verwijderd, hoger was dan de hoeveelheid toegediende kalium.

De belangrijkste conclusies betreffende het PermVeg model en permanente productiesystemen van vollegrondsgroenten in de RRD zijn: 1) PermVeg is een nuttig instrument om gewassequenties te ontwerpen voor permanente productiesystemen van vollegrondsgroenten in de RRD of in andere regio's, waar groenten continu worden geteeld. 2) Permanente productiesystemen van vollegrondsgroenten kunnen het inkomen van de boer verbeteren. 3) Groenteteelt heeft een positieve invloed op de bodemfysische en -chemische eigenschappen in zowel permanente productiesystemen van vollegrondsgroenten als in het traditionele systeem.

Publication list

Journal articles

Huong, P.T.T., A.P. Everaarts, J.J. Neeteson, P.C. Struik, 2013. Vegetable production in the Red River Delta of Vietnam. I. Opportunities and constraints. NJAS - Wag. J. Life Sci. 67: 27-36.

Huong, P.T.T. A.P. Everaarts, J.J. Neeteson, P.C. Struik, 2013. Vegetable production in the Red River Delta of Vietnam. II. Profitability, labour requirement and pesticide use. NJAS - Wag. J. Life Sci. 67: 37-46.

Huong, P.T.T., A.P. Everaarts, W. van den Berg, J.J. Neeteson, P.C. Struik, 2014. PermVeg: a model to design crop sequences for permanent vegetable production systems in the Red River Delta, Vietnam. (accepted for publication in Journal of Agronomy and Crop Science).

Huong, P.T.T., Everaarts, A.P., Neeteson, J.J., Struik, P.C., 201X. Performance of permanent vegetable production systems in the Red River Delta of Vietnam. (submitted).

Everaarts, A.P., Neeteson, Huong, P.T.T., Struik, P.C., 201X. Vegetable production after flooded rice improves soil properties in the Red River Delta, Vietnam. (submitted).

Conference papers

Huong, P.T.T, A.P. Everaarts, J.J. Neeteson, P.C. Struik, 2012. Developing permanent vegetable production systems for the Red River Delta, Vietnam. Acta Hort. 958: 53-58.

Huong, P.T.T, N.T. Sau, 2011. Role of urban and peri-urban agriculture on food security in Vietnam with the focus on vegetable production in the peri-urban of Hanoi. Proceeding of the workshop “Roles of urban and peri-urban agriculture for future foood security”, December, 2011, Bangkok.

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6.0 ECTS)

- Vegetable production in the Red River Delta in Vietnam and permanent field vegetable production in the world (2007)

Writing of project proposal (4.5 ECTS)

- Designing and testing permanent vegetable production systems for the Red River Delta of Vietnam (2006)

Post-graduate courses (8.0 ECTS)

- The art of modelling (2010)
- Soil ecology (2010)
- Basic statistics (2010)
- Agricultural and natural resources - a multi-criteria approach (2010)

Laboratory training and working visits (3.0 ECTS)

- Genstat training by Wim van den Burg; Applied Plant Research, Wageningen UR at Lelystad (2006)
- Soil science training; Plant Research International, Wageningen (2007)

Competence strengthening / skills courses (3.1 ECTS)

- Competence assessment; WUR (2007)
- Information literacy, including introduction endnote; WUR (2007)
- Techniques of writing and presenting a scientific paper; WUR (2007)
- Mobilizing your scientific network; WUR (2010)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- PE&RC Weekend (2009)
- PE&RC symposia: symposium "Neotropical forest" and the seminar "Wicked problems and clumsy solutions"

Discussion groups / local seminars / other scientific meetings (5.5 ECTS)

- Discussion group at Centre for Crop Systems Analysis (CSA), WUR
- Presentation at the experiment field for students of Hanoi University of Agriculture in Hanoi (2009)
- Final workshop “Modelling permanent vegetable production for the Red River Delta, Vietnam” in Hanoi (2009)
- Meetings at PPO, Lelystad (2010)
- Seminar meetings at Field Crops Research Institute, Hanoi, Vietnam (2011-2013)

International symposia, workshops and conferences (6.0 ECTS)

- Workshop “Year-round supply of vegetables in North Vietnam” in Hanoi (2008)
- Sustainable vegetable production in Southeast Asia; ISHS meeting in Indonesia (2011)
- Workshop “Roles of Urban and Peri-urban Agriculture for Future Food Security”, Kasesart University, Bangkok, Thailand (2011)

Curriculum vitae

Pham Thi Thu Huong was born in Hai Duong, Vietnam, on 21st of January, 1972. She studied at Hanoi University of Agriculture in Vietnam from 1989 to 1994 for her BSc. degree in Crop Sciences. She has been working at the Field Crops Research Institute in Vietnam since 1994 as a research assistant in horticulture. She studied the MSc. programme of Plant Sciences at Wageningen University, with the specialization Plant Breeding and Genetic Resources from February, 2004 and got her MSc. degree in March 2006. Her MSc. thesis was entitled “Marker assisted selection in tomato breeding for resistance to *Botrytis cinerea*”. She did her internship on tomato breeding at Rijk Zwaan Company, De Lier, The Netherlands. She was offered a PhD position within the framework of an academic exchange programme between Hanoi Agricultural University, Hanoi, Vietnam and Wageningen University and Research Centre, Wageningen, The Netherlands. Most of the research was carried out in Vietnam. The project included designing, modelling and testing permanent vegetable production systems compared with production systems in which vegetables are included in a crop rotation with flooded rice. The project started in May 2006.

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