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Assessment of the sustainability of the rice-maize cropping system in the Red River Delta of Vietnam and developing reduced tillage practices in rice-maize system in the area

Đánh giá sự bền vững của hệ thống canh tác lúa-ngô và phát triển kỹ thuật canh tác làm đất tối thiểu trong hệ canh tác lúa ngô ở đồng bằng sông Hồng ở Việt Nam

Review paper

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Rice and maize are global staple food and play an important role in world's food security strategy. Vietnam is one of rice leading export countries but annually it has to import a considerate amount of maize for cattle food processing. Red River Delta in the north of Vietnam is the second rice bucket of the country, which is responsible for more than 20% of total rice production. The priority crops in the areas are rice and maize and rice-maize system is the leading cropping system in the area. Currently, it is reported that the rice-maize cropping system is not sustainable and its profit is reducing in most of production areas in the Red River Delta. Improving rice cropping system aims is not only to increase rice and maize yields and production but also to improve the land use efficiency, decline the cost of the production and to increase system sustainability. To increase sustainability there must be a linkage of various factors. This review emphasizes on increasing rice-maize crop sustainability by applying appropriate agriculture practices such as reducing chemical fertilization and intensive tillage.

Gạo và ngô là nguồn lương thực chính cho toàn cầu và đóng một vai trò quan trọng trong chiến lược an ninh lương thực của thế giới. Việt Nam là một trong những nước dẫn đầu về xuất khẩu gạo nhưng hàng năm vẫn phải nhập một số lượng lớn ngô để chế biến thức ăn gia súc. Đồng bằng sông Hồng là một trong hai vựa lúa lớn của Việt Nam sản xuất khoảng 20% sản lượng lúa gạo của cả nước. Ở đồng bằng sông Hồng, lúa và ngô là hai cây trồng chính là hệ canh tác lúa-ngô là cơ cấu cây trồng hàng đầu trong vùng. Tuy nhiên, trong những năm gần đây, rất nhiều đánh giá cho thấy hệ thống canh tác lúa-ngô là hệ thống canh tác không bền vững và các lợi nhuận của mang lại từ cơ cấu canh tác ở hầu hết các khu vực sản xuất ở vùng đồng bằng sông Hồng của Việt Nam đã và đang giảm dần. Do đó, việc cải thiện cơ cấu canh tác lúa -ngô không chỉ nhằm mục đích tăng năng suất lúa và ngô mà còn nâng cao hiệu quả sử dụng đất, giảm chi phí sản xuất và tăng cường hệ thống canh tác bền vững. Tuy nhiên, để tăng tính bền vững của hệ thống canh tác thì phải liên kết nhiều yếu tố khác nhau. Bài viết này dựa vào các kết quả nghiên cứu của các tác giả khác nhau để đưa ra những giải pháp tích cực làm tăng tính bền vững của hệ thống canh tác lúa - ngô bằng cách áp dụng các phương pháp canh tác hợp lý như giảm sử dụng phân hóa học và các biện pháp canh tác thâm canh như áp dụng phương pháp làm đất tối thiểu.

Keywords: rice-maize cropping system, Red River Delta, reduced tillage, agriculture

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1. Introduction

In the Red River Delta in the north of Vietnam the rice-maize system is increasing and is becoming the dominant cropping system. However, the literature shows that the rice-maize system is challenged by several constraints and that profit from the system is reducing (Pham et al., 1995; Mussnug et al., 2006; Mai et al., 2010). One of the most serious barriers to hinder rice-maize system is the degradation of fertile soil due to the intensive tillage associated with the traditional cultivation method (Timsina, 2010; Timsina et al., 2010; Uphoff et al., 2008). Though reduced tillage has been introduced to the area, this system is not widely used when compared to conventional agriculture (Stuart, 1996; Vladimir, 2007). This report will review the current rice-maize cropping system's constraints, providing assessment of the sustainability of the system, suggesting strategies to improve the system and giving guidelines to approach conservation agriculture through reduced tillage practices.

2. The rice maize cropping systems

Rice and maize are major cereals in the Red River Delta (RRD) of Vietnam. They are the major crops contributing to the food security and income of the country. In the RRD rice or maize can be grown as a monoculture or in rotation with each other. However, with the decline of the agriculture land, rotation and intensive cropping are reasonable options (Mussnug et al., 2006; Ali et al., 2008). The dominant cropping systems in the RRD are rice-rice, rice-cash crop, and rice-maize. Rice-rice, and rice-cash cropping were common systems in the past, but the demand for maize in recent years has shifted the cropping system to rice-maize cropping systems (Timsina et al., 2001; Timsina 2010). In addition, the rice-rice and rice-cash crop can be implemented only under particular climatic conditions, whereas the rice-maize system exists in all climates from tropical to subtropical and warm temperate regions (Pham et al., 1995; Timsina, 2010).

The RRD's climate is characterized as tropical monsoonal with four cropping seasons such as spring, summer, fall and winter. Rice is the main crop in summer. Others, like maize, chickpea, peas, potatoes, and brassicas are the winter crops. Maize, bean, cowpea and rice are the spring crops (Hoanh et al., 2002). The RRD is known as one of the most densely populated rural areas in Asia and the second largest rice production area in Vietnam. The rice cropping system in the RRD in Vietnam is responsible for about 20% of the rice production in the whole country. The rice production areas in the RRD have remained relatively constant or reduced lightly over the past 25 years, and rice productivity has gradually decreased (Tran et al. 2004; Jennifer 2006). Le et al. (1998) reported that from the period of 1977-1987 to 1987-1997 the rice yield in the RRD decreased about 0.6 t/ha. Similarity, Timsina (2010) indicated that most of rice maize cropping systems in South Asia constantly was reduced in yield and there is the larger gap between potential yields and attainable yields and between attainable and actual yields in rice and maize.

Maize was introduced to the RRD in the period of 1662-1762 from China, and now it is grown almost everywhere in the country (Vietnamese Maize Knowledge Bank, 2013). In the last three decades maize production has been increasing rapidly from 730,000 ha in 2001 to 1,126,900 ha in 2010 (General Statistical Office, 2011), but its production does not meet the demand of the country. Annually, Vietnam imports more than 1 million ton of maize for processing livestock and poultry food. In addition, the maize yield as well as its quality is lower than other countries with similar ecological condition (Uy et al., 1998; Dao et al., 2002; Dang et al., 2004).

3. Rice-maize cropping system constraints

Increasing yields in the rice-maize system for the farmer in the RRD in Vietnam is currently a primary concern since the agriculture land has become limited. However, several studies have shown that under conventional cultivation in rice-maize system, the soil fertility declines (Whitbread et al., 2003; Tran et al., 2004; Timsina, 2010). Timsina (2010) and Timsina et al. (2001) reported that in most rice-maize crop systems, the very little crop residue is returned to the soil and other organic inputs are low, which results in the loss of soil organic. The changes in soil organic carbon could be used to evaluate the carbon sequestration and sustainability (Dobermann et al., 2000; Tittonell et al., 2008). Mai et al. (2010) researched nitrogen leaching in intensive rice based cropping system in Tam Duong district, RRD of Vietnam. The research showed a significant loss of N by leaching in conditions of high rainfall and irrigation. The losses would be greater if the application of nitrogen was not based on the crop demand and soil analysis data.

Moreover, the conventional agriculture in the RRD was found to use agrochemicals in excess quantities in their attempt to reduce pests and diseases (Naylor, 1994; Shepard et al., 2009). Naylor (1994) reviewed the spraying of pesticides in the rice field in the RRD of Vietnam. It was found that pesticides were misused and abused in the area, and half of pesticides used were not equivalent to the current pests and diseases status. In addition, though, new pest resistant rice varieties were introduced, the frequency of pesticide spray remaining high. Naylor (1994) reported that according to the WHO about 20% of the chemical pesticides used in rice field were extremely hazardous. The continued high use of pesticides on rice production has significant impact on the rice export industry, and also presents a major impact on soil, underground and human and animal's health (Norton et al., 2005; Pham et al., 2011b). In contrast, conservation agriculture does not depend on external inputs. The basic principles of conservation agriculture are to meet the economic, ecological, and social needs with consideration for the development of future generations (Uphoff et al., 2003).

4. Assessment of the sustainability of rice-maize system

Hobbs et al. (1990) reviewed the rice-maize cropping system in South and Southeast Asia. He concluded that the rice-maize systems were showing a decreasing trend in rice productivity and quality. Sistani et al. (1998) pointed out that the rice-maize system in the RRD in Vietnam and other Asian regions was associated with significant negative impact on land and the production systems, bringing doubts about the long-term sustainability of the system. Mahapatra et al. (1985) reported that in India under the rice-maize cropping system the decline of rice productivity was associated with soil constraint, rainfall, and inappropriate cultural practices. In Australia, Dumanski et al. (2006) warned that even restorative actions could bring unforeseen degradation effects such as salinisation from irrigation, acidification from the legumes' residues and fertilizers, and other pollutants from animal manures. Soil degradation seems to be the main problem under the rice-maize cropping system, but the assessment of soil degradation is a complex issue, difficult to conduct (Howard et al., 1993).

In the RRD, the dominant cultivation method was the traditional or conventional agriculture. Traditional agriculture is characterized by being capital intensive and agrochemical dependent. Though the crop productivity is high, the cost to environment and human health is at an alarming level. In conventional agriculture the crop remains or residuals are removed from the field and the field will undergo several agricultural practices such as ploughing, harrowing and leveling (Clark et al., 1999; Jenifer, 2006; Ladha et al., 2009).

5. Strategies to improve the sustainability of rice-maize cropping systems

5.1. Application of fertilizers

A number of trials on cropping systems in the RRD had been conducted by Mussgnug et al. (2006). The authors pointed out that under the rice-based system, potassium was found to be the yield-limiting macronutrient and regular potassium application could both increase the rice yield and improve the profitability of other mineral nutrients. Similarly, Tran et al. (2004) conducted research on numerous farms in the RRD and found that potassium could be a serious yield-limiting factor in rice-maize cropping system on degraded soil. Though the soil exchangeable potassium initially was 0.22 $Cmolkg^{-1}$, the potassium rapidly became a yield limitation factor on rice and maize yield.

Under different cultivated condition (aerobic and flooded systems), the potassium dynamics and soil supply differs (De Datta and Mikkelsen, 1985). In maize, potassium application could affect the Zn uptake while Mg was often found to be yield limiting in maize (Larson and Pierce, 1991; Tran et al., 2004). In addition, nitrate loss in the flooded rice is high, so that it is recommended that high crop yields in the RRD can be approached if the nitrogen and potassium management could match with the soil resource and crop demand (Tran et al., 2004).

5.2. Shifting from intensive tillage to reduced and zero tillage

Reduced tillage is an agricultural practice that minimizes soil disturbance and returns crop residue and stubble to soil to building up soil organic matter and protecting soil structure and keeping soil water. According to Lampkin (1994), under conventional agriculture, tillage is used to soften the soil surface and create seedbeds to transplant seedling or direct seed. Tillage also helps to control weeds and create advantages for crop to compete with weeds in the early growth cycle. Tillage also helps to release some nutrient via mineralization and oxidation after exposing soil organic matter to the air. Tillage can help to control soil born diseases and some insects. However, Li et al. (2011) indicated that tillage killed the profit worm, buried soil microorganisms, disturbed the soil surface and caused the leaching of several nutrients and led to unsustainable agriculture systems.

It was found that under conventional agriculture, agrochemical is abused and overused. The accumulation of agrochemical residues in the environment leads to water and air contamination. The agrochemical residue on crop products can harm human and animal health (Hobbs et al., 1990). Considering the rising problems associated with traditional agriculture, a holistic approach of crop cultivation that was in harmony with the environment (namely "sustainable agriculture" or "conservation agriculture") was developed. The principles of sustainable agriculture are minimal soil surface disturbance, maintaining the soil cover and implementing crop rotations (Hobbs et al., 2008; Karlen et al., 1994).

Several steps are necessary for the shift from conventional agriculture to conservation agriculture. However, this paper just focuses on the possibility to change from extensive tillage practice in rice-maize system to reduced tillage practice. Though the proportion of the reduced tillage areas is small compared with that of conventional agriculture, reduced tillage has been adopted and is expanding in many countries. Derpsch and Moriya (1999) reported that in Brazil a reduced tillage system helped to increase the crop yield by 67.2 million tons within 15 years while bringing 10 billion dollars in revenue. In addition, zero tillage also reduced the fuel used to run tractors and reduced the cost of labor. Hobbs et al. (2008) reviewed the effect of managing crop residues and cultural practices on soil quality, soil nitrogen nutrient and crop productivity in reduced tillage practice. The review reported that the crop residues used as mulch played an important role in improving crop production because crop residue improved the soil physical, chemical and biological characteristics as well as having good effects on soil water and soil quality. In addition, using crop residues can possibly reduce the rainfall intensity on the soil surface, protects soil aggregates, reduced clogging of soil pores, reduces water infiltration to prevent surface runoff and soil erosion and it leads to a higher yield than tilled soils (Dumanski et al., 2006). Surface mulch reduces the soil water losses by preventing evaporation and helps moderate soil temperature, promotes soil biological activities and increases nitrogen mineralization in the surface layers (Karlen et al., 1994).

5.3. Building integrated pest management and integrated crop management

Research on the utility of pesticides in Vietnam showed that the application of insecticides on rice was sometimes unnecessary, and most of the pesticides (42%) were used to remove the green leafhopper. However, the application of pesticides did not associate with the current pest situations (Naylor, 1994; Berg 2011, Pham et al., 2011b). According to Naylor (1994) millions of farmers in Asia considered insecticides as an advanced product with medicinal qualities that protects their crops from the ailments. Due to this misconception farmers have been overusing pesticides. In the Philippines the increase in agriculture productivity the last three decades was the result of the utilization of pesticides and chemical fertilizers. Around 70% of farmers use pesticides as their main crop protection method. Moreover, some restricted pesticides are even used (Javier et al., 2003). A survey in Southeast Asia showed that of all the farmers who participated in the study, 31% of them considered all insects as pests, and most of them applied insecticides when there was a sign of any type of pests (Gallagher et al., 2009). Besides that, though there was an introduction of new pest resistant rice varieties to farmers, the pesticide spraying levels are still constant. According to the World Health Organization, 20% of the chemical pesticides used in Vietnam were classified as extremely hazardous. The utility of pesticides does not influence the rice exportability, but the residuals of pesticides remain in the soil and will affect the future rice crop yields (Naylor, 1994).

Literature reflects that early pest control methods brought serious potential adverse effects to the environment, beneficial insects and human health (Friedrich, 1998). In addition, the abuse of pesticides in traditional farming system reduced the famers' crop productivity and lessened their income from their farms (Naylor, 1994; Norton et al., 2005; Shepard et al., 2009).

IPM is an environmentally sensitive pest control that tries to bring benefits to farmers. From implementing IPM famers know more about their farming system, so that IPM has the potential to gain more acceptances from farmers than other pest control methods (Maredia, 2003). In 1986, there was an outbreak of the brown plant hopper in Indonesia. Researchers showed that the constant use of pesticides had been encouraging the development of pesticide resistance in the brown plant hopper. When IPM was applied, the utility of pesticides was dropped by 75%. Significant increase of rice yield encouraged Indonesian farmers to adopt IPM program effectively (Norton et al., 2005). The Food and Agriculture Organization (FAO) launched a program that brought IPM to the farmer in Southeast Asian paddy rice in the 1980s and 1990s. The program had 35,000 trainees and about 1.2 million farmers exposed to IPM (Shepard, 2009). Van de Fliert (1998) found that the farmers who applied the IPM program on their field obtained higher yields than that of non-IPM fields. Besides that the income returns from the crop was higher because the expenditure for pesticides was cut down. In China, after the IPM training course provided by FAO in 1989, the IPM trained farmers saved more than 30% on pesticides in rice but still obtained a 7% higher yield than that of untrained farmers (Maredia, 2003). Javie et al. (2003) indicated the same result in the Philippines with the increase of rice yield by 4.6 to 62% and the 15% of pesticide expenditure (in total cost) was mostly eliminated. In Vietnam, the pesticide utility on rice was reduced 80 to 90%, in some agro ecological areas there were no pesticides used with the increase in rice yield of 4% and over 20% increase in profits (Gallagher et al., 2009). The same good result from IPM was found in Indonesia (Oka, 2003).

Numerous destructive pests and diseases have challenged rice-maize systems in the RRD. Both rice and maize are host plants to the same pests and diseases so that it is recommended that a practical IPM should be implemented in the field to control pests and diseases (Llanto et al., 2004).

Integrated Crop Management (ICM) is considered as a sustainable approach to the rice-maize production system in the Red River Delta of Vietnam (Pham et al., 2011a). ICM in rice-maize system is not only focusing on crop protection but also on other aspects such as soil, variety, IPM, social and environmental management. According to Pham et al., (2011a), the fields in the RRD that applied ICM technologies package could bring 15-22% higher income. However, it can be denied that together with the growing of interest in IPM and ICM, the constraints and challenges to implementing IPM and ICM worldwide have also emerged. Sherpa et al. (2009) compared the implementation of IPM in the developing countries and developed countries. The result showed that in the developed countries the farmers welcomed more the IPM program than farmers in the developing countries. Besides that, in the developed countries farms are usually larger and the farmers are better educated than in developing countries. A survey conducted in Northeast USA found that the public's awareness of IPM term and how it works are not well developed. The research also indicated that 45% of consumers did not care how their food was produced (ICM or non ICM farming) (Anderson et al., 1996). In the developing countries, the IPM farming system has not reached all the growers and not all the growers who knew about IPM were ready to change their traditional farming styles (Sherpa et al., 2009). However, with the good documentation of these programs and the published papers, the attitude of both growers and consumers about the contamination with agrochemicals of the environment and the impact on human health was increased (Anderson et al., 1996). In addition, in developing countries, the government policies have made some good signs to reduce agrochemicals and banned some toxic pesticides and invested in developing a new farming system (Sherpa et al., 2009).

6. Zero and reduced tillage advantages

In order to shift from the conventional agriculture to conservation agriculture, there are several steps. However, this paper just focuses on the possibility to change from extensive tillage practice in rice-maize system to reduced tillage practice. Though the proportion of the reduced tillage areas is small compared with that of the conventional agriculture, reduced tillage has been adopted and is expanding in many countries. Derpsch and Moriya (1999) reported that in Brazil a reduced tillage system helped to increase the crop yield by 67.2 million tons within 15 years and bring revenue of 10 billion dollars. In addition, zero tillage also reduced the fuel used to run tractors and reduced the cost of labor. Hobbs et al. (2008) reviewed the effect of managing crop residues and cultural practices on soil quality, soil nitrogen nutrient and crop productivity in reduced tillage practice. The review reported that the crop residue used as mulch played an important role in improving crop production because crop residues improved the soil physical, chemical and biological characteristics as well as having good effects on soil water and soil quality. In addition, using crop residue as possible can reduce the rain intensity on the soil surface, protect soil aggregates, clogging of soil pores, reduce water infiltration to prevent surface runoff and soil erosion and give a higher yield than tilled soils (Dumanski et al., 2006). Surface mulch reduces the soil water losses by preventing evaporation and helps moderate soil temperature, promotes soil biological activities and increases nitrogen mineralization in the surface layers (Karlen et al., 1994).

In Vietnam, reduced tillage practices have been certified by the Vietnamese Ministry of Agricultural and Rural Development (MARD) in several crop productions such as in potato, in maize and soybean. The result has shown that the application of the reduced tillage increased the potato yield by 10-15% and saved more than 30% compared with the conventional practices (Nguyen, 2013). According to Hoang (2013), in several provinces in RRD the application of reduced tillage is increasing. In Nam Dinh, the maize areas that applied reduced tillage in 2013 are estimated at 4,000-5,000 ha. In addition, the RRD is usually exposed in September to heavy rains and flooding, therefore applying reduced tillage practices in the rice-maize system is an effective way to sowing maize in time without any lost to final yield (Hoang, 2013).

7. Guidelines to approach reduced tillage practice

The adoption of zero tillage based on conservation agriculture is high among commercial farmers in Southeast Asia. However, the adoption of these farming practices among smallholder communal farmers is not very high (Dumanski et al., 2006). In order to increase the adoption of reduced tillage among smallholder farmers, a significant conservation agriculture program needs to be developed (Hobbs et al., 2008). In the RRD, though the reduced tillage has been introduced in the area but the application is not high. In addition, the farmers still neglect or hesitate about its advantages. Therefore, the suggested guidelines to develop conservation agriculture in rice cultivation in the RRD are as below:

- Organising workshops, conferences or information leaflets for the farmers to:
  - Improve the awareness and appreciation of the limitation of conventional agriculture;
  - Introduce conservation agriculture by raising awareness of possible technological options to address the conventional agriculture limitation.
- Demonstrate the advantages of conservation agriculture by:
  - Conducting conservation agriculture in target areas by choosing farmer leaders in each community to implement conservation and invited farmers to come and visit;
  - Using public media to advertise the research results;
  - Technical and financial assistance to help the farmers who are willing to apply the technology.
- Accessing the benefits of conservation agriculture with the conventional method. The assessment should focus on the impact on the soil, environment, the crop yield and quality, and the farmer income.

8. Conclusion

The current traditional cultivation method in rice maize systems in Vietnam is found to be unsustainable and the major reason to induce this was the impact of extensive tillaging on the soil properties. Reduced tillage practice was introduced as part of sustainable agriculture to the rice maize cropping system in the RRD of Vietnam and several reduced practices have been developed for primarily crops in the areas. However, this technology has not been widely accepted by the farmers. To encourage people to adopt this new technology, there is a lot of work such as improving the farmers' awareness about the current issues in their traditional cultivation, demonstrating the reduced tillage advantages and the profits. It is also recommended that the government needs to have a policy to support conservation agriculture in order to encourage farmers to participate in shifting to new cultivation methods, and the agricultural research institutes should develop conservation practice package for each crops and provide technical and financial support to growers.

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