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NUTRIENT BALANCES IN TERRACED PADDY FIELDS UNDER TRADITIONAL IRRIGATION IN INDONESIA

Thesis submitted in fulfillment of the requirements
for the degree of Doctor (PhD) in Applied Biological Sciences

Dutch translation of the title:
NUTRIENTENBALANSEN IN TRADITIONEEL GEIRRIGEERDE RIJSTVELDTERRASSEN IN INDONESIE

Cover illustration:
Front: General view of terraced paddy fields in Keji Village, Indonesia (DS 2004)
Back:
Monthly meeting with the participating farmers, key persons, researchers and the village head
Planting elephant grass and king grass to increase productivity of dry land agriculture and to provide fresh fodder in Keji Village

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Kris, April 2007

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List of abbreviations

AVG	Average
BPS	Biro Pusat Statistik means the Statistic Agency
BS	Base Saturation
CEC	Cation Exchange Capacity
CFP	Conventional Farmer Practices
CFP + RS	Conventional Farmer Practices + Rice Straw
DAT	Day After Transplanting
DS 2004	Dry Season 2004
FFTC	Food and Fertilisers Technology Centre
HYV	High Yielding Variety
IN	Input parameter
IRRI	International Rice Research Institute
IT	Improved Technology
IT + RS	Improved Technology + Rice Straw
IWMI	International Water Management Institute
KCl	Kalium Chlorida (Potassium Chloride)
l	litre
MSEC	Management of Soil Erosion Consortium
OUT	Output parameter
ORBA	Orde Baru means the New Order Government
PELITA	Pembangunan Lima Tahun means Five-Year Development Plan
PRA	Participatory Rural Appraisal
RS	Rice Straw
S	Sediment Concentration
s	Second
SRI	Soil Research Institute
TSP	Triple Super Phosphate
WMO	World Meteorological Organisation
WS 2003-04	Wet Season 2003-04

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Chapter 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

1.1. Background

Agriculture plays an important role in the developing economy of Indonesia. It provides 46.3 % of the job opportunities, contributes for about 6.9 % to the total non-gas and petroleum export and for about 17.5 % to the Gross National Product (GNP). It consists of four sectors, namely agriculture, forestry, livestock, and fishery (Anonymous, 2004; BPS, 2004a; National Information Agency, 2003). In the agricultural sector there are various levels of management, from modern (by national and private estates) to traditional (by farmers), from big companies to small holder farmers. Various kinds of commodities are cultivated, from perennials (such as industrial and estate crops), to annual crops (such as food crops, cash crops and vegetables).

In the year 2025, the predicted Indonesian population will be about 270 million an increase of 45 million people from the current figure of 225 million. This brings about a growing food, water, and land demand. For unhusked rice alone annual consumption may increase by 30 %, representing about 17 million tons from the current 53 million tons annual consumption (Agus *et al.,* 2006). The pressure on the land and fresh water resources is becoming high. Land for housing, industrial areas, road facilities, and other infrastructure will result in a significant conversion of agriculture land. It is reported that about one million ha or 30 % of the rice field areas on Java island or 1.6 millions ha in Indonesia have been converted to non-agricultural purposes between 1981 and 1999 (Adimihardja *et al.,* 2004; BPS, 2002a). Irrigated agriculture also faces competing demands from other sectors, such as industry and urbanisation. The available water for irrigation, therefore, is becoming increasingly scarce, thus constraining for more rice production. With these situations, the great challenge ahead of agriculture in Indonesia is how to produce more food from limited land and water. Hence, more attention should be given to other wetland rice systems such as terraced paddy field systems.

The changes in political (from a centralised government to district autonomy systems), social, and economical approaches in general are identified as the main reasons in the rapid conversion of land-use. The rate of conversion of rice field or agricultural land to non-agricultural utilisation tends to increase by the time because of following reasons (Agus *et al.,* 2006; Sukristiyonubowo *et al.,* 2004):

- There is no valid and accurate master plan at district level providing information of the area that should not be converted (as protected lowland rice areas) because of high productivity and good infrastructure
- There is no reward nor punishment to those keeping and selling lowland rice or agricultural land with high productivity and good infrastructure
- Involvement of various agencies in the issuance of land conversion permits has weakened the control of conversion
- Autonomy has often been interpreted by the district government as an opportunity to increase the local government revenues that can easily be generated if more land is used for industrial and urban development purposes
- Conversion of paddy field or agricultural land to industrial and housing areas has been seen by local farmers as an opportunity to earn more money and obtain higher 'social status'
- Selling paddy fields is considered as an opportunity to earn cash for investment in other sectors.
- Lack of awareness at policy maker and community levels concerning the significant negative impacts of land use change.

More than 90% of the rice (*Oryza sativa* L.) is produced and consumed in Asia. Most rice growing areas in tropical Asia are monsoonal, characterised by a distinct monsoon season and a non-rainy season. In the rainy season, rice is cultivated with supplemental irrigation or only using rainwater, whereas during the dry period rice is fully irrigated. Meanwhile in rainfed lowland rice production, the rice lands often remain fallow or are used to produce legume during the dry season. Rice in Indonesia is extensively cultivated from the lowland to the upland areas as staple food. In 1996 about 8.5 millions ha of land were farmed to produce rice. This has been reduced to 7.8 millions ha in the year 2002 (BPS, 2002a).

In the past, most work was conducted in lowland rice with half or fully regulated technical irrigation systems to maximise rice production with high inputs and good facilities. As a result, in 1984 Indonesia successfully reached self-sufficiency in rice. Afterwards, however, rice farming in Indonesia faced many problems, such as in the beginning of 1990's levelling off in rice production and since 1997 increasing prices of agricultural inputs and reducing management levels. Regarding these problems, Indonesian farmers need a technological breakthrough (applicable technology) to manage their rice fields and improve the yields. Therefore, since the last decade, an economically cheap, socially accepted and environmentally friendly agriculture has been developed. Priorities are given to increasing agricultural production, to minimising environmental problems, and to supporting food security programmes for future generations.

In most rice-growing areas, irrigation and fertilisation are considered as two keys in managing paddy fields. As rice farming is done by farmers with different levels of management and socio-economic status, the scientific community is challenged to provide quantitative technical information to guide the farmers in making decisions in order to optimise the dual goal: to improve rice yield and lessen environmental degradation.

In Keji Village, where the research was located, most farmers only apply urea of a rate of 50 kg $ha^{-1}season^{-1}$. These practices obviously reduce soil fertility and rice yield, which was shown from a preliminary study. Therefore, the proper use of fertilisers is crucial and becoming one of the main factors to increase and to sustain soil fertility and rice yield (Agus and Sukristiyonubowo, 2003; Sukristiyonubowo *et al.,* 2004; 2003). It is also interesting to note that in this village terraced paddy fields with traditional irrigation systems are commonly found to produce rice and that agricultural practices are largely based on farmers' experiences, whereas in the past most studies have generally been carried out in lowland rice fields with technical irrigation systems.

1.2. Site Description

1.2.1. Socioeconomic setting

Historically, Keji Village, where the Babon catchment is situated, is a dynamic village in terms of agricultural, social and economical activities. It has a total population of about 1,852 people with a population density of about 1,000 persons per km^2. The number of households is 405 and most of them are farmers. Only about one-third earn money from off-farm activities. Keji Village, administratively under Ungaran Sub District, is located about 3 km west of Ungaran, the capital city of the Semarang District, and about 20 km south of

Semarang, the capital city of the Central Java Province. Accessibility from the village to both capitals of district and province is not very low. This gives opportunity to the villagers to communicate with others, to move, and to have off-farm activities, such as trader, carpenter and labour. Therefore, off-farm activity is becoming an important source of family income. A socio-economical survey revealed that around 40 % of the village labour force can expect more than Rp 2,000,000 (250 US dollars) annual income from off-farm activity while only about 22 % of villagers can make more than Rp 2,000,000 (250 US dollars) annual income from on-farm sources. On average, 36% of total family income (Rp 2,980,400 or 375 US dollars) is earned from off-farm sectors (Agus *et al.,* 2001b). Although the off-farm sector is important, farming is still conducted for food security and additional income. Farmers also realise that the lower income of on-farm activities is due to low-external input application. From the annual expenditures, only 5 % of annual incomes are allocated to agricultural inputs, which is lower than for social and miscellaneous secondary consumption.

The rice farming systems practiced by most farmers living in this village are categorised as subsistence. They are not market-oriented and they cultivate mainly to fulfil their own family demand. Fertiliser application is imbalanced due to a lack of capital. Family ties and communal systems are strong among the villagers. This means that new technologies or programmes will be more successfully introduced if they are created and developed among people having communal ties. When the members or key person give positive response, we can hope that the technology will easily be accepted and implemented. So far, the office of the village head also plays an important role in farming and development programmes. A monitoring and evaluation survey conducted in 2002 indicated that new programmes are usually acknowledged and registered in the village head office. In addition, the secretary of village, and the head of sub villages are actively involved in the agricultural activities (Sukristiyonubowo *et al.,* 2002).

1.2.2. Biophysical setting

The study area is located at an elevation between 390 and 510 m above sea level. About 55 % of the area is steep to very steep (25-75 % slope) and only a small portion of the valley bottom has plain and undulating slopes. Two seasons, a wet season, from November to April, and a dry season, from May to October, characterise the climate. The mean annual rainfall is about

3 140 mm and is bigger than the mean annual precipitation of the Ungaran Sub District (3 063 mm) and the Semarang District (2 635 mm) (Agus *et al.,* 2003; BPS. 2003b; 2002b; 2000; Sukristiyonubowo *et al.,* 2004; 2003).

Inceptisols are the dominating soils in the Babon catchment. Four groups and five subgroups were identified from the soil characterisation. Eutrudepts, Endoaquepts, Epiaquepts and Dystrudepts are the main soil groups, while Aeric Epiaquepts, Andic Eutrudepts, Humic Eutrudepts, Aquic Eutrudepts, and Andic Dystrudepts are dominating soil subgroups (Figure 1. 1). Detailed soil profile descriptions have been published by Siswanto (2006).

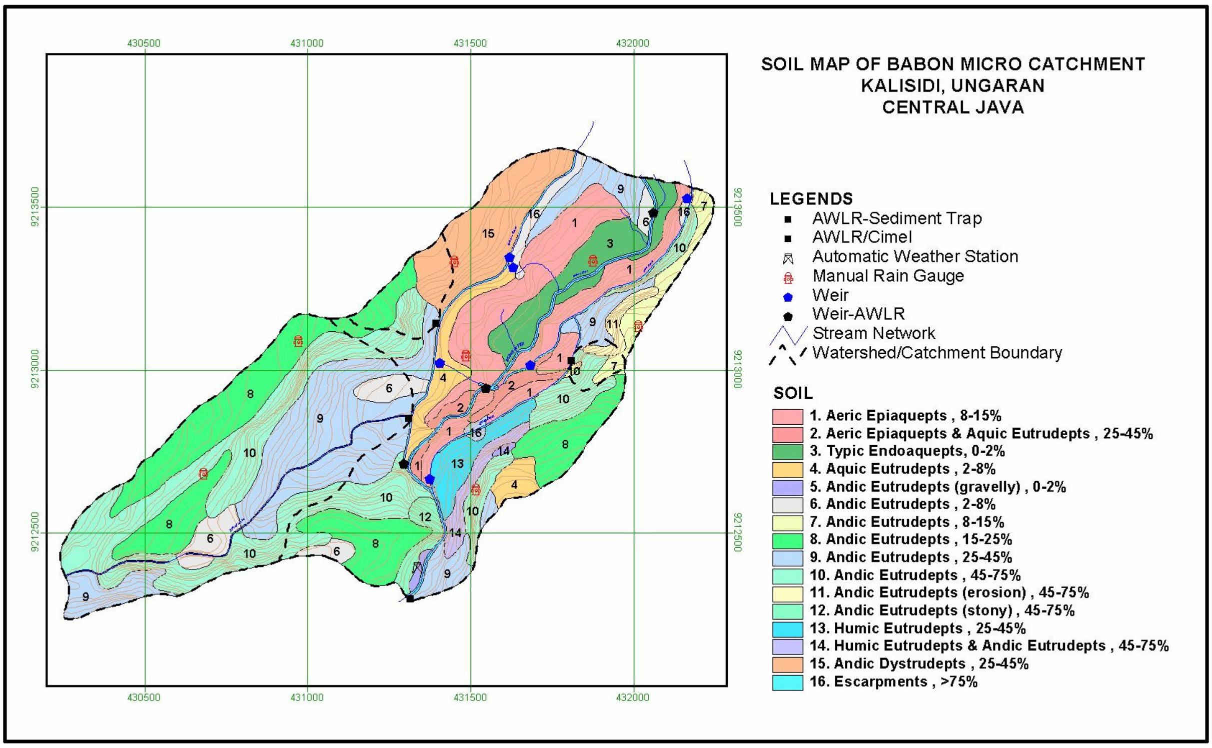


Figure 1.1. Soil map of the Babon Catchment, Ungaran Sub District, Semarang District

Agricultural commodities commonly found in the Babon Catchment area include wetland rice (*Oryza sativa* L.), cassava (*Manihot esculenta*), peanut (*Arachis hypogea*), bamboo (*Bambusa vulgaris*), elephant grass (*Pennisetum purpureum*), banana (*Musa paradisiaca*), coconut (*Cocos nucifera*), gnetum (*Gnetum gnemon*), rambutan (*Nephelium lappaceum*), nutmeg (*Myristica fragrans*), coffee (*Coffea robusta*), *Albizia falcataria*, and durian (*Durio zibethinus*) (Figure 1. 2). Except for rambutan, all commodities are managed in a traditional way and mainly grown in a simple agroforestry system. Wetland rice, elephant grass, and rambutan are the dominating crops. Wetland rice as a terraced paddy field system is spread out along the valley bottom, covering an area of about 17 ha out of the 139 ha of the lower Babon catchment (Agus *et al.,* 2001).

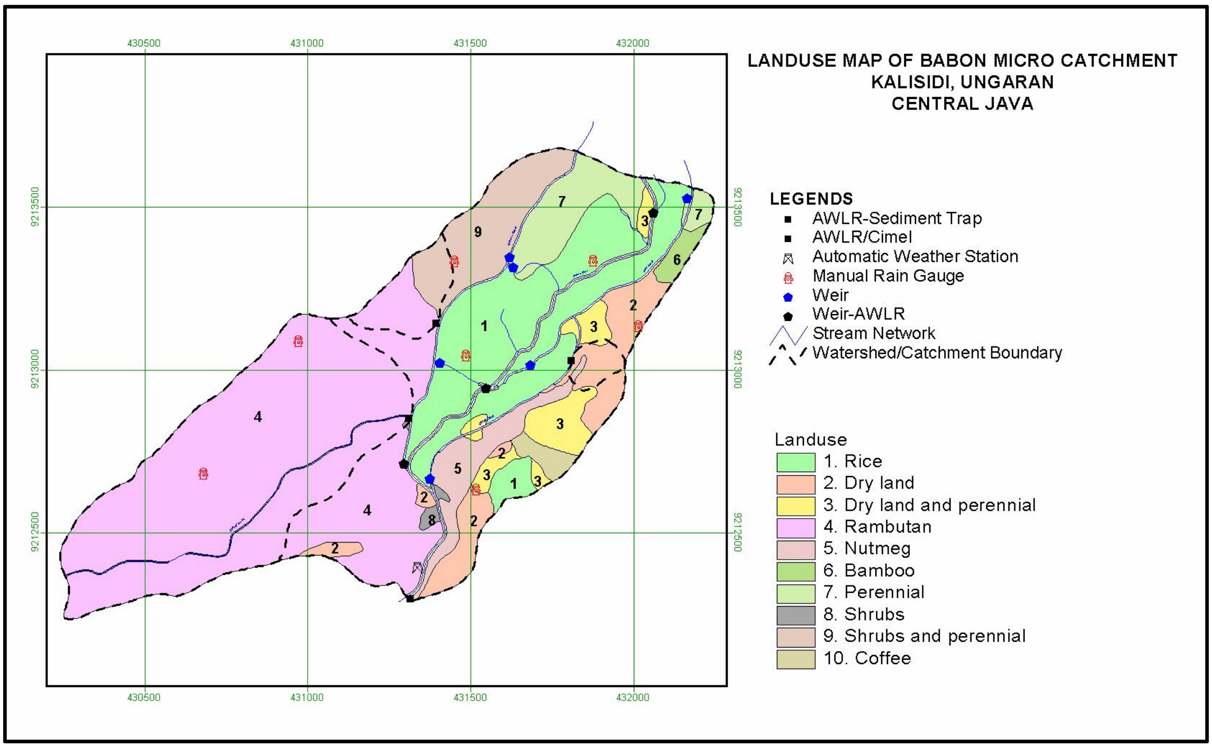


Figure 1.2. Land use map of the Babon Catchment

1.3. Objectives

In the current study, simple treatments that have been developed and tested together with the farmers during previous studies are continuously modified to improve rice yields. Moreover, rice straw recycling to improve soil fertility and to balance nutrients is evaluated, as rice straw was found to be rich in nutrients. Other studies identified variations in inflowing and outgoing sediment and nutrient amounts during the rice-growing period (Sukristiyonubowo *et al.,* 2004; 2003). Therefore, the following research objectives can be distinguished:

i. To study sediment and nutrient movements and behaviour at different agronomic activities

ii. To study nutrient uptake during rice growth and development under different fertiliser and rice straw management
iii. To evaluate the effect of conventional farmer practices and improved technology on biomass production and nutrient balances
iv. To assess the supplementation of 33 % of rice straw produced $ha^{-1}season^{-1}$ on rice yield and nutrient balances
v. To evaluate the evolution of the rice production from 1978 to 2003
vi. To evaluate nutrient balances of wetland rice farming systems using inorganic and organic fertilisers

These objectives were investigated at the field scale during the cropping season 2004: a wet season 2003-04 and a dry season 2004. Bottom up approach was applied involving twelve farmers. The results are presented in the five following chapter. In chapter 2, sediment and nutrient (N, P, and K) movement behaviour in terraced paddy fields system is discussed. Irrigation water and run off sediments were sampled at harrowing and fertilising. In chapter 3, nutrient concentrations and uptake during rice growth are explored. In chapter 4, the effect of farmer practices and improved technology combined with rice straw application on rice production is discussed. Four treatments were developed along with the farmers and tested both in the wet season 2003-04 and dry season 2004. In chapter 5, a nutrient (N, P, and K) balance is set up according to input and output data presented in the previous chapters. Finally, in chapter 6, the nutrient balance for the wetland rice farming at district level is also analysed using secondary data. Data of rice yield, producing area, total rice production and rainfall from 1978 to 2003 mainly provided by BPS (*Biro Pusat Statistik* meaning Statistic Agency) at district, provincial and national levels were considered to calculate nutrient budgets. This period displayed different situations including the severe economic crisis that struck Indonesia in 1998. The data were grouped according to a Five-Year Development Programme (*PELITA*) executed in Indonesia to achieve national development goals.

Chapter 2

SEDIMENT AND NUTRIENT MOVEMENT BEHAVIOUR IN TERRACED PADDY FIELDS SYSTEM

SEDIMENT AND NUTRIENT MOVEMENT BEHAVIOUR IN TERRACED PADDY FIELDS SYSTEM

Abstract

We aimed to evaluate inflowing and outgoing sediments and nutrients in terraced paddy fields system and to study sediment and nutrient movement behaviour at harrowing and fertilising under traditional irrigation. The study was conducted at Keji Village, Semarang District, Central Java Province during two cropping seasons, a wet season 2003-04 and a dry season 2004. A rice field with eight terraces was selected. The terraces were flat, different in size, and arranged descending to the river. Suspended sediments were sampled at harrowing and fertilising, from the main inlet, outlet of terrace 1, outlet of terrace 2, outlet of terrace 3, outlet of terrace 4, outlet of terrace 5, outlet of terrace 6, outlet of terrace 7 and main outlet. Samples were collected in 600 ml plastic bottles. The results indicate that at harrowing outgoing sediment (measured at the main outlet) was higher than incoming sediment (measured at the main inlet), both during the wet season 2003-04 and dry season 2004. About 0.53 and 0.27 t ha^{-1} day^{-1} of soil were eroded during harrowing in the wet season 2003-04 and the dry season 2004, respectively. However, a week before and after fertilising both in the wet season 2003-04 and dry season 2004, the incoming sediment amounts from irrigation canal (measured at the main inlet) were higher than the outgoing (measured at the main outlet). In the wet season 2003-04, incoming sediment amounts were three to four times higher than outgoing both a week before and after fertilising. During the wet season 2003-04, about 0.31 and 0.34 t ha^{-1} day^{-1} of the sediments were deposited in terraces a week before and after fertilising, respectively. During the dry season 2004, the incoming sediment amounts were ten times higher than the outgoing. On average, the amounts of sediment deposited were about 0.07 and 0.08 t ha^{-1} day^{-1} a week before and after fertilising, respectively. Contrary to sediment movement at harrowing, the amounts of incoming nutrients were higher than the outgoing, except for P in the wet season 2003-04. However, at fertilising incoming nutrients were higher than the outgoing both during the wet season 2003-04 and dry season 2004. This was similar to the sediment behaviour. A net input of N and K was observed at harrowing during the wet season 2003-04 and dry season 2004. This also occurred at fertilising, but gained amounts of N, P, and K were greater. Every terrace presented a different behaviour in transporting and trapping sediment and nutrients. In terraces having greater surfaces, more sediment and nutrients were deposited than terraces with smaller sizes. These results demonstrated that terraced paddy field system is not only the way to produce rice, but also provides environmental services like trapping sediment and conserving nutrients, which may reduce a negative environmental impact downstream.

2.1. Introduction

Rice is the oldest and most important food crop in the world (Mikkelsen *et al.,* 1995). According to Bhagat *et al.* (1996) about 148 million hectares of wetlands are planted every year, taking into account two or three cropping seasons. About 90 % is produced and consumed in Asia. A fast population growth, increasing land demands for housing and industrial areas, and water pollution result in the shrinking of agricultural land, increasing fresh water scarcity, and decreasing rice production (Agus *et al.,* 2006; Bhagat *et al.,* 1996; Bouman and Tuong, 2001). It has been reported that in many Asian Countries, fresh water availability declined about 40 - 60 % per capita between 1955 and 1990. Good water control is still lacking in most parts of tropical Asia (Bhagat *et al.,* 1996; Bouman and Tuong, 2001). As in fact 75 % to 97 % of the total rice production comes from irrigated lowlands, the challenges ahead in rice growing areas are to save water and thus increase water productivity in conditions of limited land availability (BPS. 2003a; Bouman and Tuong, 2001). Hence, enhancing the role of terraced paddy fields in Indonesia to meet the growing rice demand is becoming urgent.

Topographically, rice farming systems in Indonesia are conducted from the low lands to the high lands or mountainous areas as terraced paddy field systems. The rice produced is called either lowland rice or upland rice. Depending on the water sources, distinction can be made between irrigated lowland rice, rain fed lowland rice, irrigated terraced paddy field, and rain fed terraced paddy field systems. In most terraced paddy field areas (including the research site), traditional irrigation is commonly applied. In this system, upstream water flows through streams and natural canals with little or no irrigation facilities are constructed.

Rice (*Oryza sativa* L.) in Indonesia is mostly grown under lowland conditions with one to three cropping seasons per year, depending upon rainfall, availability of irrigation water, and rice variety. In the Central Java Province, one of the 33 provinces in Indonesia, about 1.58 millions ha of lowlands were cultivated to produce rice in 2002 (BPS. 2003a). The first step in wetland rice production is land preparation, commonly named puddling. During this activity, water is added to the rice field until ponding water reaches a level of one to five cm above the soil surface. The process generally consists of land soaking, ploughing, and harrowing. The intensity of puddling varies among farmers and villages. In traditional rice growing areas, two ploughings and one or two harrowings under submerged conditions are carried out. Ploughing is usually done using a hoe and harrowing using draught animals, such as buffaloes and cows with associated implement devices. Puddling, hence, breaks down and disperses soil aggregates into micro-aggregates and individual particles. This results in soft muddy conditions before planting, facilitating transplanting of rice seedlings (young plants).

In the Keji Village, where the experiments are located, two ploughings and one harrowing are usually carried out for land preparation. Before ploughing, water from a canal is flown to the field area until it reaches a layer of 0.5 cm above the soil surface. This is maintained for one or two days (land soaking) to wet and soften the soil. The water levels are gradually increased up to 3 or 5 cm above the soil surface at harrowing. The first ploughing is aimed to cleanse the weed, to turn the soil-weed-rice residues, to break down the soil, and to strengthen the dykes. The second ploughing is mainly done to break down the soil into small aggregates and to fix the inlet and outlet of each terrace. It is followed by harrowing. Harrowing is conducted to puddle, to flatten the soil, and to equalise the water levels above the surface. During harrowing main inlet and main outlet (outlet of the last terrace) are opened allowing runoff water going to the river. This allows soil and nutrients to be carried away from the rice field.

Since water is also allowed to go in and out the systems during the rice growing period, sediment and nutrients may move in the field. This might lead to loss of nutrients, reduce wetland productivity, and reduce environmental quality. The movement of sediment and nutrients in every terrace should be studied to know how much sediment and nutrients are transported and deposited in every terrace. The objectives of this chapter were to evaluate in flowing and out going sediments and nutrients and to study sediment and nutrient behaviour at harrowing and fertilising in a terraced paddy field under traditional irrigation during the cropping season 2004: a wet season 2003-04 and a dry season 2004.

2.2. Literature Review

The whole management practice in wetland rice cultivation includes land preparation, planting, weeding, fertilising, pest and disease control, harvesting and processing. Transplanting and direct seeding are dominant planting systems in wetland rice production. These systems require a soft muddy soil structure resulting from land preparation. In wetland rice systems, a ponding water layer of about 5-10 cm above the soil surface is maintained in the field throughout the rice growing period, especially during vegetative to reproductive phases (Anbumozhi *et al.,* 1998; Bhagat *et al.,* 1996; Bouman and Tuong, 2001; Sukristiyonubowo *et al.,* 2004). During rainy seasons, rainwater is the major water source whereas irrigation water is dominantly applied to compensate water needs during dry periods.

The first management process in rice cultivation is land preparation. The aims are to reduce the loss of water and nutrients through excessive percolation, to control weeds, to soften the soil, to create land levelling, to uniform water depth, and to facilitate transplanting. The effect of puddling on physical and chemical properties as well as on rice yield has been researched and reported, although the effect of puddling on rice yield is still not clear (Adachi,. 1990; Cabangon and Tuong, 2000; Kirchhof *et al.,* 2000; Kukal and Sidhu, 2004; Sharma *et al.,* 2005). Puddling has however been reported to increase rice yield (Ghildyal, 1971; Naphade and Ghildyal, 1971; Sanchez, 1973; Sharma *et al.,* 2005).

It is known that among other crops, rice is less efficient in water use (Taball *et al.,* 2002). Water is usually added from land preparation to the generative phase and is stopped when the rice is entering the ripening stage. In Asia, about 45 % to 50 % of diverted fresh water is allocated to irrigate rice (Bouman and Tuong, 2001; Cabangon *et al.,* 2002; Kukal and Sidhu, 2004). The amount of water to produce one kg of rice varies between 3000 and 5000 litres and is significantly greater than for other cereals (Bhuiyan *et al.,* 1994; Bhuiyan, 1992; IWMI. 2004). Other studies mentioned that the rice productivity on a water use basis in continuously flooded rice in India is about 0.2 - 0.4 g rice per kg water and about 0.14 - 1.1 g per kg water in the Philippines (Bouman *et al.,* 2005; Bouman and Tuong, 2001; Taball, *et al.,* 2002). Anbumozhi *et al.* (1998) specifically reported that the rice productivity on a water use basis on a Vitric Andosol in Japan is about 1.52 g rice grains.

More than half of the water input to produce rice is allocated to land preparation. Theoretically, the water required for land preparation is about 150 - 200 mm, but it can increase up to 650 - 900 mm when the duration is longer (De Datta *et al.,* 1981; Bhuiyan *et al.,* 1994). Bouman *et al.* (2005) reported that the total amount of water used for wetland preparation (soaking and puddling) varies from 260 to 434 mm. In terraced paddy field systems, it is about 95 - 112 mm especially during harrowing (Sukristiyonubowo *et al.,* 2004; 2003).

Sediment can be transported by wind, water, and tillage or mass movement. Erosion has been identified as a serious environmental problem or irrigated farmlands, requiring expanded research (Agus *et al.,* 2003; Agus and Sukristiyonubowo, 2003; Aksoy and Kavvas, 2005; Duque *et al.,* 2003; Lal *et al.,* 1998; Phomassack *et al.,* 2003; Sojka *et al.,* 1992; Sukristiyonubowo *et al.,* 2003; Toan *et al.,* 2003). It was reported that about 0.12 tons ha^{-1} soil are eroded during land preparation (Sukristiyonubowo *et al.,* 2004 and 2003). As soil erosion has impact on agricultural productivity and environmental quality, it is interesting to study incoming and outgoing sediment and nutrients in the wetland rice system. Tarigan and Sinukaban (2001) reported that besides land preparation, other important activities such as weeding and fertilising should also be taken into account when determining in and out flowing sediments from terraced paddy fields.

Hasyim *et al.* (1998) reported that the nutrient loss by soil erosion is the result of soil loss and nutrient content in the sediment, but in certain conditions it may also be estimated from soil loss and the nutrient content in topsoil. According to El-Swaify (1989), trapping and measuring the quantity of soil removed or estimating the quantity from measurable changes in soil levels are common procedures to determine soil loss with runoff water.

Scientists reported that the amounts of nutrients moving from agricultural fields are influenced by climate, soil, topography, land use, and management practices (Agus *et al.,* 2003; Lal *et al.,* 1998; Robichaud *et al.,* 2006; Sukristiyonubowo *et al.,* 2003; Udawatta *et al.,* 2006). Related to the climate, the amount, intensity, and timing of the first rainfall event after application of agro-chemicals are the most important among factors affecting loads in surface run-off (Daniel *et al.,* 1998). Specifically, Schuman and Burwell (1974) noticed that the intensity and duration of the storm, antecedent moisture, rate of infiltration, and fertility of the soil influence NH_4-N and NO_3-N concentrations in the run off. So far, Douglas *et al.* (1998) and Kissel *et al.* (1976) concluded that N and P losses through runoff are very small, even though the fertiliser is surface broadcasted and tillage is uphill and downhill. Meanwhile, Alberts *et al.* (1978) reported that soluble N and P losses are less than 2% of annual fertiliser application and terracing is an extremely effective nutrient conservation practice when compared to losses from the contour-farmed watershed.

2.3. Materials and Methods

This experiment has been conducted in terraced paddy fields system located in the valley bottom of the Babon meso catchment, sub catchment of Kaligarang Watershed, Keji Village, Ungaran Sub District, Central Java Province, Indonesia. Soils are classified as Aquandic Epiaquepts, medial, isohyperthermic. Water velocity, water discharge, sediment concentration and nutrient contents in irrigation water and runoff water were measured at harrowing and fertilising in the cropping season 2004, the wet season 2003-04 and the dry season 2004.

The way of ploughing, harrowing, adjusting the flux of incoming and outgoing water, and fertiliser use were fully based on farmers' experiences. The only intervention was placing a V-notch weir at every terrace outlet to accurately measure water discharge using the Bucket Method and to facilitate sampling of sediment runoff.

A terraced paddy area with eight terraces has been selected for this study. The terraces were flat, different in size, and arranged descending to the river (Photo 2. 1). The total surface is about 904 m^2. Outlets with a 90^0 V-notch were placed on each successive terrace arranged alternately on the left, centre and right edges descending to the river. More details of the arrangements are given in Figure 2. 1.

2.3.1. Land Preparation

Land preparation was done in three steps: land soaking, ploughing, and harrowing (Photos 2. 2 and 2. 3). The first ploughing included rice straw distribution and was carried out about one week after harvesting and processing. The second took place a week later followed by harrowing a day after the second ploughing. The puddled soil was untouched for three or four days until the rice seedlings in the seedbed reached the age of about 21 days.

In the wet season 2003-04 (WS 2003-04), harrowing was carried out on 27 December 2003 and in the dry season 2004 (DS 2004) on 8 May 2004 by a couple of buffaloes equipped with a conventional puddler (Photo 2. 3). The works started one day after the second ploughing from 07:00 am to 02:30 pm, beginning at the top terraces. More detailed agronomic activities in the wet and dry season are given in Table 2.1.

Table 2. 1. Date of agronomic activities, sampling of irrigation water and runoff water, and measurement of water discharge at harrowing and fertilising in the wet season 2003-04 and dry season 2004

		Date of activity	
No.	Agronomic Activity	WS 2003-04	DS 2004
1.	Direct Seeding in the Nursery	10 December 2003	24 April 2004
2.	Land Preparation:		
	• Straw distribution	18 December 2003	30 April 2004
	• Land Ploughing I	19 December 2003	1 May 2004
	• Land ploughing II	26 December 2003	7 May 2004
	• Harrowing	27 December 2003	8 May 2004
	Sampling and Discharge measurement at harrowing	27 December 2003	8 May 2004
3.	Transplanting	31 December 2003	15 May 2004
4.	Fertilising I	21 January 2004	6 June 2004
	Sampling and discharge measurement a week before fertilising	15 to 19 January 2004	1 to 5 June 2004
	Sampling and discharge measurement a week after fertilising	24 to 30 January 2004	8 to 13 June 2004
5.	Fertilising II	4 February 2004	19 June 2004
6.	Harvest and rice threshing	19 - 22 April 2004	28 - 30 August 2004

Principally, sampling and measuring discharge were started when the puddled runoff sediment as indicated by brown colour passed the outlet of the terrace and finished when the colour of water was almost the same as the colour of incoming water at the main inlet (Photo 2. 4). Measurements were carried out from 07:00 am, when the farmers started harrowing, to 05:30 pm, three hours after finishing harrowing. Even though the observation was ended at 05:30 pm, the calculations of inflowing and outgoing sediments and nutrients were done on daily basis, as the inlet and outlet were opened for 24 hours to flatten the soil and to equalise the water level. The last samples taken from outlet of each terrace at 05:30 pm or when the colour of runoff water was almost equal to incoming water were used to estimate incoming and outgoing sediments and nutrients until 07:00 am of the following day. The detailed procedures of sampling and discharge measurement are given below.

Photo 2. 1. General view of terraced paddy field systems in Keji Village (T1-8 indicate terraces)

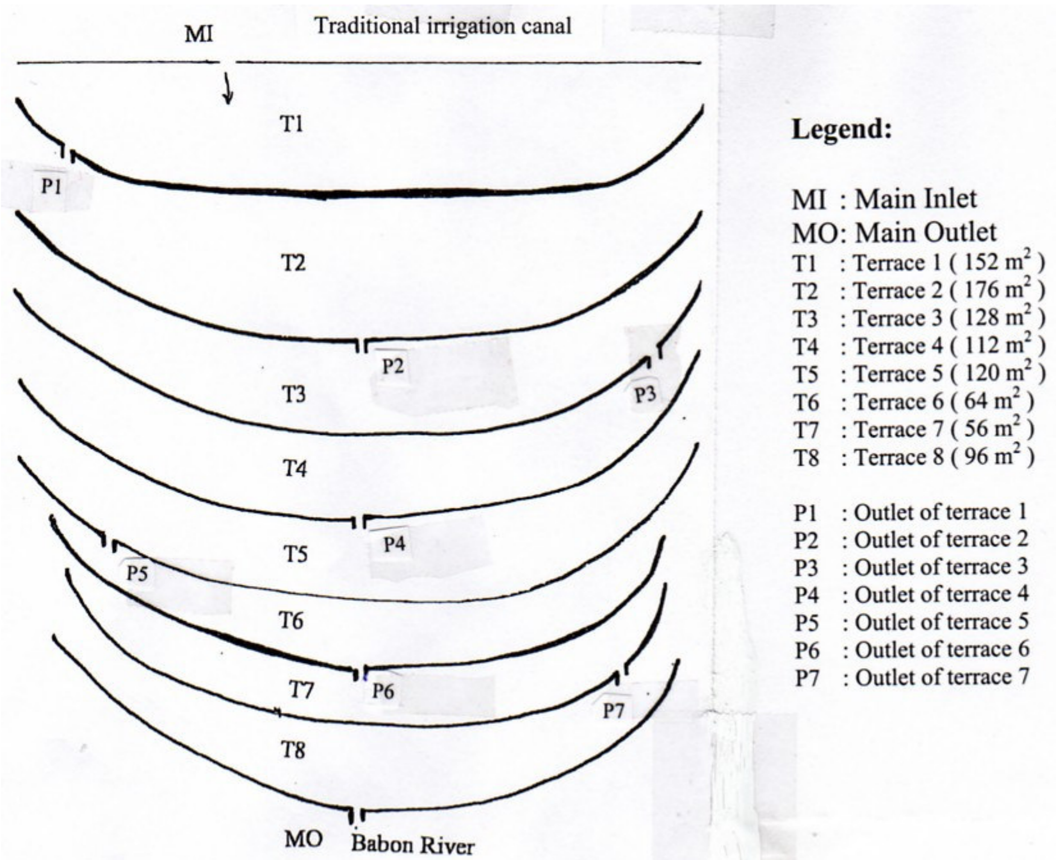


Figure 2. 1. Position of 90^o V-notch weir in every terrace (Scale 1:300 only for terrace size)

2.3.2. Sampling

Sampling of runoff water and measurement of water discharge both at harrowing and fertilising have been described by Sukristiyonubowo *et al.* (2003). However, modifications were made because of differences in objectives. Sampling of runoff water and measurement of water discharge at harrowing were carried out on 27 December 2003 and on 8 May 2004, for the WS 2003-04 and DS 2004, respectively. For a week before fertilising, they were done from 15 to 19 January 2004 and from 1 to 5 June 2004 for the WS 2003-04 and the DS 2004, respectively. For a week after fertilising, they were carried out from 24 to 30 January 2004 and from 8 to 13 June 2004 for the WS 2003-04 and the DS 2004, respectively (Table 2.1).

2.3.2.1. At harrowing

During the wet season 2003-04 and the dry season 2004, irrigation water and suspended sediments were sampled from every terrace, starting from the main inlet to the main outlet, where the runoff went out to the river**.** During harrowing, irrigation water and suspended sediment samples were collected every 30 minutes, starting when the first runoff sediment passed the V-notch weir of the first terrace's outlet and ending when the colour of outgoing water was almost the same as the colour of incoming water passing the main inlet. This was done continuously and simultaneously to the second until the last terrace. At each sampling time, two 600-ml plastic bottles were filled. These samples were used to estimate sediment concentration and to determine N, P, and K in the irrigation water and sediment runoff.

2.3.2.2. At fertilising

During the rice growing period, 50 kg ha^{-1} of urea has been applied in two times, at 21 and 35 days after planting. One day before fertilising, the water was drained from the field by closing the main inlet and opening the main outlet (Photo 2. 5). Two days after broadcasting, both inlet and outlet were opened for a week. The main outlet was closed followed by the main inlet when the water levels reached three to five cm, depending on plant height.

Sampling was conducted a week before and after the first fertilising. Irrigation water and runoff water of each terrace were collected three times a day at 08:00, 12:00 and 16:00 o'clock. These interval times coincided with the daily water level monitoring of canals and

Babon River for hydrological purposes. Samples were also collected in two 600-ml plastic bottles, as done at harrowing.

2.3.3. Measurement of discharge

To estimate amounts of incoming and outgoing sediments and nutrients, water discharge has to be known. At harrowing, water discharges of the main inlet and the outlets of each terrace were measured every 30 minutes. At fertilising, this was done a week before and a week after fertilising, three times daily (at 08:00; 12:00 and 16:00 o'clock), both after sampling irrigation water and runoff sediment.

For measuring the discharge of the main inlet, where the water flowed to the first terrace, the Floating Method with stopwatch was used. According to WMO (1994) measurement of discharge by the Floating Method is used when the use of a Current Meter is impossible because of unsuitable velocities or depths, presence of material in suspension, and when discharge measurement must be made in a very short time. In the Floating Method, data such as water level, cross section, and time were compiled. In this experiment, the cross-section used was 150 cm x 60 cm. The time was monitored from the start to the finish lines along 150 cm, at the interval points 10, 30 and 50 cm. The measurement was replicated three times for each cross-section points. The discharge, therefore, was computed as

$$Q = (L \times W \times H) \times 1000/t \quad \ldots\ldots\ldots\ldots \quad (1)$$

where,

Q: discharge ($l\ s^{-1}$)

L: distance (m)

W: width (m)

H: water level (m)

t: average time (s)

1000 is conversion from m^3 to l

As $L/t = V$ (velocity) ………………………………….. (2)

W x H is cross section area (a) ……………..……… (3)

$$Q = (V \times a) \times 1000 \quad \ldots\ldots\ldots\ldots \quad (4)$$

Discharges at other terraces were determined by the Bucket Method. Buckets with an 11 litres volume were used. When the runoff water reached the volume of 11 litres, time was recorded. Every measurement was replicated three times. The discharge, consequently, was calculated by dividing the volume of the bucket by the mean time.

2.3.4. Determining sediment and nutrient yields

Sediment and nutrient yields were calculated as the differences between inputs and outputs. Sediment content is determined in the laboratory according to Ceisiolka and Rose (1998):

Sediment Concentration (S) = Oven dry mass sediment/ Vol. of (sediment + water) . .. (5)

Total incoming or outgoing water or volume (A) = Q x T .... (6)

Where,

A : Volume (l)

Q : Discharge (l s^{-1})

T : Total time (s)

S : Sediment Concentration (g l^{-1})

From the equations 5 and 6, soil loss was calculated

Soil loss or Suspended Load (E) = (A x S)/1000 .... (7)

Where,

E : Soil loss (kg)

A : Volume (l)

S : Sediment concentration (g l^{-1})

1000 is conversion from g to kg

Determination of dissolved mineral nutrients was focused on the primary major elements including N (NO_3^- and NH_4^+), P (PO_4^-), and K (K^+) according to procedures of the Laboratory of Soil Research Institute, Bogor, Indonesia. Ammonium (N-NH_4), nitrate and phosphate were determined using colorimetric procedures, whereas flame photometry was used for the determination of potassium (Soil Research Institute, 2004). Nutrients in the sediments were not determined as the amounts of sediments in every sampling time were not enough to be measured. However, estimation was made according to total soil loss and nutrient content in the top soil. The results are given in Appendix 5.1 and discussed in chapter 5, as this was considered as an output (OUT-3) in the assessment of nutrient balances.

Photo 2. 2. The terrace after the first ploughing done a week after harvest and processing

Photo 2. 3. The puddling in a terraced paddy field system, Keji Village, DS 2004

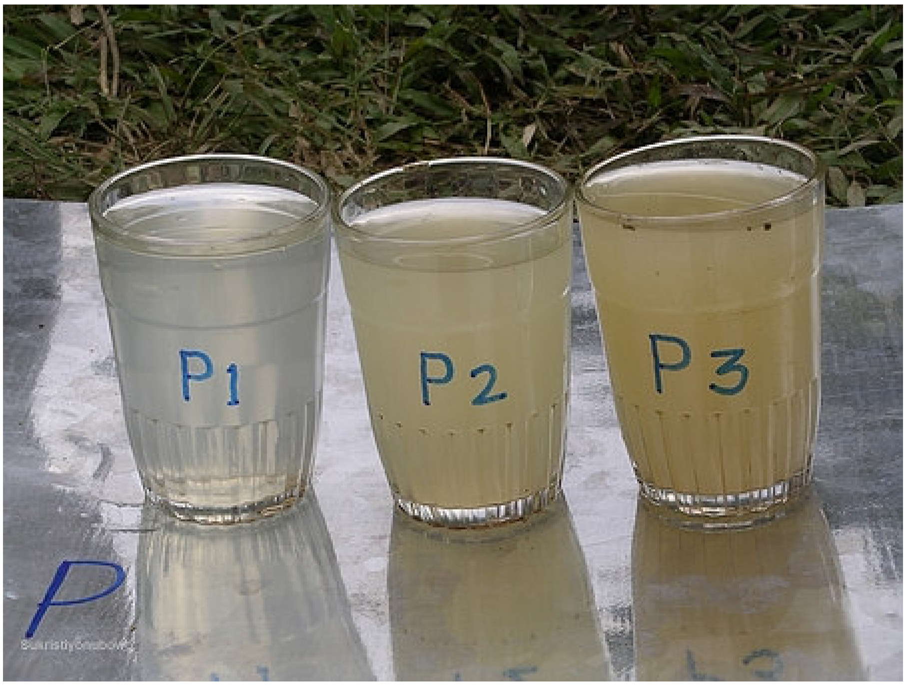


Photo 2. 4. Comparison of runoff water, the cleanest runoff water of P1 indicates end of sampling. P1, P2 and P3 were sampled from the outlet of terrace 1, terrace 2 and terrace 3, respectively on 27 December 2003, during the WS 2003-04.

Photo 2. 5. Water was drained from the rice field prior to fertilising

2.4. Results and Discussion

2.4.1. Incoming and outgoing sediments during land preparation

Data of incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediments measured at the main inlet and the main outlet, respectively are given in Figure 2.2. During land preparation, especially at harrowing, amount of incoming sediment from the irrigation water were lower than outgoing, both in wet and dry seasons. It means that during these activities, sediments from the rice field are carried away by runoff to the river. The travelling distance from terrace to terrace combined with the water discharge greatly affected the amount of soil loss. Net of about 0.53 and 0.27 t ha^{-1} day^{-1} of soil were eroded during harrowing in the wet season 2003-04 and the dry season 2004, respectively. The results also suggest that the total soil loss in the wet season 2003-04 was two times higher than in the dry season 2004. High rainfall occurring in the middle of harrowing caused splash erosion both from planting areas and dykes, which resulted in more eroded soil in the runoff water. This was pointed out by increased sediment transport, particularly from terrace 4 to terrace 8 (Figure 2. 4).

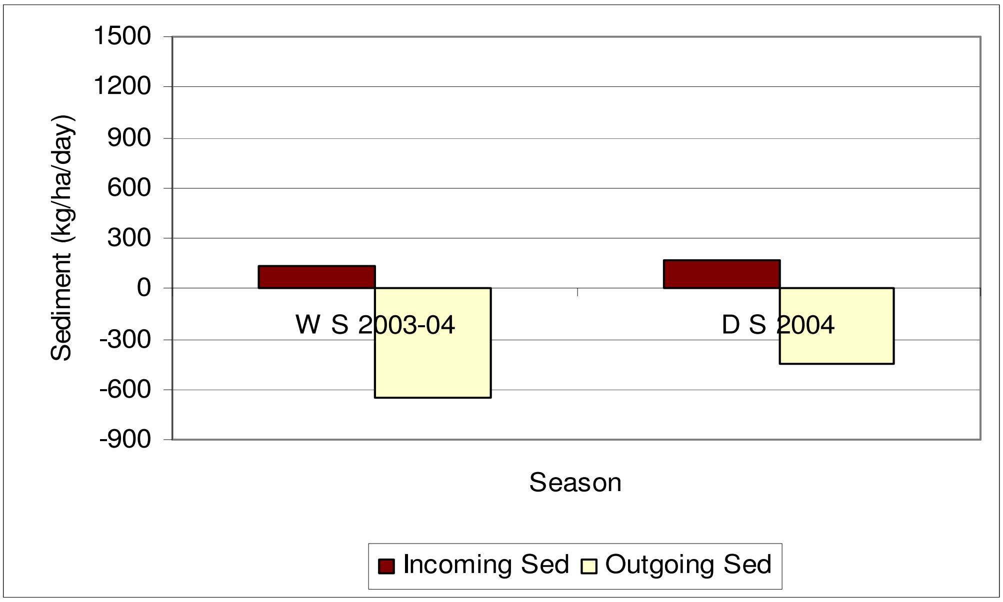


Figure 2. 2. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediments in a terraced paddy field under traditional irrigation systems at harrowing during the wet season (WS) 2003-04 and the dry season (DS) 2004

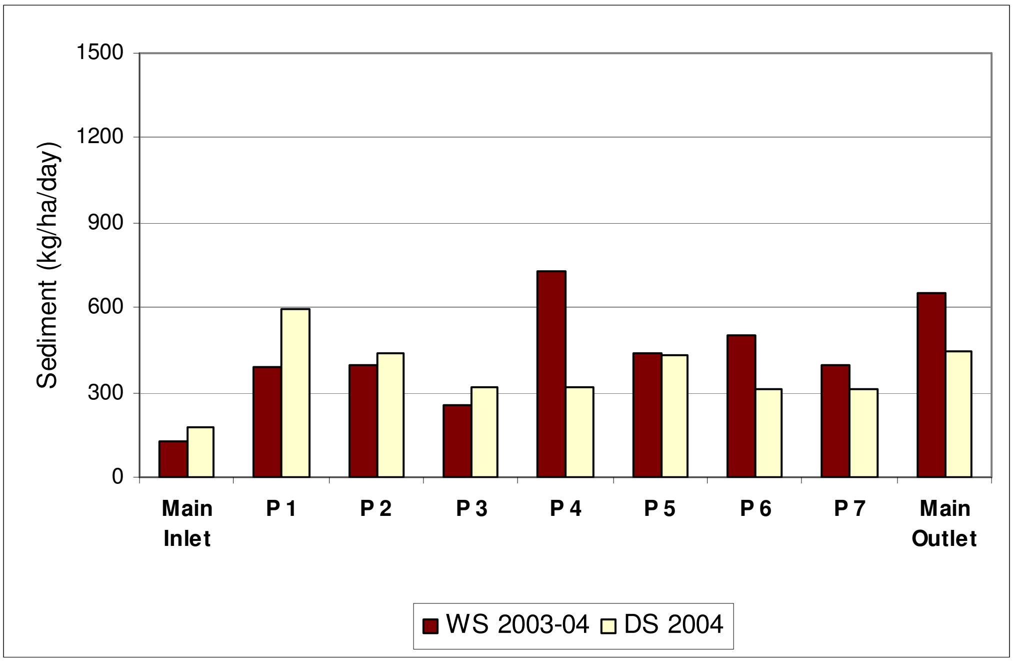


Figure 2. 3. Sediment at the main inlet and outlet of every terrace at harrowing, in the wet season 2003-04 and the dry season 2004

Interestingly, every terrace showed a different behaviour in transport and deposit of sediments (Figures 2. 3 and 2. 4).

It is noticed that the first terrace (T1) and the last terrace (T8) are most susceptible to soil loss both during rainy and dry seasons. This may be explained by (i) the harrowing was started at T1, (ii) during harrowing the water discharges at the main inlet and outlet of terrace 1 (P1) were the highest causing more sediment runoff, (iii) the total incoming sediment of T1 (measured at the main inlet) was smaller than the outgoing (measured at P1), and (iv) for T8 the incoming runoff sediment from T7 was re-dispersed during harrowing and directly went to the river along with the sediment of T8.

However, in the wet season 2003-04, T4 presented the highest soil loss. This may be explained by the amounts and duration of rain events (about 54 mm and 59.6 mm in about 20 minutes, respectively) taking place when the working was started and ended at this terrace. These events caused splash erosion to bare lands both at planting areas and dykes thus causing more eroded soil in the runoff. In addition to this, the high rainfalls gradually increased the discharge and sediment concentration of T4, from 0.49 to 2.93 litre $second^{-1}$ and from 190 to 495 mg l^{-1}, respectively. For the previous terraces (T1, T2, and T3), the impact was minimal because the sediments already were settled and ponding water had reached a layer of about 4 cm, strong enough to protect the puddled soil from rain drop impact.

Other scientists provided confirmation that the amount of sediment and nutrients moving from agricultural fields is influenced by climate, soil, topography, catchment size, land use, and management practices (Agus *et al.,* 2003; Aksoy and Kavvas, 2005; Lal *et al.,* 1998).

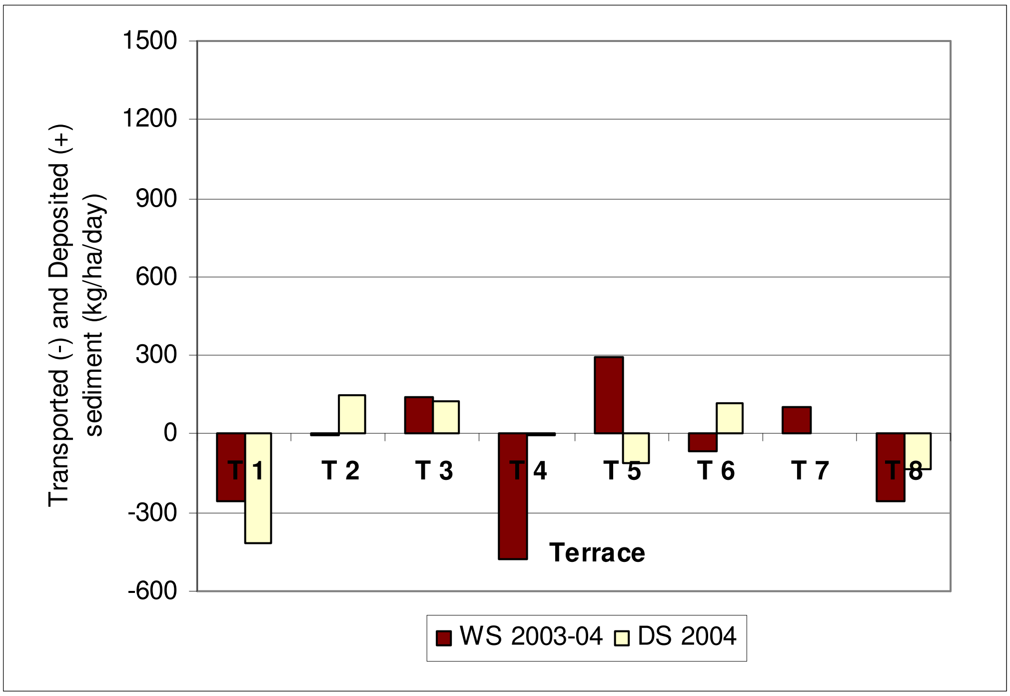


Figure 2. 4. Deposited (+) and transported (-) sediment in every terrace during harrowing in the wet season 2003-04 and the dry season 2004 (T1= Main Inlet – P1, T2 = P1 – P2, T3 = P2 – P3, T4 = P3 – P4, T5 = P4 – P5, T6 = P5 – P6, T7 = P6 – P7 and T8 = P7 – Main Outlet).

2.4.2. Incoming and outgoing sediments during fertilising

In contrast to harrowing, fertilising was carried out without any significant disturbance to the soil. The rainfall, application of fertilisers, and other activities done in upstream locations, therefore, dominantly influenced incoming and outgoing sediments and nutrients. During the monitoring period, precipitation was very high resulting in increased water velocity, discharge, and erosion (splash, farm road erosion, dyke erosion), causing more mass movement. Hence, in the wet season 2003-04, incoming sediments (measured at the main inlet) were higher than outgoing (measured at the main outlet) both a week before fertilising (from 15 to 19 January 2004) and after fertilising (from 24 to 30 January 2004). The average incoming sediments were three to four times higher than outgoing, both a week before and after fertilising. About 0.31 and 0.34 t ha^{-1} day^{-1} of sediments were deposited from the incoming sediment loads of 0.41 and 0.51 t ha^{-1} day^{-1} a week before and after fertilising, respectively (Figures 2. 5 and 2. 6).

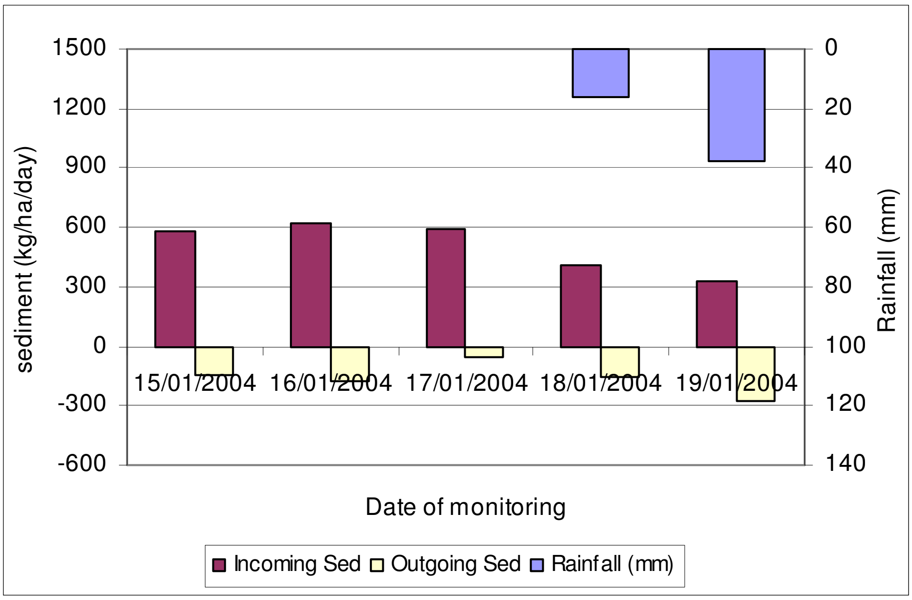


Figure 2. 5. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediment loads a week before fertilising (from 15 to 19 January 2004) in a terraced paddy field system, in the wet season 2003-04

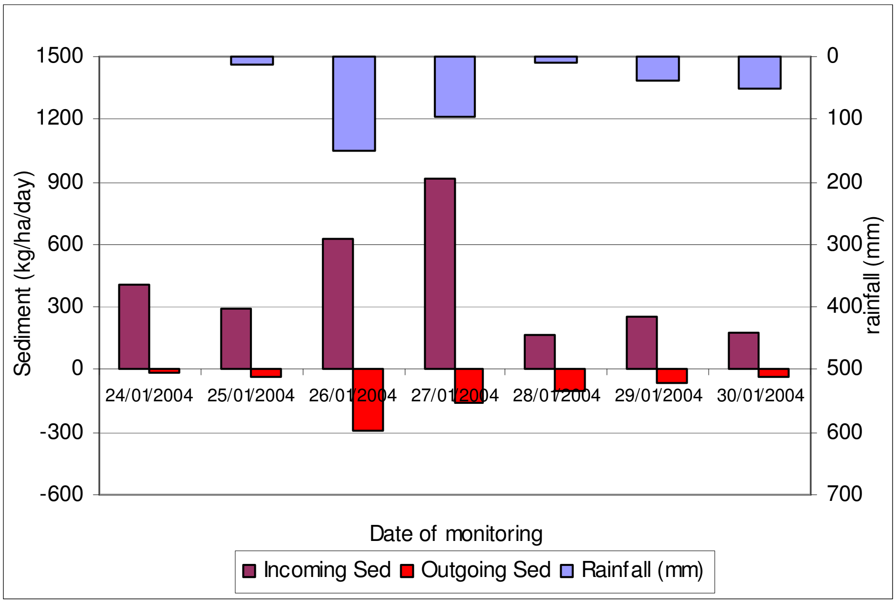


Figure 2. 6. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediment loads a week after fertilising (from 24 to 30 January 2004) in a terraced paddy field system, in the wet season 2003-04

A similar deposition pattern was shown in the dry season 2004 both a week before and after fertilising. The amounts of incoming sediments were ten times higher than outgoing (Figures 2. 7 and 2. 8).

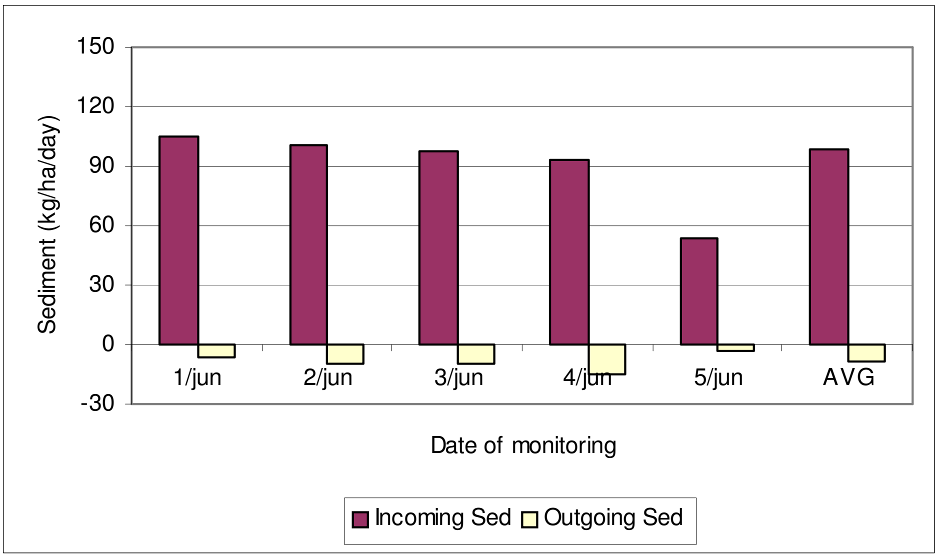


Figure 2. 7. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediment loads a week before fertilising (from 1 to 5 June 2004) in a terraced paddy field system, in the dry season 2004. AVG was the average of incoming sediment and outgoing sediment, respectively.

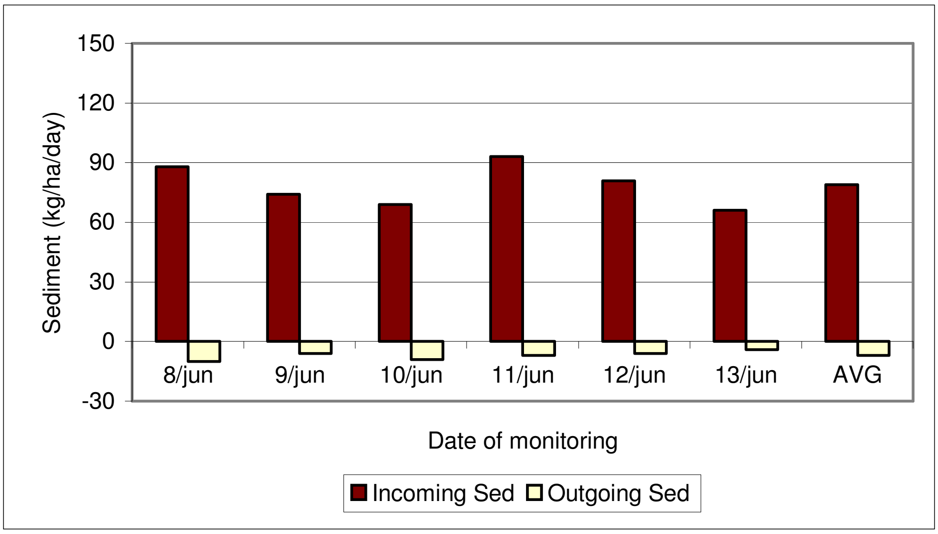


Figure 2. 8. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) sediment loads a week after fertilising (from 8 to 13 June 2004) in a terraced paddy field system, in the dry season 2004. AVG was the average of incoming sediment and outgoing sediment, respectively

On average, the sediment amounts deposited were about 0.08 and 0.07 t ha^{-1} day^{-1} from the average incoming sediment loads of 0.09 and 0.08 t ha^{-1} day^{-1} a week before and after fertilising, respectively (Figures 2. 7 and 2. 8).

It is interesting to note that the sediment transport is closely related to the rainfall amount (Figures 2. 9 to 2. 12). When the rain occurred upstream, the incoming sediment load (measured at the main inlet) was enhanced. When the rain occurred on the site, the outgoing sediment load (measured at the main outlet) was increased, but when the event happened both upstream and on the site, both the incoming and outgoing sediment loads increased.

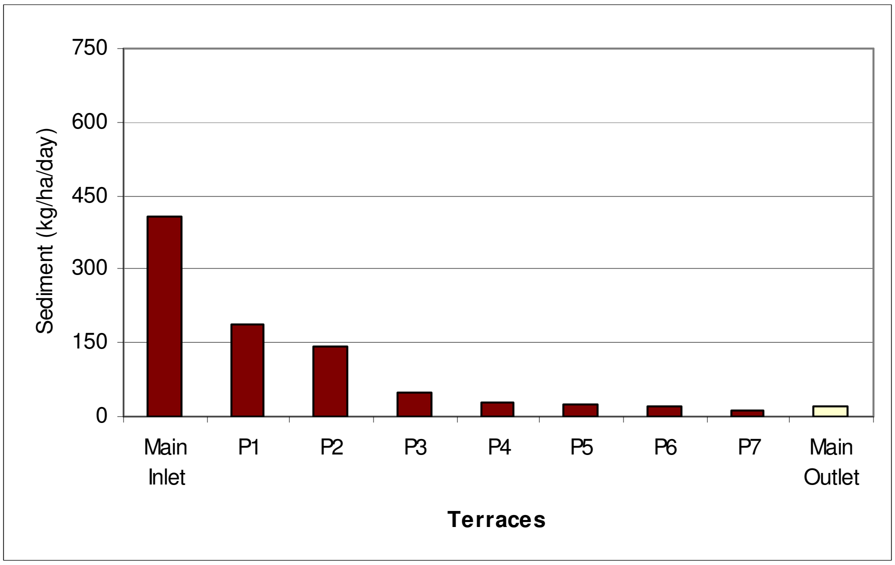


Figure 2. 9. Sediment transported in every terrace (measured at the main inlet and outlet of every terrace) with no rainfall event on the site, on 24 January 2004

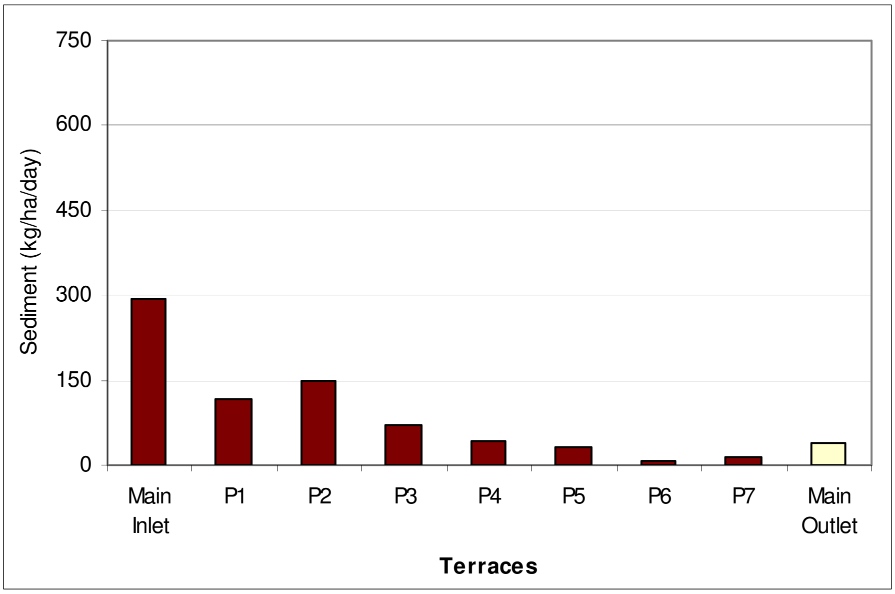


Figure 2. 10. Sediment transported in every terrace (measured at the main inlet and outlet of every terrace) with the rainfall event of 12 mm, occurring on the site on 25 January 2004

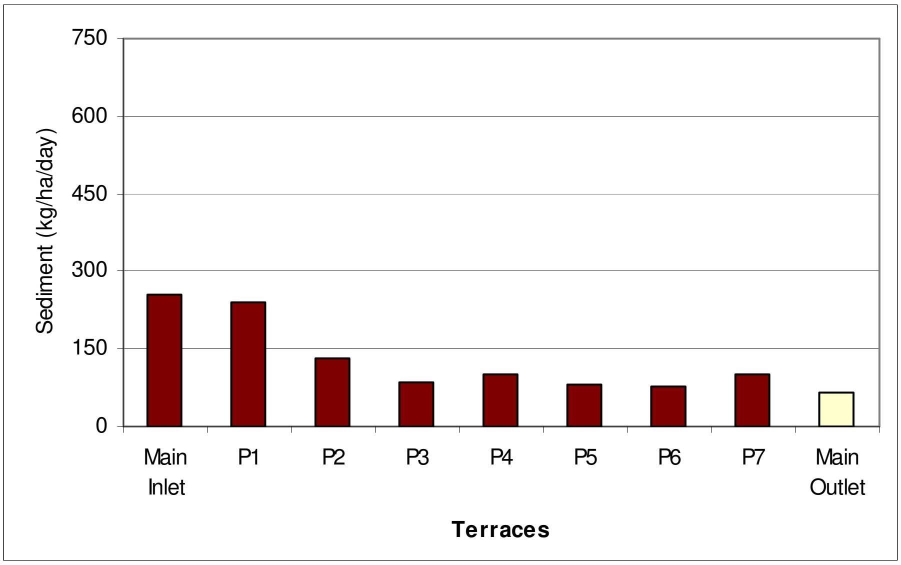


Figure 2. 11. Sediment transported in every terrace (measured at the main inlet and outlet of every terrace) with the rainfall event of 50 mm, occurring on the site on 29 January 2004

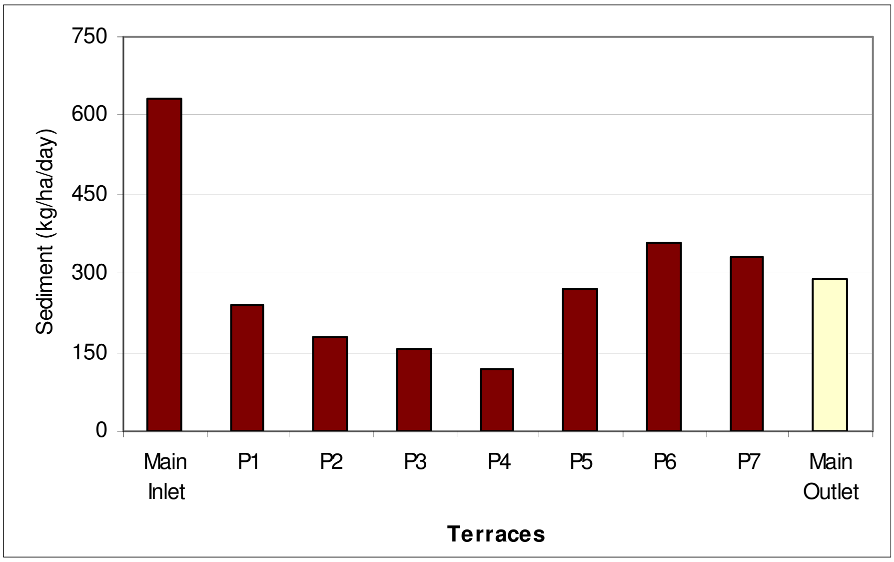


Figure 2. 12. Sediment transported in every terrace (measured at the main inlet and outlet of every terrace) with the rainfall event of 150 mm, occurring on the site on 26 January 2004

The relationship between rainfall amount and sediment transport may be expressed as $Y = 26.548 + 0.059\ X + 0.011\ X^2$ ($r^2 = 0.962$), where X is rainfall in mm and Y is outgoing sediments in kg ha^{-1} day^{-1}.

The sediment movement behaviour in every terrace a week before and after fertilising showed great differences in sediment deposition compared to sediment movement behaviour at harrowing. Terraces with greater sizes (see legend of Figure 2.1) had less impact from rainfall, resulting in less sediment transported and more sediment deposited (Figures 2. 13 and 2. 14).

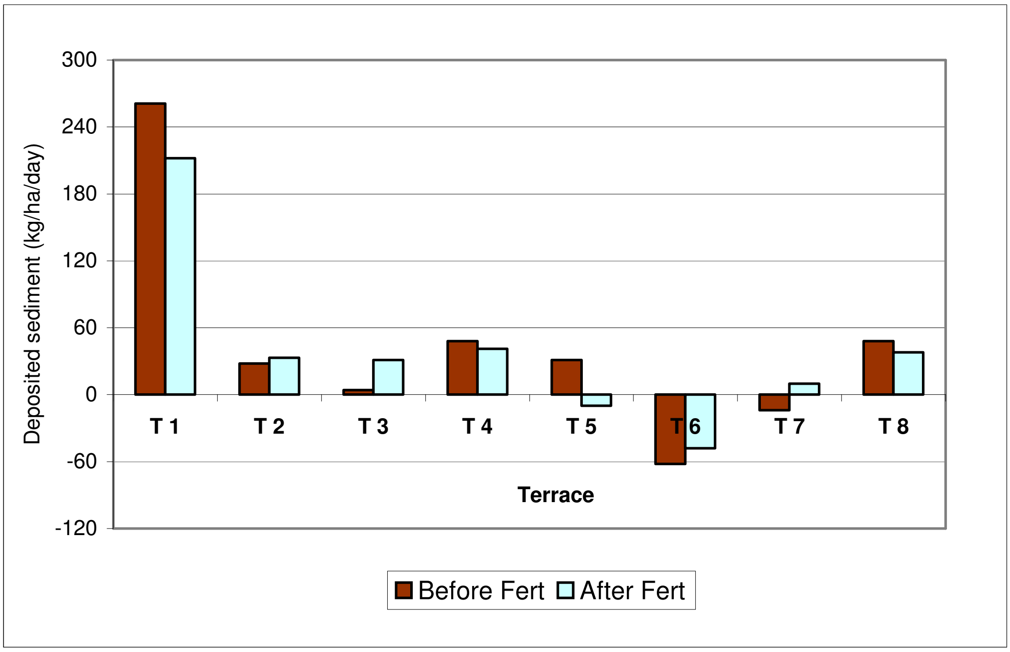


Figure 2. 13. Mean deposited (+) and transported (-) sediments in every terrace a week before and after fertilising, in the wet season 2003-04 (T1= Main Inlet – P1, T2 = P1 – P2, T3 = P2 – P3, T4 = P3 – P4, T5 = P4 – P5, T6 = P5 – P6, T7 = P6 – P7 and T8 = P7 – Main Outlet).

Compared to the wet season 2003-04, the re-deposited sediment in each terrace was completely different with the dry season 2004, both a week before and after fertilising. During the dry season 2004, sediments were proportionally transported and trapped in every terrace. Run off of sediment was not detected, yielding positive sediment balances in every terrace (Figure 2. 14).

From the results a week before and after fertilising, it may be concluded that a terraced paddy field system will reduce the negative impact of erosion by trapping sediments. The amounts of sediment moved and deposited in each terrace depend on rainfall, size and position of terrace, travelling distance, and activities carried out upstream. The relationship between rainfall amount and sediment transport is expressed as $Y = 26.548 + 0.059 X + 0.011 X^2$ ($r^2 = 0.962$), where X is rainfall in mm and Y is outgoing sediment in kg ha^{-1} day^{-1}. Quantitatively, the total sediment depositions a week before and after fertilising were about 4.5 and 1.1 t ha^{-1} during the wet season 2003-04 and the dry season 2004, respectively.

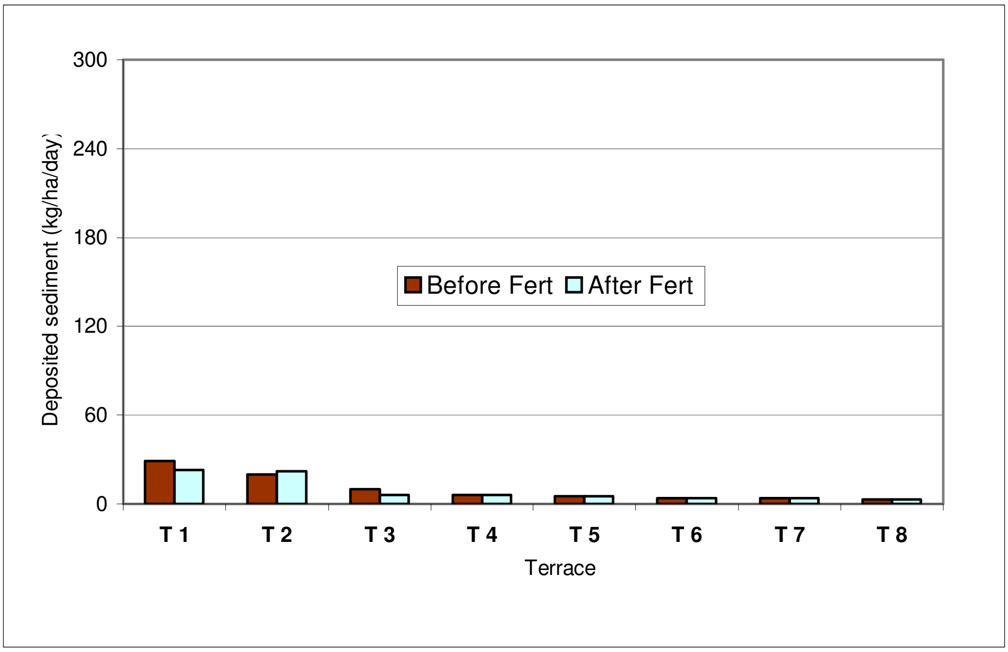


Figure 2. 14. Mean deposited sediments in every terrace a week before and after fertilising, in the dry season 2004 (T1= Main Inlet – P1, T2 = P1 – P2, T3 = P2 – P3, T4 = P3 – P4, T5 = P4 – P5, T6 = P5 – P6, T7 = P6 – P7 and T8 = P7 – Main Outlet).

2.4.3. Incoming and outgoing nutrients at harrowing

Although at harrowing both in the wet season 2003-04 and dry season 2004, soils were eroded through runoff of sediment, nutrient behaviour showed different patterns. The amounts of incoming dissolved nutrients were greater than outgoing both in the wet and dry seasons, except for P in the wet season 2003-04. Nitrogen and potassium carried away upstream through irrigation water were the main reason for the high nutrient input. During the monitoring periods, the rambutan (*Nephelium lappaceum*), clove (*Eugenia aromatica*), coffee (*Coffea robusta*) and tea (*Camelia sinensis*) plantations located upstream, applied N, P, and K fertilisers at the beginning of the wet season. Nitrogen, phosphorous and potassium were applied as urea, TSP and KCl, respectively in a ring broadcast system. In addition to this, the farmers upstream also applied fertilisers, mainly urea, for the wetland rice crop production.

The total inputs of nutrients into this terraced paddy system were 1.04 kg N ha^{-1} day^{-1} and 1.25 kg K ha^{-1} day^{-1} and 0.49 kg N ha^{-1} day^{-1}, 0.004 kg P ha^{-1} day^{-1} and 0.87 kg K ha^{-1} day^{-1} during the wet and dry seasons, respectively (Tables 2. 2 and 2. 3). The negative balance of phosphorous, about - 0.015 kg P ha^{-1} day^{-1}, in the wet season 2003-04 may be explained by high phosphorus amounts removed with sediments during rain events.

Table 2. 2. Incoming (In) and outgoing (Out) N, P and K and gain (+) and loss (-) at harrowing, in the wet season 2003-04

Terrace	NO_3-N (kg ha^{-1} day^{-1})		NH_4-N (kg ha^{-1} day^{-1})		N (kg ha^{-1} day^{-1})		P (kg ha^{-1} day^{-1})		K (kg ha^{-1} day^{-1})	
	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss
Inlet	0.31		2.33		2.64		0.046		3.68	
T 1	0.97	-0.66	1.85	+0.48	2.82	-0.17	0.089	-0.043	2.88	+0.80
T 2	0.38	+0.59	0.60	+1.25	0.98	+1.84	0.007	+0.082	3.07	-0.19
T 3	0.33	+0.05	0.48	+0.12	0.81	+0.17	0.008	-0.001	2.42	+0.65
T 4	0.57	-0.24	1.65	-1.17	2.21	-1.40	0.063	-0.055	2.55	-0.13
T 5	0.30	+0.26	1.55	+0.10	1.85	+0.36	0.073	-0.010	2.57	-0.02
T 6	0.38	-0.08	1.63	-0.08	2.01	-0.16	0.074	-0.001	2.25	+0.32
T 7	0.40	-0.02	1.56	+0.07	1.96	+005	0.063	+0.011	2.11	+0.14
T 8	0.40	+0.00	1.20	+0.36	1.60	+0.36	0.061	+0.002	2.43	-0.31
		Balance				+ 1.04		- 0.015		+ 1.25

In general, when looking at differences between terraces, the nutrient movement behaviour during harrowing in the wet season 2003-04 is different from the pattern of sediment movement. However, for T1, T4 and T6 the trends of N and P movements were similar. These terraces showed the highest nutrient loss like displayed by the sediment. In the dry season 2004, T1 also shows the highest N, P and K losses as observed for the sediments at harrowing.

Table 2. 3. Incoming (In) and outgoing (Out) N, P and K and gain (+) and loss (-) at harrowing in the dry season 2004

Terrace	NO3-N (kg ha^{-1} day^{-1})		NH4-N (kg ha^{-1} day^{-1})		N (kg ha^{-1} day^{-1})		P (kg ha^{-1} day^{-1})		K (kg ha^{-1} day^{-1})	
	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss	In-and Out	Gain/loss
Inlet	0.13		0.56		0.69		0.013		1.09	
T 1	0.33	-0.20	0.47	+0.09	0.80	-0.11	0.037	-0.024	1.15	-0.06
T 2	0.15	+0.18	0.35	+0.12	0.50	+0.30	0.002	+0.035	0.91	+0.24
T 3	0.09	+0.06	0.29	+0.06	0.38	+0.12	0.004	-0.002	0.72	+0.19
T 4	0.13	-0.04	0.26	+0.03	0.39	-0.01	0.020	-0.016	0.72	0
T 5	0.09	+0.04	0.20	+0.06	0.29	+0.10	0.016	+0.004	0.54	+0.18
T 6	0.06	+0.03	0.18	+0.02	0.24	+0.05	0.013	+0.003	0.35	+0.19
T 7	0.09	-0.03	0.17	+0.01	0.26	-0.02	0.014	-0.001	0.39	-0.04
T 8	0.05	+0.04	0.15	+0.02	0.20	+0.06	0.009	+0.005	0.22	+0.17
		Balance				+ 0.49		+ 0.004		+ 0.87

The nutrient amounts removed by soil loss in this system could be estimated varied between 0.24 and 0.48 kg N, 0.33 and 0.64 kg P, 0.05 and 0.10 kg K ha^{-1} day^{-1}, depending on the season.

2.4.4. Incoming and outgoing nutrients at fertilising

In general, the incoming nutrients (N, P and K) were higher than the outgoing a week before and after fertilising, both in the wet season 2003-04 and dry season 2004 (Figures 2. 15 to 2. 18). The amount of nitrogen gained was the highest, followed by K and P. On an average, the amounts of nutrients gained in the wet season 2003-04 were 4.0 kg N ha^{-1} day^{-1}, 0.05 kg P ha^{-1} day^{-1}, and 2.6 kg K ha^{-1} day^{-1} and 3.0 kg N ha^{-1} day^{-1}, 0.03 P kg ha^{-1} day^{-1}, and 2.2 K kg ha^{-1} day^{-1} a week before and after fertilising, respectively. In the dry season 2004, the amounts were 0.4 kg N ha^{-1} day^{-1}, 0.02 kg P ha^{-1} day^{-1}, and 0.18 kg K ha^{-1} day^{-1} and 0.6 kg N ha^{-1} day^{-1}, 0.02 kg P ha^{-1} day^{-1}, and 1.0 kg K ha^{-1} day^{-1} a week before and after fertilising, respectively.

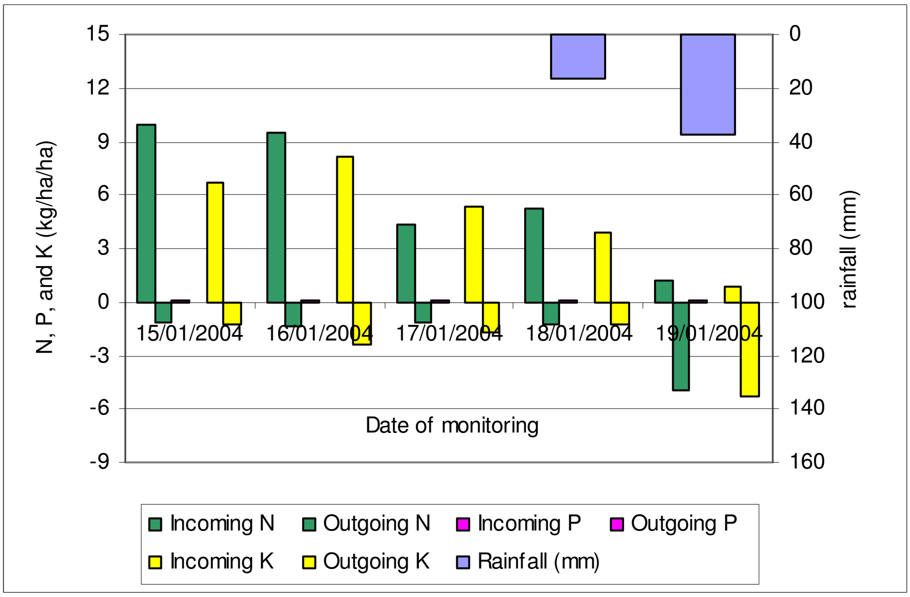


Figure 2. 15. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) N, P and K a week before fertilising (from 15 to 19 January 2004) in a terraced paddy field under traditional irrigation systems, in the wet season 2003-04

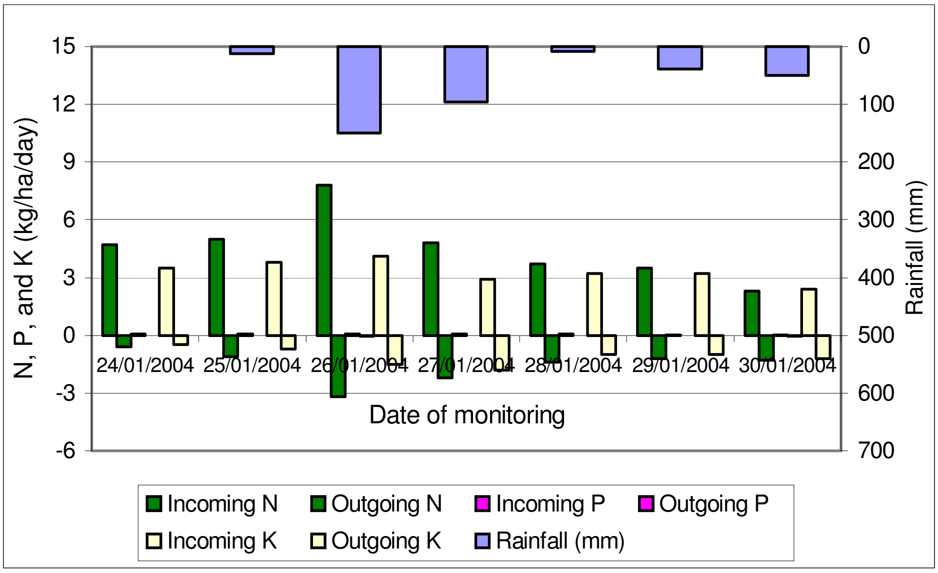


Figure 2. 16. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) N, P and K a week after fertilising (from 24 to 30 January 2004) in a terraced paddy field under traditional irrigation systems, in the wet season 2003-04

It is also interesting to note that the amounts of outgoing nutrients a week after fertilising both in the wet and dry seasons were higher than a week before fertilising, suggesting that nutrients from fertilisers were also washed away.

The N and K movements during the wet season 2003-04 a week before and after fertilising were closely related to rainfall intensity (Figures 2. 15 and 2. 16). When rain occurred upstream, elevated incoming nutrient amounts were observed. When it rained on the site, the outgoing nutrient amounts increased. Furthermore, when it rained both upstream and on the site, both elevated incoming and outgoing nutrient amounts were observed. Schuman and Burwell (1974) reported similar findings.

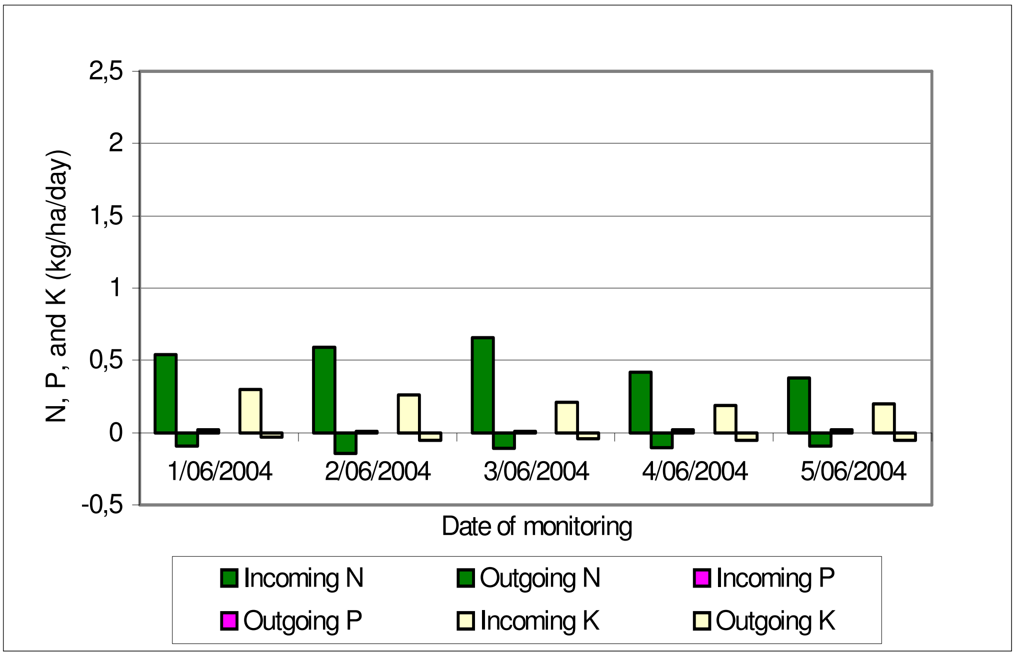


Figure 2. 17. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) N, P, and K a week before fertilising (from 1 to 5 June 2004) in a terraced paddy field under traditional irrigation systems, in the dry season 2004

It is noticed that the nutrients at each terrace a week before and after fertilising shows similar deposition patterns as the sediment, both in the wet season 2003-04 and the dry season 2004. In general, terraces with bigger surfaces conserved more nutrients than terraces with smaller sizes. More than 75 % of the nutrients were trapped at terraces having greater surfaces and positioned close to the main inlet, i.e. T1 and T2 (Figures 2. 19 and 2. 20). In the dry season

2004 a week before and after fertilising no terrace showed a negative nutrient balance (Figure 2. 20).

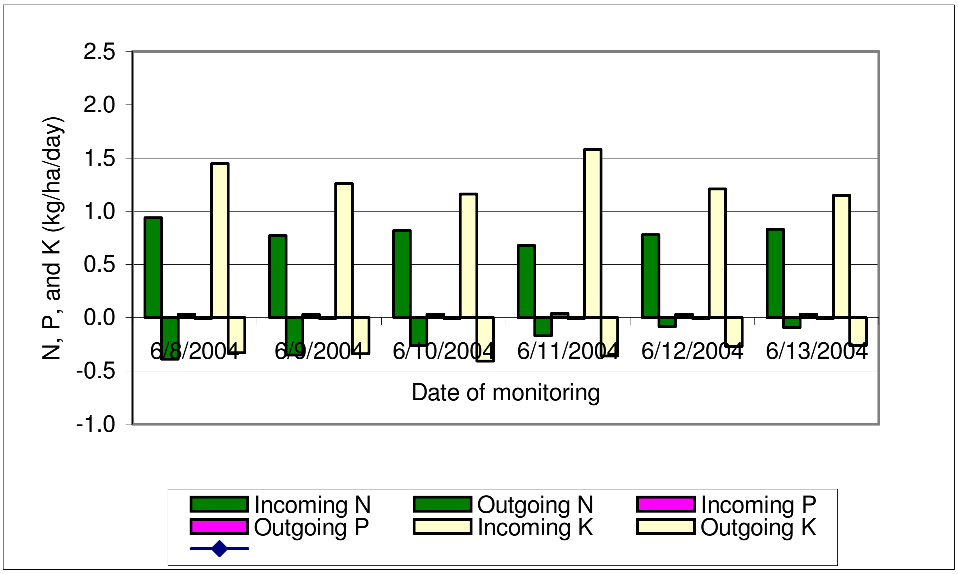


Figure 2. 18. Incoming (measured at the main inlet) and outgoing (measured at the main outlet) N, P, and K a week after fertilising (from 8 to 13 June 2004) in a terraced paddy field under traditional irrigation systems, in the dry season 2004

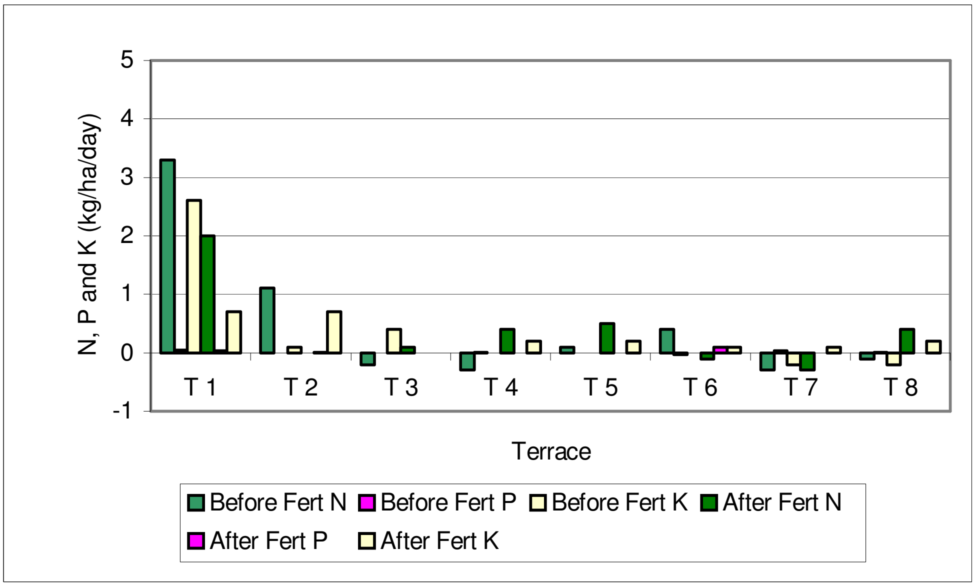


Figure 2. 19. Mean gain and loss of N, P, and K in every terrace a week before and after fertilising, in the wet season 2003-04 (T1= Main Inlet – P1, T2 = P1 – P2, T3 = P2 – P3, T4 = P3 – P4, T5 = P4 – P5, T6 = P5 – P6, T7 = P6 – P7 and T8 = P7 – Main Outlet).

From these results, it may be concluded that a terraced paddy field system will conserve nutrients, thus improving outlet water quality. The outlet water may be used for domestic purposes.

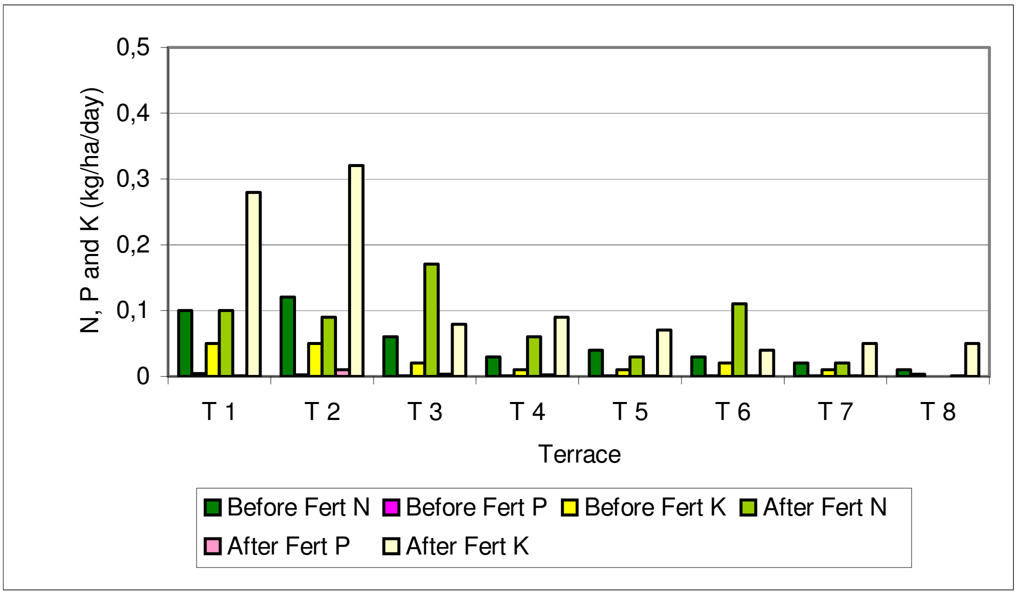


Figure 2. 20. Mean gain of N, P, and K in every terrace a week before and after fertilising, in the dry season 2004 (T1= Main Inlet – P1, T2 = P1 – P2, T3 = P2 – P3, T4 = P3 – P4, T5 = P4 – P5, T6 = P5 – P6, T7 = P6 – P7 and T8 = P7 – Main Outlet).

2.5. Conclusions

Taking into account the growing rice demand in Indonesia, more attention should be given to the terraced paddy field systems. Studies on sediment and nutrient movement behaviour in a terraced paddy field under traditional irrigation indicate that sediment was displaced mainly during harrowing, both in the wet and dry seasons. On the experimental site in Keji Village about 0.53 and 0.27 t ha^{-1} day^{-1} of soil were eroded during harrowing, in the wet season 2003-04 and the dry season 2004, respectively. Contrary, sediments were deposited on every terrace a week before and after fertilising. In the wet season 2003-04, about 0.3 t ha^{-1} day^{-1} of sediments were deposited, while during the dry season 2004, they were about 0.07 to 0.08 t ha^{-1} $day^{-1.}$

Both at harrowing and fertilising, the amounts of incoming dissolved nutrients were higher than the outgoing as well in the wet season 2003-04 as in the dry season 2004. At harrowing, nutrient inputs of about 1.04 kg N ha^{-1} $day^{-1}$and 1.25 kg K ha^{-1} day^{-1} and 0.49 kg N ha^{-1} day^{-1}; 0.004 kg P ha^{-1} day^{-1} and 0.87 kg K ha^{-1} day^{-1} were observed in the wet season 2003-04 and dry season 2004, respectively. At fertilising about 3 - 4 kg N ha^{-1} day^{-1}, 0.03 - 0.05 kg P ha^{-1} day^{-1}, and 2.2 - 2.6 kg K ha^{-1} day^{-1} and about 0.4 - 0.6 kg N ha^{-1} day^{-1}, 0.02 kg P ha^{-1} day^{-1}, and 0.18 - 1.0 kg K ha^{-1} day^{-1} were trapped during the wet season 2003-04 and the dry season 2004, respectively.

Every terrace presented a different behaviour in transporting and trapping the sediment and nutrients. Terraces having greater surfaces trapped higher amounts of sediments and nutrients than terraces with smaller sizes. Thus, terraced paddy field system is not only a way to produce rice, but it also provides environmental services like sediment trapping from surface waters and nutrients conservation.

Chapter 3

NUTRIENT UPTAKE DURING RICE GROWTH AND DEVELOPMENT

NUTRIENT UPTAKE DURING RICE GROWTH AND DEVELOPMENT

Abstract

Field experiments have been carried out in Keji Village (Ungaran Sub district, Central Java Province) during the wet season 2003-04 (WS 2003-04) and the dry season 2004 (DS 2004). A high yielding rice variety (HYV) of IR-64 was selected by the participating farmers, both for the wet and dry seasons. Twenty-one days-old seedlings were transplanted with 25 cm x 25 cm crop spacing and about three seedlings per hill. Four treatments were used during the study, namely conventional farmer practice (CFP), conventional farmer practices + rice straw (CFP + RS), improved technology (IT) and improved technology + rice straw (IT + RS). For the conventional farmer practice, only 50 kg of urea ha^{-1} $season^{-1}$ was applied. Meanwhile, about 100 kg each of urea, Triple Super Phosphate (TSP), and KCl ha^{-1} $season^{-1}$ were applied in the improved technology treatments. These fertiliser application rates were selected by the participating farmers, based on the recommended fertiliser application rate provided by the Food Crops Institute at District level. About 33% of rice straw produced was recycled in the treatments of conventional farmer practices + rice straw (CFP + RS) and improved technology + rice straw (IT + RS). Each treatment was replicated three times and arranged in the Randomised Complete Block Design (RCBD). Urea application was split and took place 21 and 35 days after transplanting (DAT), while all Triple Super Phosphate (TSP) and KCl were applied at 21 days after transplanting. Plants were sampled five times, at 45, 60, 75, 90 and 105 days after transplanting. These times represent the vegetative, reproductive, ripening, and harvest phases of the rice growth cycle. The results indicate that both in the WS 2003-04 and DS 2004 concentrations of N, P, and K in shoots and roots significantly decreased during rice growth. The highest nutrient concentrations were observed 45 days after transplanting, representing the end of the vegetative period and beginning of flowering. The nutrient concentrations both in shoots and roots in the dry season were higher compared to the wet season, but statistical evidence was not consistent. In contrast to the concentrations, the N, P, and K uptake increased during the rice growth. The highest N, P, and K concentrations and uptake in shoots and roots always occurred in the IT + RS treatment. Depending on the treatments, total nutrient removal through rice grains and rice straw varied from 88 to 164 kg N, 8 to 16 kg P, and 104 to 198 kg K ha^{-1} $season^{-1}$ in the WS 2003-04 and from 94 to 165 kg N, 10 to 18 kg P, and 107 to 179 kg K ha^{-1} $season^{-1}$ in the DS 2004.

3.1. Introduction

The effects of fertilisers on crop production in terms of quantity and quality of yields have been studied and well documented. It is strongly believed that fertilising increases crop productivity. Many functions have been used to demonstrate the relationship between fertiliser input and crop yield. However, researchers also reported many inconsistencies in the influence of fertilisers on yield quality. They noticed that several internal and external factors interact in processes affecting quality. Among them, climatic variables (heavy rain and drought periods), variety characteristics (local and improved varieties), cultural practices, and soils (dry and irrigated regions) are apparently involved.

Like other plants, rice also requires additional nutrition from fertilisers to get better yields. However, up to four decades ago, before the Green Revolution established in 1970, the rate of fertiliser application was low. This was due to the fact that local low yielding rice varieties were planted in most rice growing areas in the developing countries. Genetically, these local varieties require less nutrient input. Hence, rice productions were low and not enough to support food demands in major rice producing countries. Yields ranged between 1 and 2 tons ha^{-1} $season^{-1}$ with an average application of about 0 - 12 kg of NPK ha^{-1} $season^{-1}$. Only three countries, including Japan, Taiwan and Korea, achieved high rice yields of about 5.5, 4.1, and 3.8 t ha^{-1} $season^{-1}$, respectively (Uexkull, 1970).

Studies on the effect of fertilisers on rice production have tremendously increased since the development of high yielding varieties (HYV) of rice between 1970 and 1980. Intensification of fertiliser use so far runs harmonically with the cultivation of HYV and is also related to the intensification of agricultural programmes to improve rice yield, to enhance farmers' income, and to contribute to food security. At this moment, most rice producing developing countries became self-sufficient (FFTC, 2000).

In Indonesia, the Government also paid attention to increasing rice production via the co-ordination of the Ministry of Agriculture by creating programmes to cultivate HYV of rice and to enhance fertiliser use. Hard efforts are still being conducted by the Government through programmes, like BIMAS (*Bimbingan Masal* = mass guidance) and INMAS (*Intensifikasi Masal* = mass intensification). These programmes are also providing credits for agricultural inputs, supported construction of irrigation facilities, establishment of daily TV programmes at regional and national levels for farmers, establishment of farmer groups, and organisation of group meetings. These efforts have successfully brought Indonesia to achieve self-sufficiency in rice in 1984 and to sustain a high rice yield. Specifically, So *et al.* (2000) noted that the success of the BIMAS and INMAS programmes is partly due to the realistic setting of production targets, which are negotiated for each province, district, and village joining the programme.

Unfortunately, a recent multi-dimensional crisis (political, social, and economic crises) in Indonesia since the beginning of 1997 and slow economic recovery had a large impact. In major rice producing areas, the programmes mentioned above have not been well overseen and implemented. In accordance with fertilising, a lack of funds to purchase agricultural inputs and the high prices of fertilisers are becoming the main constraints in cultivating rice. Previous studies showed that the farmers only add nitrogen in the form of urea for about 50 kg ha^{-1} $season^{-1}$ but no phosphorus (P) and potassium (K) in Keji Village. Additionally, intensification of livestock under the cattle fattening programmes in this village leads to largely increased use of rice straw. Rice straw is removed from the field to feed cows and buffaloes (Sukristiyonubowo *et al.,* 2003; Photo 3. 1). It seems that balanced fertilisation, in terms of kind and rate of fertilisers, and returning rice straw to the field should be recommended. However, the decision to add both organic and inorganic fertilisers depends on the farmers.

The objectives in this chapter were (i) to study the nutrient uptake during rice growth and development under different treatments and (ii) to evaluate the seasonal nutrient uptake variations during the wet and dry seasons in terraced paddy field systems.

Photo 3. 1. Rice straw is removed from the rice field for cattle feeding

3.2. Literature Review

The soil itself originally can supply some of the nutrients required by plants. However, the quantity of nutrients varies among soils and depends on the chemical and physical properties of the soil. Subsequently, the mineral nutrition of various crops is closely related to the properties of the soil, where the plants are cultivated. These soil properties also influence the movement and dynamics of nutrient.

In many cases major plant nutrient contents in the soil are not sufficient to support optimal rice yield. Furthermore, rice-farming using new high yielding varieties developed by IRRI (the International Rice Research Institute) also requires higher fertiliser inputs. Consequently, fertilisers are applied not only to improve rice yield and quality, but also the chemical fertility of rice fields. According to Uexkull (1970), HYV need about 2.5 times more nitrogen and phosphorus and 4.5 times more potassium than the traditional varieties.

It is also interesting to note that response of rice yield and quality on fertiliser application varies depending on varieties, soil-climate, and cultural practices (Cooke, 1970; Uexkull, 1970). Furthermore, the response of crops to fertiliser application also depends on the main limiting factors, which are determined by the soil or region.

It is also well documented that incorporation of organic substances, including organic manure and straw, in paddy soils improves soil fertility, root morphological characteristics, and yield (Eneji *et al.,* 2001; Hasegawa *et al.,* 2005; Muhammad *et al.,* 1992; Singh *et al.,* 2001; Yang *et al.,* 2004). Furthermore, Yang *et al.* (2004) observed that incorporation of organic manure in alternating wet and dry water regimes significantly increases N, P, and K uptake by the rice plants and facilitates translocation of P to rice panicles and grains. Specifically, Hasegawa *et al.* (2005) reported that organic amendments significantly affect the pools of Bray-2 P, NH_4OAc extractable K, and balances of nutrients in the organic rice fields. Annual surplus amounts of +100 kg N ha^{-1}, +102 kg P ha^{-1}, +130 kg K ha^{-1}, +133 kg Ca ha^{-1} and +33 kg Mg ha^{-1} are found in rice fields treated by application of chicken compost and straw incorporation.

Similar conclusions are also drawn for other farming systems. Manure application and cover crop incorporation in the organic and low-input farming practices consistently improve soil chemical properties (Campbell and Zentner, 1993; Clark *et al.,* 1998; Rasmussen and Parton, 1994; Sommerfeldt *et al.,* 1988; Wander *et al.,* 1994).

The growth cycle of rice is conveniently divided into three development phases, including vegetative (fast and slow vegetative stages), reproductive or generative, and ripening phases (Anonymous, 1977; Mikkelsen *et al.,* 1995). The duration of each growth stage is influenced by internal (genetics of variety) and external factors (plant nutrient supply, agronomic practices, and climatic conditions). Tiller formation and panicle initiation largely characterise the vegetative phase. The reproductive phase extends from panicle initiation to flowering, and the ripening stage occurs from the flowering/milky stage to grain maturity.

Furthermore, Anonymous (1977), Mikkelsen *et al.* (1995), Uexkull (1970) reported that assimilates produced during vegetative to flowering stages are translocated to stem and leaves, while from flowering to ripening they are stored in grains. Concentrations of about 1.50 – 1.59 % N and 0.29 – 0.32 % P are found in rice grains and 1.05 – 1.13 % N and 0.12 – 0.14 % P are observed in rice straw.

Many studies reported that the uptake of nutrients depends on variety, cultural practices, nutrients supply, and climate (Kemmler, 1971; Sanchez and Calderon, 1971; Sukristiyonubowo *et al.,* 2003; Uexkull, 1970). In accordance with variety and climate, Uexkull (1970) observed that the total nutrients removal through rice grains and rice straw in the wet season is 77 kg N, 14 kg P, and 150 kg K ha^{-1} $season^{-1}$ and these are lower than in the dry season. So far, nutrients removed through harvest products of high yielding varieties are higher than improved local varieties. Depending on nutrient inputs, the total nutrients removed through harvest products of high yielding varieties range between 192 and 248 kg N, 24 and 34 kg P, 125 and 198 kg K ha^{-1} $year^{-1}$ (Sukristiyonubowo *et al.,* 2003; Uexkull, 1970).

3.3. Materials and Methods

Field experiments were carried out at Keji Village during the planting season 2004, the WS 2003-04 and DS 2004. The soils were classified as Aquandic Epiaquepts medial isohyperthermic (Siswanto, 2006). Detailed soil profile descriptions are given in Appendices 3.1. to 3.3. The high yielding rice variety IR-64 was selected and cultivated by the participating farmers. The IR-64 was preferred for the following reasons: (a) the potential yield is high, (b) the labelled seeds for planting are easy to buy, (c) the farmers are familiar with agronomic practices of this variety, (d) the eating quality or taste is good, (e) the selling price of rice grains is good, and (f) birds can not easily eat matured grains as the flag leaves remain in the erected position.

Four treatments were applied, including (1) Conventional Farmer Practices (CFP), (2) Conventional Farmer Practices + Rice Straw (CFP + RS), (3) Improved Technology (IT), and (4) Improved Technology + Rice Straw (IT + RS). They were arranged in the Randomised Complete Block Design (RCBD) and replicated three times. In the CFP treatments, only 50 kg ha^{-1} $season^{-1}$ of urea was applied. In the IT treatments, fertiliser application rates of 100 kg ha^{-1} $season^{-1}$ each of urea, TSP, and KCl were applied, corresponding to the recommendation fertiliser application rates for rice provided by the Food Institute at District Level. These rates were introduced since the cropping season 2000-01. In the RS treatments, the amount of rice straw recycled was 33 % of the previous rice straw production. The recycled rice straw was distributed on the field prior to the first land ploughing and incorporated during ploughing. The recycling of 33 % of rice straw production was obtained from the results of previous study (see Sukristiyonubowo *et al.,* 2003) and accepted by farmers during the meeting. Twelve farmers were involved in this study, corresponding to the four treatments and three replicates. Details about the treatments are given in Table 3. 1.

Table 3.1. The treatments, dates of transplanting, the amounts of rice straw recycled, and fertiliser application rates during the WS 2003-04 and the DS 2004

Treatment	Replication	Date of transplanting		The amount of rice straw recycled (t ha^{-1})		Fertiliser Rates (kg ha^{-1} $season^{-1}$)		
		WS 2003-04	DS 2004	WS 2003-04	DS 2004	Urea	TSP	KCl
CFP	I	11-01-04	26-05-04	-	-	50	-	-
	II	13-01-04	28-05-04	-	-	50	-	-
	III	10-01-04	27-05-04	-	-	50	-	-
CFP + RS	I	01-01-04	14-05-04	2.15	2.14	50	-	-
	II	31-12-03	15-05-04	2.97	1.74	50	-	-
	III	03-01-04	13-05-04	3.26	2.21	50	-	-
IT	I	04-01-04	16-05-04	-	-	100	100	100
	II	05-01-04	19-05-04	-	-	100	100	100
	III	06-01-04	20-05-04	-	-	100	100	100
IT + RS	I	27-01-04	05-06-04	2.48	2.61	100	100	100
	II	28-01-04	06-06-04	2.64	2.68	100	100	100
	III	29-01-04	07-06-04	2.15	2.13	100	100	100

Application of urea was split and conducted at two times, 21 and 35 DAT. All TSP and KCl were applied at 21 DAT. The amounts of fertilisers per terrace were computed as the rate of fertiliser per hectare multiplied by the ratio between the number of rice plants per terrace and the number of rice plants per hectare. The number of plants per terrace was counted during transplanting. Other cultural practices, such as pest, disease, and weed controls were done once before the second fertilising.

Transplanting was conducted in every cropping season. Twenty-one-day old seedlings were transplanted at about 25 cm x 25 cm cropping distance with about three seedlings per hill. In the wet season 2003-04 (WS 2003-04), transplanting was done in January 2004 and harvest in April 2004, while in the dry season 2004 (DS 2004), transplanting was done between May and June 2004 and harvest was from the fourth week of August to the second week of September 2004. The way of harvesting, estimating rice yield and grain yield parameters are discussed in Chapter 4.

Composite samples of topsoil, 0-20 cm layer, were taken once in December 2003, before land preparation. Samples were randomly taken from every terrace as mixed samples at five sampling points. These samples were submitted to the Analytical Laboratory of the Soil Research Institute at Bogor for analyses of chemical properties and texture of the soils. Chemical analyses included the measurement of pH (H_20 and KCl), organic matter, phosphorus, potassium, base saturation, and cation exchange capacity (CEC). Organic mater was determined using the Walkley and Black method, pH (H_2O and KCl) was measured in a 1:5 soil-water suspension using a glass electrode, total P and soluble P were measured colorimetrically using HCl 25% and Olsen methods, respectively. The total K was extracted using HCl 25% and subsequently determined by flame-spectrometry. The CEC was determined using an Ammonium Acetate 1 M, (pH 7.0) extraction and expressed in $cmol^+ kg^{-1}$ soil. Base saturation was computed based on the sum of Ca^{++}, Mg^{++}, K^+, and Na^+ relative to CEC (Soil Research Institute, 2004).

Plants were sampled five times during the rice growing cycle, at 45, 60, 75, 90, and 105 DAT or at harvest. Samples were collected from every terrace, one hill per terrace. The plant samples were divided into two parts, one part for measuring dry weight and the rest for laboratory analyses.

After pulling out, the plant roots were washed with river water. Afterwards, fresh weight of each sample was determined. Subsequently, the above and under ground parts were separated and weighed. Finally, the samples were treated in the oven at 85^0 C until a dry constant weight was obtained. The under ground parts of rice plants during vegetative, reproductive and ripening phases consisted mainly of roots, whereas at harvest stubbles were also included. The above ground parts (shoots) from vegetative to generative stages comprised leaves and stems, whereas also spikelets and grains were included from 90 DAT to harvest.

For the laboratory analyses, the samples were treated according to procedures of the Analytical Laboratory of the Soil Research Institute, Bogor. Samples were washed with deionised water to avoid any contamination, and dried at 70^0 C. The dried samples were ground and stored in plastic bottles. Nitrogen was determined by wet ashing using concentrated H_2SO_4 (97%) and selenium, while P and K were measured after wet ashing using $HClO_4$ and HNO_3 (Soil Research Institute, 2004).

The nutrient uptake by rice plants was calculated by multiplying the nutrient concentration in the rice plant with the dry weight and expressed in kg ha^{-1} $season^{-1}$, taking into account the total biomass production per ha.

All data were statistically examined by analysis of variance (ANOVA), using SPSS software. Means were compared using the Duncan test (5%).

3.4. Results and Discussion

3.4.1. Soil properties

Chemical soil properties of each treatment are given in Table 3. 2. The textures of the soils varied from silty clay loam to clay, and were classified into medium to fine textures (results not given). The pH of soils was low, varying between 5.0 and 5.7. The CEC values ranged between 13 and 17 $cmol^+$ kg^{-1}, suggesting uniformity in clay mineralogy and organic matter contents. The cation exchange capacities (CEC) may be categorised as medium. The levels of soil organic carbon (SOC) and organic N are low, ranging from 0.70 to 1.32 % and from 0.08 to 0.16 %, respectively. This may be due to the fact that in the past, all rice straw was removed from the field to be used as cattle feed. Sommerfeldt *et al.* (1988) and Clark *et al.* (1998) also observed higher soil OM levels in soils managed with animal manure and cover crops than in soils without such inputs.

Total P ranged from 1 170 to 1 630 mg P_2O_5 kg^{-1}. These values, observed both in the conventional farmer practices and improved technologies, may be classified as high. However, available P in the soils under conventional farmer practices is low, ranging between 10 and 29 mg P_2O_5 kg^{-1}. Furthermore, application of 100 kg TSP ha^{-1} $season^{-1}$ in the IT treatments since the WS 2000-01 increased the availability of P, about 3 to 8 times. Total K in the conventional farmer practices is low, varying from 150 to 250 mg K_2O kg^{-1}, while it is higher in the IT treatments, varying between 190 and 340 mg K_2O kg^{-1}. This suggests that application of 100 kg KCl ha^{-1} season $^{-1}$ since the WS 2000-01 increases the total K in the soil. Clark *et al.* (1998), Rasmussen and Parton (1994) and Wander *et al.* (1994) also reported similar findings.

Base saturation is relatively low, varying between 37 and 64 %. This is mainly due to the low concentrations of exchangeable Ca (4.25 – 7.04 $cmol^+$ kg^{-1}) and K (0.09 – 0.44 $cmol^+$ kg^{-1}). However, exchangeable Mg concentrations are relatively high (1.63 - 2.87 $cmol^+$ kg^{-1}). Looking to the ratio of exchangeable calcium, magnesium and potassium percentage, the data also indicated an imbalanced ratio. In normal conditions, the ratio ranges from 60 to 65 % of calcium, 10 to 15 % of magnesium, and 5 to 7 % of potassium. More detailed information is given in Appendix 3. 4. Therefore, it may be concluded that in general the chemical soil fertility is rather low due to low pH, low organic matter content, and low available P and K concentrations. In addition, soil properties variability was small, except for P Olsen.

Table 3. 2. Chemical soil properties (0-20 cm) of each treatment at the terraced paddy fields system. Samples were taken in December 2003

Soil Properties	Treatment			
	CFP	CFP + RS	I T	IT + RS
pH (H_20)	5.2 – 5.6	5.0 – 5.3	5.6 – 5.7	5.0 – 5.3
pH (KCl)	4.3 – 4.6	4.1 – 4.6	4.8 – 4.9	4.4 – 4.7
Organic Matter:				
C (%)	1.04 – 1.14	0.93 – 1.27	1.01 – 1.32	0.70 – 1.26
N (%)	0.8 – 0.11	0.08 – 0.11	0.11 – 0.13	0.10 – 0.16
C/N	10 - 13	12 - 13	9 - 11	7 - 8
Total P (mg P_2O_5 kg^{-1})	1 400 – 1 530	1 170 – 1 210	1 430 – 1 630	
Total K (mg K_2O kg^{-1})	180 - 250	150 - 250	190 - 340	
P Olsen (mg P_2O_5 kg^{-1})	10 - 26	25 - 29	80 - 100	81 - 105
CEC ($cmol^+$ kg^{-1})	14.28 – 16.19	16.68 – 17.54	14.49 – 16.53	13.59 – 14.59
Base Saturation (%)	48 - 63	37 - 52	58 - 64	51 - 54

3.4.2. N, P, and K uptake by rice during growth and development in the WS 2003-04

Average and standard deviations of N, P and K concentrations in shoots and roots of the rice plants during growth are given in Table 3. 3. The results indicate that the concentrations of N, P, and K in shoots and roots significantly decreased with time of rice growth and development ($p< 0.05$). The standard deviations during rice growth illustrate variations due to treatments.

The highest concentrations of N, P, and K in all parts of the rice plants were observed at 45 DAT, representing the end of the vegetative and the beginning of the reproductive phases. The concentrations of N, P, and K in shoots were 2.46 ± 0.50 % N, 0.20 ± 0.02 % P, and 3.57 ± 0.24 % K and in roots 1.41 ± 0.21 % N, 0.19 ± 0.04 % P, and 3.32 ± 0.32 % K.

The data also indicate that during rice growth, the concentrations of N, P and K in the shoots were significantly higher than in the roots. This presumably because of higher N, P and K in the shoot for photosynthesis processes. To grow and develop vegetative and reproductive organs, the plant needs energy coming from carbohydrate produced during photosynthesis. Hence, more assimilates were translocated and accumulated in the stem and the leaves than in the roots. It has been reported that between the vegetative and the reproductive stage more nutrients are required, that move and accumulate in the plant top (Anonymous, 1977; Mikkelsen *et al.,* 1995; Uexkull, 1970). It is also noticed that between 45 and 90 DAT, N and P assimilated in the plant shoots decreased about 50 %, showing that nutrient demand during periods of panicle initiation to flowering was the highest.

Table 3. 3. N, P and K concentrations in rice shoots and roots during rice growth (mean ± standard deviation)

Rice growth stage	Nutrient concentrations in shoots (%)			Nutrient concentrations in roots (%)		
	N	P	K	N	P	K
45 DAT	2.46 ± 0.50 a	0.19 ± 0.02 a	3.57 ± 0.24 a	1.41 ± 0.21 a	0.19 ± 0.04 a	3.32 ± 0.32 a
60 DAT	2.10 ± 0.43 b	0.17 ± 0.03 b	3.12 ± 0.35 a	1.09 ± 0.27 b	0.15± 0.03 b	2.60 ± 0.41 b
75 DAT	1.49 ± 0.16 c	0.13 ± 0.02 c	2.42 ± 0.25 b	0.73 ± 0.10 c	0.10 ± 0.03 c	2.10 ± 0.19 c
90 DAT	1.05 ± 0.10 d	0.10 ± 0.02 d	2.19 ± 0.20cd	0.58 ± 0.11 c	0.07 ± 0.01 d	1.89 ± 0.24 c
Harvest	1.00 ± 0.15 d	0.08 ± 0.01 d	2.09 ± 0.26 d	0.51 ± 0.05 c	0.07 ± 0.01 d	1.83 ± 0.25 c
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

When the treatments are considered, declining of the nutrients both in the shoots and roots during rice growth was also observed. However, statistical differences between treatments can only be observed at 45 and 60 DAT for N, both in the shoots and roots, and from 45 DAT to 90 DAT for P in the roots (Tables 3. 4 and 3. 5). The highest concentrations of N, P, and K in shoots and roots always occurred in the IT + RS treatments and also found at 45 DAT. These were 3.20 ± 0.11 % N, 0.21 ± 0.04 % P and 3.74 ± 0.23 % K and 1.68 ± 0.05 % N, 0.24 ± 0.06 % P, and 3.64 ± 0.43 % K, respectively.

Table 3. 4. N, P, and K concentrations in rice shoots as influenced by treatments and sampling time (mean ± standard deviation)

Treatment	Concentration (%)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
N in shoots:					
IT + RS	3.20 ± 0.11 a	2.73 ± 0.09 a	1.73 ± 0.14 a	1.21 ± 0.17 a	1.20 ± 0.32 a
I T	2.55 ± 0.06 b	2.18 ± 0.05 b	1.47 ± 0.23 a	1.04 ± 0.06 a	0.87 ± 0.11 a
CFP + RS	1.93 ± 0.07 c	1.65 ± 0.12 c	1.38 ± 0.05 a	1.00 ± 0.08 a	0.99 ± 0.16 a
CFP	2.17 ± 0.08 c	1.83 ± 0.06 c	1.40 ± 0.22 a	0.97 ± 0.11 a	0.94 ± 0.12 a
	(p = 0.000)	(p = 0.000)	(p = 0.133)	(p = 0.172)	(p = 0.454)
P in shoots:					
IT + RS	0.21 ± 0.04 a	0.18 ± 0.04 a	0.13 ± 0.02 a	0.11 ± 0.01 a	0.08 ± 0.01 a
I T	0.21 ± 0.04 a	0.17 ± 0.02 a	0.13 ± 0.03 a	0.09 ± 0.04 a	0.08 ± 0.01 a
CFP + RS	0.20 ± 0.03 a	0.16 ± 0.02 a	0.14 ± 0.02 a	0.09 ± 0.01 a	0.07 ± 0.01 a
CFP	0.16 ± 0.03 a	0.15 ± 0.03 a	0.13 ± 0.03 a	0.09 ± 0.01 a	0.07 ± 0.01 a
	(p = 0.553)	(p = 0.749)	(p = 0.916)	(p = 0.552)	(p = 0.482)
K in shoots:					
IT + RS	3.74 ± 0.23 a	3.19 ± 0.18 a	2.50 ± 0.23 a	2.46 ± 0. 18 a	2.37 ± 0.03 a
I T	3.46 ± 0.37 a	3.12 ± 0.32 a	2.38 ± 0.13 a	2.13 ± 0.15 a	2.14 ± 0.12 a
CFP + RS	3.50 ± 0.28 a	3.13 ± 0.27 a	2.37 ± 0.25 a	2.17 ± 0.23 a	1.94 ± 0.16 a
CFP	3.59 ± 0.18 a	3.01 ±0.15 a	2.43 ± 0.13 a	2.02 ± 0.18 a	1.78 ± 0.18 a
	(p = 0.885)	(p = 0.957)	(p = 0.651)	(p = 0.542)	(p = 0.211)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Table 3. 5. N, P, and K concentrations in rice roots as influenced by treatments and sampling time (mean ± standard deviation)

Treatment	Concentration (%)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
N in roots:					
IT + RS	1.68 ± 0.05 a	1.41 ± 0.24 a	0.84 ± 0.11 a	0.61 ± 016 a	0.57 ± 0.09 a
I T	1.47 ± 0.15 ab	1.22 ± 0.09 a	0.73 ± 0.04 a	0.59 ± 0.10 a	0.50 ± 0.04 a
CFP + RS	1.29 ± 0.03 b	0.88 ± 0.16 b	0.62 ± 0.14 a	0.53 ± 0.10 a	0.50 ± 0.05 a
CFP	1.21 ± 0.36 b	0.85 ± 0.14 b	0.69 ± 0.03 a	0.57 ± 0.15 a	0.46 ± 0.06 a
	(p = 0.007)	(p = 0.009)	(p = 0.091)	(p = 0.897)	(p = 0.278)
P in roots:					
IT + RS	0.24 ± 0.05 a	0.18 ± 0.02 a	0.12 ± 0.03 a	0.09 ± 0.01 a	0.08 ± 0.01 a
I T	0.21 ± 0.06 ab	0.15 ± 0.03ab	0.11 ± 0.02 a	0.08 ± 0.01 ab	0.07 ± 0.01 ab
CFP + RS	0.16 ± 0.01 b	0.11± 0.04 b	0.08 ± 0.01 b	0.07 ± 0.01 b	0.05 ± 0.01 c
CFP	0.16 ± 0.03 b	0.15 ± 0.02 ab	0.08 ± 0.02 b	0.07 ± 0.01 b	0.06 ± 0.01 bc
	(p = 0.102)	(p = 0.159)	(p= 0.076)	(p = 0.035)	(p = 0.002)
K in roots:					
IT + RS	3.64 ± 0.43 a	2.86 ± 0.27 a	2.36 ± 0.26 a	2.21 ± 0.20 a	2.14 ± 0.24 a
I T	3.50 ± 0.31 a	2.97 ± 0.28 a	2.11 ± 0.08 a	1.87 ± 0.19 a	1.87 ± 0.13 a
CFP + RS	2.90 ± 0.31 a	2.05 ± 0.29 a	1.90 ± 0.22 a	1.62 ± 0.21 a	1.53 ± 0.15 a
CFP	3.24 ± 0.32 a	2.53 ± 0.31 a	2.04 ± 0.19 a	1.88 ± 0.04 a	1.78 ± 0.14 a
	(p = 0.365)	(p = 0.141)	(p = 0.797)	(p = 0.298)	(p = 0.248)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

At harvest, nutrients contents were separately estimated for rice residues (stubbles and roots), rice straw, and rice grains (Table 3. 6). The data indicate that the highest N and P concentrations were observed in rice grains, while K was mainly found in rice straw. The N and P concentrations in the grains were 1.34 ± 0.04 % N and 0.19 ± 0.04 % P, while the K concentration in straw was 2.37 ± 0.05 % K. Similar results were also reported in many studies (Ghildyal, 1971; Naphade and Ghildyal, 1971; Sanchez and Calderon, 1971; Sukristiyonubowo *et al.,* 2004 and 2003). Furthermore, Ghildyal (1971) and Naphade and Ghildyal (1971) observed that concentrations of N and P in rice grains are higher than in rice straw. The real concentrations are significantly influenced by land preparation (puddling), water regime, and rice variety, besides nutrient inputs.

Among the treatments, the IT+RS treatment demonstrated the highest concentrations of N, P, and K in rice grains, rice straw, and rice residues. However, a statistical difference was only observed for P concentrations in rice grains and rice residues and for K concentration in rice residues. Therefore, it may be concluded that application of 100 kg of urea, 100 kg of TSP, and 100 kg of KCl ha^{-1} $season^{-1}$ along with returning rice straw as applied in the IT + RS treatment is beneficial to improve nutrient content in rice.

Table 3. 6. Nutrient concentrations and uptakes by rice grains, rice straw and rice residue at harvest as influenced by different treatments in the WS 2003-04 (mean ± standard deviation)

	Concentration of nutrient (%)			Nutrient uptake (kg-$ha^{-1}season^{-1}$)		
Treatment	N	P	K	N	P	K
In rice grain						
IT + RS	1.34 ± 0.04 a	0.19 ± 0.04 a	0.35 ± 0.02 a	76.48 ± 6.25 a	10.84 ± 3.03a	20.27 ± 2.38 a
I T	1.25 ± 0.17 a	0.15 ± 0.02ab	0.32 ± 0.06 a	51.87 ± 11.25b	5.99 ± 0.75 b	13.47 ± 4.28 b
CFP + RS	1.27 ± 0.12 a	0.12 ± 0.02 b	0.31 ± 0.02 a	48.70 ± 10.11b	4.54 ± 0.46 b	11.74 ± 1.83 b
CFP	1.21 ± 0.13 a	0.12 ± 0.02 b	0.30 ± 0.01 a	38.63 ± 6.89 b	3.86 ± 0.93 b	9.46 ± 0.73 b
	(p = 0.658)	(p = 0.027)	(p = 0.243)	(p = 0.005)	(p = 0.003)	(p = 0.005)
In rice straw						
IT + RS	1.20 ± 0.33 a	0.08 ± 0.01 a	2.37 ± 0.05 a	87.77 ± 12.17 a	5.78 ± 0.82 a	178.04± 22.08 a
I T	0.87 ± 0.11 a	0.09 ± 0.01 a	2.14 ± 0.12 a	54.43 ± 8.50 b	5.40 ± 0.22 a	133.41 ± 3.86ab
CFP + RS	0.99 ± 0.16 a	0.08 ± 0.01 a	1.94 ± 0.27 a	60.08 ± 6.25 b	4.76 ± 1.19 a	120.59 ± 30.14b
CFP	0.94 ± 0.32 a	0.08 ± 0.01 a	1.78 ± 0.58 a	49.17 ± 17.80b	4.40 ± 0.84 a	94.86 ± 37.33 b
	(p = 0.454)	(p = 0.482)	(p = 0.211)	(p = 0.018)	(p = 0.368)	(p = 0.028)
In rice residue						
IT + RS	0.57 ± 0.09 a	0.08 ± 0.01 a	2.14 ± 0.24 a	43.13 ± 7.29 a	5.21 ± 0.94 a	152.81 ± 59.10a
I T	0.50 ± 0.04 a	0.07 ± 0.01ab	1.87 ± 0.13 ab	23.35 ± 6.46 b	3.27 ± 0.67 b	88.00 ± 21.90ab
CFP + RS	0.50 ± 0.05 a	0.05 ± 0.01 c	1.53 ± 0.15 b	22.90 ± 7.28 b	2.29 ± 0.60 b	72.05 ± 32.95 b
CFP	0.46 ± 0.06 a	0.06 ± 0.01bc	1.78 ± 0.14 b	21.02 ± 1.58 b	2.74 ± 0.78 b	81.84 ± 16.47ab
	(p = O.278)	(p = 0.002)	(p = 0.048)	(p = 0.023)	(p = 0.004)	(p = 0.093)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Contrary to the concentrations, the N, P, and K uptake increased in accordance with the rice growth (see Appendices 3. 5 to 3. 10). This is due to a significant increase of rice plant weights during rice growth (see Appendices 3. 11 and 3. 12).

Nutrient uptakes by rice plants at harvest are also given in Table 3. 6. For all treatments, the results confirmed that the highest nutrient uptakes were observed in this phase. According to rice physiologists, about 80-90 % of the carbohydrates in the grains are photosynthesised between flowering and ripening stages. The rest is produced before flowering, accumulates in stem and leaves and moves to grains during ripening (Anonymous, 1977; Chandler, 1970). The highest nutrient uptakes were about 76 kg N, 11 kg P, and 18 kg K ha^{-1} $season^{-1}$; 88 kg N, 6 kg P, and 178 kg K ha^{-1} $season^{-1}$; and 39 kg N, 5 kg P, and 152 kg K ha^{-1} $season^{-1}$ for rice grains, rice straw, and rice residues, respectively and were observed for the IT + RS treatment. These results confirm the results of a previous study (Sukristiyonubowo *et al.,* 2003).

As in fact only rice residues were left in the field, the nutrient amounts taken up by rice straw and rice grains reflect the nutrients removal from the field through harvest. The total removal ranged between 88 and 164 kg N, 9 and 16 kg P, 104 and 196 kg K ha^{-1} $season^{-1}$ depending on the treatments. Similar ranges have been reported in other studies. Uexkull (1970) found that about 77 kg N, 14 kg P, and 151 kg K ha^{-1} $season^{-1}$ were removed through rice straw and rice grains during a wet season by a high yielding variety. These amounts are higher than those removed by an improved local variety. Sanchez and Calderon (1971) also noticed that the N uptake at harvest ranges from 34 to 107 kg N ha^{-1} $season^{-1}$, depending on rice variety. Kemmler (1971) observed that with a yield of 5 t ha^{-1} $season^{-1}$, between 90 and 100 kg N, 20 and 30 kg P, 60 and 80 kg K are removed from the field by high yielding varieties.

3.4.3. N, P, and K uptake by rice during growth and development in the DS 2004

Average and standard deviations of N, P, and K concentrations in shoots and roots of rice plants during growth in the DS 2004 are given in Table 3. 7. As in the WS 2003-04, significant decreases of N, P, and K concentrations in shoots and roots were also observed during growth and development ($p < 0.05$). The standard deviations were due to treatments and these results confirm the results of the WS 2003-04.

The highest N, P, and K concentrations both in shoots and roots of rice plant were also found at 45 DAT. The N, P, and K concentrations in shoots were 2.65 ± 0.46 % N, 0.21 ± 0.03 % P, and 3.41 ± 0.37 % K and in roots were 1.57 ± 0.29 % N, 0.19 ± 0.03 % P, and 3.17 ± 0.33 % K.

Table 3. 7. N, P and K concentrations in shoots and roots during rice growth in the DS 2004 (mean ± standard deviation)

Rice growth stage	Nutrient concentrations in shoots (%)			Nutrient concentrations in rice roots (%)		
	N	P	K	N	P	K
45 DAT	2.65 ± 0.46 a	0.21 ± 0.03 a	3.41 ± 0.37 a	1.57 ± 0.29 a	0.19 ± 0.03 a	3.17 ± 0.33 a
60 DAT	2.30 ± 0.41 a	0.17 ± 0.02 b	3.12 ± 0.21 b	1.27 ± 0.22 b	0.15 ± 0.02 b	2.82 ± 0.34 a
75 DAT	1.58 ± 0.35 b	0.13 ± 0.01 c	2.50 ± 0.19 c	0.92 ± 0.11 c	0.11 ± 0.02 c	2.40 ± 0.20 b
90 DAT	1.15 ± 0.14 c	0.10 ± 0.01 d	2.26 ± 0.25cd	0.68 ± 0.12 d	0.08 ± 0.02 d	1.98 ± 0.21 c
Harvest	1.09 ± 0.14 c	0.08 ± 0.01 d	2.16 ± 0.27 d	0.56 ± 0.08 d	0.07 ± 0.01 d	1.89 ± 0.22 c
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

The data also indicate that during rice growth, the concentrations of N, P and K in the shoots were significantly higher than in the roots. It is also interesting to note that the N and P concentrations in shoots decreased about 50 % between 45 and 90 DAT. These results confirm the results of WS 2003-04 and Mikkelsen *et al.* (1995).

As in the WS 2003-04, the N, P, and K concentrations in shoots and roots also decreased in all treatments during growth in the DS 2004 (Tables 3. 8 to 3. 9). Moreover, the highest nutrient concentrations also always occur in the IT + RS treatments, proving that more nutrients were available during growth.

Compared to the Conventional Farmer Practices (CFP), the CFP + RS, IT, and IT + RS treatments increased the concentrations of N, P, and K in shoots and roots. Depending on the treatments and development stage, the magnitude of enhancement in shoots of rice plants ranged between 3 and 67 %, 6 and 67 %, 2 and 32 % for N, P, and K, respectively. In roots, they varied from 6 to 51 %, 10 to 40 %, and 1 to 23 % for N, P, and K, respectively. The greatest differences both in shoots and roots were observed between CFP and IT + RS treatments.

Table 3. 8. N, P, and K concentrations in shoots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	Concentration of nutrient (%)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
N in shoots:					
IT + RS	3.25 ± 0.30 a	2.87 ± 0.06 a	2.05 ± 0.09 a	1.35 ± 0.13 a	1.28 ± 0.10 a
I T	2.82 ± 0.16 b	2.43 ± 0.06 b	1.66 ± 0.10 b	1.17 ± 0.06 b	1.07 ± 0.06 b
CFP + RS	2.30 ± 0.10 c	2.02 ± 0.08 c	1.29 ± 0.09 c	1.08 ± 0.08 b	1.03 ± 0.06 b
CFP	2.23 ± 0.15 c	1.87 ± 0.10 d	1.22 ± 0.88 c	1.05 ± 0.05 b	0.95 ± 0.05 b
	(p = 0.001)	(p = 0.000)	(p = 0.000)	(p = 0.011)	(p = 0.002)
P in shoots:					
IT + RS	0.25 ± 0.05 a	0.19 ± 0.04 a	0.14 ± 0.02 a	0.11 ± 0.01 a	0.09 ± 0.01 a
I T	0.21 ± 0.01 ab	0.17 ± 0.02 a	0.13 ± 0.01 a	0.11 ± 0.02 a	0.08 ± 0.01 ab
CFP + RS	0.20 ± 0.01 ab	0.17 ± 0.02 a	0.13 ± 0.01 a	0.10 ± 0.01 a	0.07 ± 0.01 b
CFP	0.18 ± 0.02 b	0.16 ± 0.01 a	0.12 ± 0.01 a	0.09 ± 0.01 a	0.07 ± 0.01 b
	(p = 0.065)	(p = 0.378)	(p = 0.153)	(p = 0.209)	(p = 0.043)
K in shoots:					
IT + RS	3.89 ± 0.08 a	3.40 ± 0.08 a	2.75 ± 0.25 a	2.55 ± 0.31 a	2.47 ± 0.21 a
I T	3.52 ± 0.23 b	3.17 ± 0.19 ab	2.53 ± 0.06 ab	2.33 ± 0.08 ab	2.23 ± 0.05 b
CFP + RS	3.20 ± 0.18 c	3.00 ± 0.25 b	2.37 ± 0.10 b	2.12 ± 0.11 b	1.95 ± 0.05 c
CFP	3.03 ± 0.06 c	2.92 ± 0.08 b	2.35 ± 0.05 b	2.03 ± 0.06 b	1.90 ± 0.09 c
	(p = 0.010)	(p = 0.027)	(p = 0.027)	(p = 0.024)	(p = 0.001)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Table 3. 9. N, P, and K concentrations in roots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	Concentration of nutrient (%)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
N in roots:					
IT + RS	1.97 ± 0.06 a	1.57 ± 0.06 a	1.05 ± 0.05 a	0.80 ± 0.05 a	0.66 ± 0.05 a
I T	1.57 ± 0.15 b	1.33 ± 0.06 b	0.95 ± 0.05 b	0.77 ± 0.06 a	0.57 ± 0.06 ab
CFP + RS	1.43 ± 0.15 bc	1.13 ± 0.11 c	0.88 ± 0.03 c	0.60 ± 0.09 b	0.50 ± 0.05 b
CFP	1.30 ± 0.05 c	1.08 ± 0.13 c	0.78 ± 0.03 c	0.55 ± 0.09 b	0.47 ± 0.08 b
	(p = 0.001)	(p = 0.001)	(p = 0.000)	(p = 0.007)	(p = 0.023)
P in roots:					
IT + RS	0.23 ± 0.03 a	0.18 ± 0.03 a	0.14 ± 0.03 a	0.10 ± 0.02 a	0.08 ± 0.01 a
I T	0.19 ± 0.01 ab	0.16 ± 0.02 ab	0.11 ± 0.01 ab	0.08 ± 0.01 b	0.07 ± 0.00 a
CFP + RS	0.16 ± 0.02 b	0.14 ± 0.02 b	0.09 ± 0.01 b	0.07 ± 0.01 b	0.07 ± 0.00 a
CFP	0.18 ± 0.03 b	0.14 ± 0.01 b	0.10 ± 0.01 b	0.07 ± 0.01 b	0.07 ± 0.00 a
	(p = 0.024)	(p = 0.020)	(p = 0.013)	(p = 0.018)	(p = 0.095)
K in roots:					
IT + RS	3.58 ± 0.15 a	3.17 ± 0.03 a	2.67 ± 0.10 a	2.26 ± 0.04 a	2.18 ± 0.13 a
I T	3.33 ± 0.08 b	3.07 ± 0.08 a	2.42 ± 0.08 b	2.00 ± 0.05 b	1.97 ± 0.03 b
CFP + RS	2.90 ± 0.13 c	2.53 ± 0.11 b	2.23 ± 0.08 c	1.82 ± 0.06 c	1.72 ± 0.03 c
CFP	2.87 ± 0.08 c	2.52 ± 0.03 b	2.27 ± 0.03 c	1.82 ± 0.05 c	1.70 ± 0.01 c
	(p = 0.00)	(p = 0.00)	(p = 0.00)	(p = 0.00)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

The N, P, and K uptakes in shoots during rice growth are given in Appendices 3. 13 to 3. 18. The nutrients taken up by shoots increased as rice plants weight significantly increased (Appendices 3. 19 and 3. 20). However, there is a tendency that the uptakes slightly decrease during ripening as assimilates are moved to grains.

Nutrient concentrations and uptakes at harvest in the DS 2004 are given in Table 3.10. Depending on the treatments, the N, P, and K uptakes in kg ha^{-1} $season^{-1}$ ranged from 45 to 83 for N, 5 to 12 for P, and 10 to 22 for K by rice grains, 49 to 82 for N, 4 to 6 for P, 97 to 157 for K by rice straw, and 24 to 43 for N, 4 to 5 for P, and 88 to 143 for K by rice residues. This means that the nutrient removal by harvest products, including rice grains and rice straw ranged between 94 and 165 kg N, 9 and 18 kg P, 107 and 179 kg K ha^{-1} $season^{-1}$.

The IT + RS treatment shows the highest N, P and K concentrations and uptake. They were significantly different from other treatments ($p < 0.05$), except for concentration P in the rice residues, in which the p was higher than 0.05 (Table 3.10).

Table 3. 10. Nutrient concentrations and uptakes by rice grains, rice straw, and rice residue at harvest as influenced by different treatments in the DS 2004 (mean ± standard deviation)

	Concentration of nutrient (%)			Nutrient uptake (kg-$ha^{-1}season^{-1}$)		
Treatment	N	P	K	N	P	K
In rice grains						
IT + RS	1.40 ± 0.05 a	0.20 ± 0.02 a	0.37 ± 0.03 a	82.78 ± 7.19 a	12.01 ± 1.11 a	21.72 ± 2.95 a
I T	1.32 ± 0.07ab	0.16 ± 0.01 b	0.35 ± 0.06 a	58.77 ± 9.56 b	7.09 ± 0.53 b	15.74± 2.12 b
CFP + RS	1.25 ± 0.05 b	0.13 ± 0.05 c	0.30 ± 0.06 b	51.47 ± 3.54bc	5.50 ± 0..54 c	12.50 ± 0.91 bc
CFP	1.22 ± 0.03 b	0.12 ± 0.02 c	0.28 ± 0.03 b	44.99 ± 1.89 c	4.56 ± 0.58 c	10.36 ± 1.09 c
	(p = 0.014)	(p = 0.000)	(p = 0.002)	(p = 0.000)	(p = 0.000)	(p = 0.001)
In rice straw						
IT + RS	1.28 ± 0.10 a	0.09 ± 0.01 a	2.47 ± 0.21 a	81.72 ± 6.44 a	5.95 ± 0.43 a	157.07 ± 12.81a
I T	1.07 ± 0.06 b	0.09 ± 0.01a	2.23 ± 0.03 b	59.22 ± 11.36b	4.77 ± 0.61 b	123.50 ± 19.13b
CFP + RS	1.03 ± 0.06 b	0.08 ± 0.01 b	1.95 ± 0.05 c	55.26 ± 12.98b	4.00 ± 0.27 b	103.92 ± 21.20b
CFP	0.95 ± 0.05 b	0.07 ± 0.01 b	1.90 ± 0.09 c	48.62 ± 7.01 b	3.76 ± 0.67 b	97.10 ± 12.02 b
	(p = 0.002)	(p = 0.043)	(p = 0.001)	(p = 0.016)	(p = 0.004)	(p = 0.010)
In rice residue						
IT + RS	0.65 ± 0.05 a	0.08 ± 0.01 a	2.18 ± 0.03 a	42.60 ± 3.98 a	5.23 ± 0.55 a	143.05 ± 6.40 a
I T	0.57 ± 0.06ab	0.07 ± 0.00 a	1.97 ± 0.03 b	32.46 ± 6.60 ab	3.99 ± 0.48 b	111.94 ± 13.10b
CFP + RS	0.50 ± 0.05 b	0.07 ± 0.01 a	1.72 ± 0.03 c	27.23 ± 5.09 b	3.72 ± 0.61 b	91.32 ± 16.71 b
CFP	0.47 ± 0.08 b	0.07 ± 0.00 a	1.70 ± 0.01 c	24.34 ± 7.12 b	3.61 ± 0.49 b	87.66 ± 12.11 b
	(p = 0.023)	(p = 0.095)	(p = 0.020)	(p = 0.020)	(p = 0.021)	(p = 0.002)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

3.4.4. Seasonal variations of nutrient concentrations and uptake

Concentrations of N, P, and K in shoots and roots of rice grown in the wet and dry seasons are compared in Appendices 3. 21 to 3. 22. Although the concentrations of N, P, and K are higher in the dry season than in the wet season, statistical evidences are not consistent ($p > 0.05$). It was observed that during the DS 2004, higher solar radiation and fewer disturbances during flowering and ripening resulted in a better yield than in the WS 2003-04. Uexkull (1970) also reported that rice grains and rice straw yields and nutrient uptakes in the dry season are greater than in the wet season.

Seasonal variations at harvest are given in Table 3. 11. The results show that both yield of grains and residues and nutrient concentrations and uptakes in all treatments are higher in the dry season, but statistical evidences are not consistent ($p > 0.05$). Only N and K concentrations in the shoots were found to be significantly different ($p < 0.05$). In addition, the yield of rice straw was higher in the wet season than in the dry season due to the presence of unproductive tillers occurring during ripening.

Table 3. 11. Seasonal variations of rice grain yield, rice straw production, rice residue production, nutrient concentrations, and nutrient uptake at harvest (mean ± standard deviation)

Season	Yield	Concentration of nutrient (%)			Uptake (kg ha^{-1} season^{-1})		
	(t ha^{-1})	N	P	K	N	P	K
Rice grains:							
WS 2003-04	4.24 ± 1.07 a	1.26 ± 0.12 a	0.15 ± 0.03a	0.32± 0.04 a	53.25±16.4 a	6.43±3.16 a	13.50 ± 4.78 a
DS 2004	4.54 ± 0.92 a	1.30 ± 0.09 a	0.16 ± 0.03a	0.33± 0.04 a	59.52±15.9 b	7.29±3.06 b	15.08 ± 4.78 a
	(p = 0.436)	(p = 0.462)	(p = 0.416)	(p = 0.675)	(p = 0.406)	(p = 0.450)	(p = 0.495)
Rice straw:							
WS 2003-04	6.29 ± 1.03 a	1.00 ± 0.25 a	0.08 ± 0.01a	2.05± 0.36 a	62.87±18.6 a	5.08±1.18 a	132.56 ± 38.73a
DS 2004	5.58 ± 0.79 a	1.09 ± 0.14 b	0.08 ± 0.01a	2.17± 0.30 b	61.21±15.47a	4.62±0.99 a	119.56 ± 28.21a
	(p = 0.072)	(p = 0.030)	(p = 0.681)	(p = 0.053)	(p = 0.815)	(p = 0.268)	(p = 0.422)
Residue:							
WS 2003-04	5.19 ± 1.39 a	0.55 ± 0.07 a	0.07 ± 0.01a	1.83±0.37 a	28.50±9.19 a	3.63±1.42 a	98.67 ± 45.50 a
DS 2004	5.68 ± 0.80 a	0.56 ± 0.09 a	0.07 ± 0.01a	1.89±0.21 a	31.66±8.90 a	4.14±0.82a	108.49±25.37 b
	(p = 0.304)	(p = 0.238)	(p = 0.094)	(p = 0.632)	(p = 0.196)	(p = 0.196)	(p = 0.521)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

3.5. Conclusions

Concentrations of N, P, and K in shoots and roots significantly decrease during rice growth. The highest nutrient concentrations are observed 45 days after transplanting. The time (split) of fertiliser application should be adapted to the rice growth and nutrient demand.

The application of 100 kg ha^{-1} $season^{-1}$ of each urea, Triple Super Phosphate, and Potassium Chloride (KCl) along with 33 % of rice straw produced ha^{-1} $season^{-1}$, as applied in the treatment of Improved Technology, increases N, P, and K concentrations in shoots and roots, as well as nutrient uptakes during rice growth. However, significant improvement of concentrations and uptakes are only found in the dry season.

Application of only 50 kg of urea ha^{-1} $season^{-1}$, as applied in the conventional farmer practice always shows the lowest nutrient concentrations and uptakes. Therefore, it should be left out to avoid on site negative impacts including nutrient mining and declining quantity and quality of rice yields.

Depending on the inputs and season, total nutrient removal through rice grains and rice straw varied from 88 to 165 kg N, from 8 to 18 kg P, and from 104 to 198 kg K ha^{-1} $season^{-1}$.

The concentrations and uptakes of N, P, and K in the dry season are higher than in the wet season, but statistical evidences are not consistent.

Chapter 4

RICE PRODUCTION IN TERRACED PADDY FIELD SYSTEMS: EFFECT OF RICE STRAW ADDITION

RICE PRODUCTION IN TERRACED PADDY FIELD SYSTEMS: EFFECT OF RICE STRAW ADDITION

Abstract

Studies on rice production in terraced paddy field systems have been carried out for the wet season 2003-04 and dry season 2004 at Keji Village, Semarang District. As in Chapter 3, four treatments, including Improved Technology + Rice Straw (IT+RS), Improved Technology (IT), Conventional Farmer Practices + Rice Straw (CFP+RS), and Conventional Farmer Practice (CFP) were applied. They were arranged in Randomised Complete Block Design and replicated 3 times. The objectives were (1) to evaluate the effect of improved technologies and farmer practices on rice production, (2) to assess the application of rice straw on rice yield, and (3) to evaluate seasonal variation of biomass production and grain yield parameters. The results indicate that biomass production for the Improved Technology + Rice Straw treatments was significantly higher than for the other treatments both in the wet season 2003-04 and dry season 2004. Significant improvement of rice grain yield was due to significant enhancement of the 1000-grains weight, the number of grains panicle^{-1}, and the number of filled grains panicle^{-1}. Significant increase of rice straw yield was due to improvement of shoot weights and for rice residue due to root weights. Significant seasonal variations were observed for grain and straw yields when rice straw was applied, as well as variations for the 1000-grains weight, the number of grains panicle^{-1}, the number of filled grains panicle^{-1} and shoot weights.

4.1. Introduction

Traditionally, agriculture is only seen as a means of production and its value is also assessed in terms of farm products. In the past, improving rice production was one of the main targets in most rice growing countries. According to IRRI (2005), the rough rice production in Indonesia augmented from 12.08 to 53.10 million tons between 1961 and 2004 and total consumption of fertilisers (N, P, K) increased from 136 in 1961 to 2,659 thousand tons in 1999.

In modern agriculture, the aims of agricultural activities are not only oriented to maximise yield and profit, but also to conserve natural resources and to protect the environment. Environmental protection is practically implemented by reducing mineral fertilisers along with increasing organic inputs. Hence, application of organic matter such as crop residue, farmyard manure, green manure, and cattle dung are highly promoted.

The findings in Chapter 2 show that terraced paddy field systems provide environmental services by trapping sediment and nutrients along the terraces. These will reduce potential negative impacts and improve water quality, as the river water is also used for domestic and drinking purposes. Furthermore, positive impacts with respect to erosion mitigation, flood prevention, and groundwater conservation may be observed in the whole catchment or landscape. Therefore, terraced paddy field systems need to be protected and intensified.

In irrigated lowland rice production, the influences of organic matter management and mineral fertilisers on soil fertility and rice production have been studied more than in other wetland rice systems. However, levelling off occurs in many rice fields in Indonesia. The inorganic fertilisers were getting more expensive, causing imbalanced and insufficient fertilising and thus nutrient mining. It is also recognised that farming systems with long improper crop residue management have resulted in considerable reduction of soil organic matter and loss of soil nutrients. Furthermore, urban markets for bio food are expanding very fast in some areas. For example, in the Sragen District (Central Java Province) the farmers are motivated to cultivate rice using nutrients from organic sources.

Particularly in the Semarang District, rice straw could either be removed from the field for cattle feeding, left in the field as organic input, or burned prior to the first land ploughing (Photos 3. 1, 4. 1 and 4. 2). Consequently, the rate of rice straw application was also challenging.

The objectives of this study were (1) to evaluate the effects of fertilisers and rice straw application on rice biomass production, and (2) to evaluate seasonal variations on biomass production and the grain yield parameter.

4.2. Literature review

Fertilisers are the most efficient input to enhance rice production and to replace nutrient removal. Moreover, high yielding rice varieties require heavy fertilising to achieve their potential yields. However, scientists also reported that the response of rice crops to fertilisers varies depending on variety, soil, climate, and agronomic practices, such as management of crop residues, land preparation, pest, disease, and weed controls (Anonymous, 1977; Ferwerda, 1970; Mikkelsen *et al.,* 1995; Sanchez and Calderon, 1971; Uexkull, 1970).

It is observed that even with a balanced use of NPK, optimal rice yield levels could not be reached and maintained without proper application of organic matter. Many recent arguments showed up including other macro- and micro- nutrient deficiencies and deterioration of the soil physical ecosystem. Other studies concluded that since rice is also known as a silicon (Si) accumulator and could get benefits from silicon nutrition, incorporation of rice straw, one of the silicon sources, is highly recommended to cope the levelling off, to increase soil fertility and to improve yield (Sudhakar *et al.,* 2004; Takahashi, 1995; Yang *et al.,* 2004).

To conserve natural resources, to protect the environment, and to reduce dependency on chemical fertilisers, organic farming is becoming a recent approach in modern agriculture systems. Moreover, the importance of organic sources including compost, straw, and leguminous green manure crops in improving soil chemical and physical properties have also received more attention in recent times (Clark *et al.,* 1998; Hasegawa *et al.,* 2005; Landa *et al.,* 1992; Mandal *et al.,* 2003; Ray and Gupta, 2001; Whitbread *et al.,* 2000; Xu *et al*., 2006).

Photo 4. 1. Rice straw is burned in the field prior to the first ploughing

Photo 4. 2. Rice straw was ploughed in during the land preparation

Mandal *et al.* (2003) reported that application of green manure (*Sesbania rostrata*, *Sesbania aculeata*, and *Vigna radiata*) together with different rates of nitrogen fertiliser application increased the concentration of soil organic matter and total nitrogen, improved total pore space, water stable aggregates, hydraulic conductivity, and reduced bulk density. The results also showed that the root length and yields are higher in green manure plots than in fallow plots, both for rice as well as for succeeding wheat crops.

Alice *et al.* (2003) observed that application of 120-50-50 kg N P K ha^{-1} + Azola and 120-50-50 kg N P K ha^{-1} + Azospirillum showed the highest tiller production, 1000 grains weight, and rice grains yield. The lowest yield was found in the plot treated with only inorganic fertiliser. Another study revealed that incorporation of inter-cropped black gram along with application of Azotobacter and 5 tons ha^{-1} FYM (farm yard manure) significantly enhanced rice grains yield (Senapati *et al.,* 2004).

Furthermore, it is also well documented that higher FYM levels significantly improve the number of roots $plant^{-1}$, length of roots, and rice yield (Bridgit and Potty, 2002). Similar results were also found in rice field managed with FYM and wheat straw under different water regimes (Yang *et al.,* 2004).

Significant improvements in nutrient uptake, rice grains, and rice straw yields were observed in trials combining 12.5 t ha^{-1} of *Gliricidia* leaves manure with inorganic phosphate fertiliser (Kaleeswari and Subramanian, 2004). Another study reported that applications of different sources of organic matter in the rice-wheat cropping system statistically increased total uptake of N, P, and K and rice yield (Singh *et al.,* 2001).

Besides having positive influence on rice production, addition of organic manure also improves the yield quality, for instance milling and cooking quality. Prakhas *et al.* (2002) observed that FYM gives higher protein contents of the Pusa Basmati variety.

Theoretically, rice grain yield at maturity is the product of four yield parameters, namely the number of panicles per square meter, the number of grains per panicle, the filled grains, and the weight of 1000 grains (Alice *et al.,* 2003; Anonymous, 1977; Casanova *et al.,* 2002; Mikkelsen *et al.,* 1995; Yoshida, 1981). The development of yield parameters depends on variety, soil nutrient and water supply, climate, and farm management practices.

4.3. Materials and Methods

Major materials for conducting field experiments, farm management practices, procedures for sampling and analyses, treatments and replications have been described in chapters 2 and 3 of this thesis. More characteristics information of the sites is given in Table 4.1. The current chapter also describes the way of harvesting, methods for measuring rice yield and yield parameters, including the number of rice grains panicle^{-1}, the number of filled rice grains panicle^{-1}, the weight of 1000 grains, and the length of panicles, besides plant height.

Rice biomass productions including grains, straw, and residues on a hectare basis were extrapolated from sampling areas of 1m x 1m. These sampling units were randomly selected at every terrace. Rice plants were cut about 10 to 15 cm above the ground surface. The samples were manually separated into rice grains, rice straw, and rice residues (Photos 4. 3 and 4. 4). Rice residues included the roots and the part of the stem (stubble) left after cutting (Photo 4. 5).

Fresh weights of rice grain, rice straw, and rice residue were immediately estimated at each sampling unit. Afterwards, samples were treated in the oven at 85^0 C until constant dry weights were obtained. The average weights of rice grains, rice straw, and rice residues were used to compute the biomass productions on the hectare basis.

Rice plants from one hill at each terrace were randomly sampled to determine grain yield parameters being the number of rice grains per panicle, the number of filled grains per panicle, the weight of 1000 grains, and the length of panicles. Randomly, three times one hundred filled grains were weighed to estimate the 1000-filled grains weight.

The length of panicles was measured from the terminal node to the end of panicle (Anonymous, 1977; Puserglove, 1968) using a metallic ruler. Plant height was monitored starting from 45 DAT to harvest from three hills of each terrace. The heights were recorded from the ground surface to the highest leaves using a 1.5 meter long metallic ruler.

Photo 4. 3. Harvest of a 1 m x 1 m plot for estimating biomass production at hectare basis

Photo 4. 4. The harvesting and yield processing, terrace by terrace, done at the research site

Data in Table 4.1 also provided information that there was no variation in planting intensity among farmers and the rice straw is needed for cattle feeding.

All data were statistically examined by analysis of variance (ANOVA) and computed using the software SPSS programme. Means were compared using Duncan tests with a 5 % degree of confidence.

Photo 4. 5. Rice residue remaining at the rice field, resulting from cutting at harvest

Table 4. 1. Some characteristics of the research sites

Farmer	Treatment	Replication	Number of terrace	Size (m^2)	Other Remarks
F-1	IT + RS	I	9	2 240	2-3 times planting rice per year, 4 cows
F-2		II	8	1 530	2-3 times planting rice per year, 2 cows
F-3		III	4	3 400	2-3 times planting rice per year, 3 cows
F-4	I T	I	7	5 000	2-3 times planting rice per year, 1 cow
F-5		II	7	4 500	2-3 times planting rice per year, 4 cows
F-6		III	8	3 070	2-3 times planting rice per year, 1 cow
F-7	CFP + RS	I	8	904	2-3 times planting rice per year, 1 cow
F-8		II	5	2 500	2-3 times planting rice per year, 1 cow
F-9		III	7	5 300	2-3 times planting rice per year, 1 cow
F-10	CFP	I	9	5 040	2-3 times planting rice per year, 1 cow
F-11		II	8	4 780	2-3 times planting rice per year, 10 cows
F-12		III	6	1 680	2-3 times planting rice per year, 1 cow, 3 buffaloes,

Source of Data: Village Head Office, personal communication, and field observation

4.4. Results and Discussion

4.4.1. Biomass production in the WS 2003-04

The average biomass production, including rice grains, rice straw, and rice residues, and their standard deviations are given in Table 4. 2. The overall production of the IT + RS treatment was significantly superior over the other treatments ($p < 0.05$). The magnitudes of improvement were 79.7 %, 42.8 %, and 51.8 % over the conventional farmer practices (CFP) for rice grains, rice straw, and rice residues, respectively. Application of only 100-kg ha^{-1} $season^{-1}$ of Urea, TSP, and KCl, without returning rice straw (the IT treatment) did not significantly increase the biomass productions. This confirms the findings observed by Alice *et al.* (2003); Bridgit and Potty (2002); Mandal *et al.* (2003); Senapati *et al.* (2004), illustrating that incorporation of organic fertiliser is essential to improve soil fertility and rice yield. The standard deviations were small, indicating the soil variability within treatment or farmers is small.

Table 4. 2. Biomass production as influenced by treatments in the WS 2003-04 (mean ± standard deviation)

Treatment	Biomass production (t ha^{-1} $season^{-1}$)		
	Rice grain	Rice straw	Rice residue
IT + RS	5.73 ± 0.62 a	7.50 ± 0.91 a	6.93 ± 1.17 a
I T	4.14 ± 0.57 b	6.25 ± 0.38 ab	4.67 ± 0.97 b
CFP + RS	3.82 ± 0.45 b	6.16 ± 0.77 ab	4.58 ± 1.39 b
CFP	3.19 ± 0.29 b	5.25 ± 0.63 b	4.57 ± 0.60 b
	(p = 0.001)	(p = 0.027)	(p = 0.006)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

The average grain yield parameters, including weight of 1000 rice grains, number of rice grains $panicle^{-1}$, number of filled grain $panicle^{-1}$, and the length of panicles, and their standard deviations are given in Table 4. 3. As for the biomass production, the grain yield parameters of the IT + RS treatment were significantly higher compared to the other treatments ($p < 0.05$). This was also observed by Alice *et al.* (2003), Casanova *et al.* (2002), Kaleeswari and Subramanian (2004), Mikelsen *et al.* (1995), Uexkull (1970b), Yang *et al.* (2004) and Yoshida (1981).

Table 4. 3. Grain yield parameters as influenced by treatments in the WS 2003-04 (mean ± standard deviation)

Treatment	Grain yield parameters			
	Weight of 1000 rice grains (g)	Number of rice grains per panicle	Number of filled rice grains per panicle	Length of panicles (cm)
IT + RS	27.11 ± 0.11 a	100.00 ± 2.00 a	91.00 ± 1.00 a	21.67 ± 0.58 a
I T	26.57 ± 0.21 a	96.33 ± 0.58 b	86.67 ± 1.53 ab	20.67 ± 0.58 ab
CFP + RS	25.28 ± 0.68 b	94.67 ± 1.15 bc	84.67 ± 0.58 b	20.33 ± 0.58 b
CFP	24.42 ± 0.62 b	93.00 ± 1.00 c	84.00 ± 1.73 b	20.33 ± 0.58 b
	(p = 0.000)	(p = 0.001)	(p = 0.002)	(p= 0.006)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Differences of grain yield parameters between the CFP and the IT + RS treatments were about 2.69 g for 1000-grains weight, 7 for rice grains per panicle, 6.33 for filled grains per panicle, and 1.33 cm for length of panicles.

The enhancement of the rice straw production was related to increase of shoot weight of rice plants per hill. The results indicate that from 45 DAT to harvest, the shoot weights at the IT + RS treatment were significantly higher than for other treatments (see appendix 3. 11). The increase was also observed for rice residue yields (Table 4. 2). This is mainly due to higher weights of roots per hill (see Appendix 3. 12), leading to greater nutrient uptake and better rice growth and development (see Appendices 3.5 to 3. 10). Other publications also showed that application of FYM increases the number of roots per plant, length of roots, and rice grain yield (Alice *et al.,* 2003; Bridgit and Potty. 2002; Chang *et al.,* 1993; Singh *et al.,* 2001; Yang *et al.,* 2004).

Data of plant heights and their standard deviations are given in Table 4. 4. In general, there are small differences among the treatments, but only the differences between the IT + RS treatment and the CFP treatment at 60, 75, and 90 DAT were found to be significant, showing that the growth rate is only slightly affected (p values were 0.050, 0.057 and 0.052, at 60, 75 and 90 DAT, respectively).

Table 4. 4. Plant height as influenced by treatments during rice growth in the WS 2003-04 (mean ± standard deviation)

Treatment	Plant height (cm)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
IT + RS	57.60 ± 2.57 a	75.30 ± 5.33 a	86.33 ± 0.91 a	97.23 ± 3.31 a	104.43 ± 3.41 a
I T	47.77 ± 2.12 a	70.30 ± 5.12 ab	82.73 ± 1.43 ab	95.67 ± 1.39 ab	103.20 ± 1.44 a
CFP + RS	47.43 ± 1.97 a	69.57 ± 3.00 ab	82.57 ± 2.67 ab	95.00 ± 2.16 ab	102.00 ± 3.80 a
CFP	46.70 ± 2.45 a	63.93 ± 2.22 b	77.83 ± 4.82 b	92.50 ± 1.85 b	101.50 ± 0.85 a
	(p = 0.199)	(p = 0.050)	(p = 0.057)	(p = 0.052)	(p = 0.571)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

4.4.2. Biomass production in the DS 2004

The average biomass productions, including rice grain, rice straw, and rice residue, and their standard deviations in the DS 2004 are given in Table 4. 5. As observed in the WS 2003-04, rice grain, rice straw, and rice residue productions in the IT + RS treatment in the DS 2004 were also significantly higher than for other treatments ($p < 0.05$). The biomass productions were about 5.91 ± 0.33, 6.37 ± 0.30, and 6.55 ± 0.21 t ha^{-1} for grain, straw and residue, respectively. They increased about 60 %, 25 %, and 26 % compared to grain, straw and residue yields in the CFP, respectively.

Table 4. 5. Biomass production as influenced by treatments in the DS 2004 (mean ± standard deviation)

Treatment	Biomass production (t ha^{-1}-$season^{-1}$)		
	Rice grain	Rice straw	Rice residue
IT + RS	5.91 ± 0.33 a	6.37 ± 0.30 a	6.55 ± 0.21 a
I T	4.45 ± 0.59 b	5.52 ± 0.79 b	5.69 ± 0.68 ab
CFP + RS	4.12 ± 0.22 bc	5.33 ± 1.05 b	5.31 ± 0.88 ab
CFP	3.69 ± 0.07 c	5.10 ± 0.48 b	5.16 ± 0.71 b
	(p = 0.000)	(p = 0.026)	(p = 0.023)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

The average grain yield parameters, including the weight of 1000 rice grains, number of rice grains per panicle, number of filled grains per panicles, length of panicles, and their standard deviations are given in Table 4. 6. Significant differences among treatments were observed for grain yield parameter. This means that the grain yield parameters for the IT + RS treatment were also superior for other treatments ($p < 0.05$). The differences compared to CFP were about 2.4 g, 8.3, 10.9, and 1.1 cm for 1000-grains weight, number of grains per panicle, number of filled grains per panicle, and length of panicles, respectively. Hence, increasing grain yield for the IT + RS treatment is supported by the improvement of all yield parameters. These results confirm the results of the WS 2003-04.

It is interesting to note that the IT treatment also showed statistical improvement of grain yield parameters and grain yield, proving adequate nutrient supply is needed to enhance grain yield.

Table 4. 6. Grain yield parameters as influenced by treatments in the DS 2004 (mean ± standard deviation)

Treatment	Grain yield parameters			
	Weight of 1000 rice grains (g)	Number of rice grains per panicle	Number of filled rice grains per panicle	Length of panicles (cm)
IT + RS	28.15 ± 0.11 a	102.22 ± 0.84 a	96.33 ± 1.00 a	22.22 ± 0.19 a
I T	27.49 ± 0.47 a	98.89 ± 0.19 b	89.45 ± 1.35 b	21.29 ± 0.19 b
CFP + RS	26.73 ± 0.38 b	95.78 ± 0.84 c	85.55 ± 0.39 c	20.47 ± 0.39 c
CFP	25.75 ± 0.51 c	93.89 ± 0.38 d	82.11 ± 0.70 d	20.12 ± 0.43 c
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Superiority of the IT + RS treatment in the DS 2004 is not only a result of direct influence of inputs applied in the beginning of the DS 2004, but also due to residual effects of the rice straw incorporation in the WS 2003-04.

Plant height data and their standard deviations in the DS 2004 are given in Table 4. 7. Contrary to the WS 2003-04, plant heights were significantly different among the treatments ($p < 0.05$). The IT + RS treatment showed the greatest plant heights. At harvest, only the plant heights at the IT + RS treatments were significantly higher than at the CFP.

Table 4. 7. Plant height as influenced by treatments during rice growth in the DS 2004 (mean ± standard deviation)

Treatment	Plant height (cm)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
IT + RS	52.82 ± 0.39 a	80.25 ± 0.31 a	84.12 ± 0.61 a	85.67 ± 0.18 a	87.69 ± 0.37 a
I T	49.23 ± 0.38 b	79.67 ± 0.15 a	83.50 ± 0.10 a	85.55 ± 0.26 a	86.93 ± 0.40 ab
CFP + RS	47.67 ± 0.47 c	75.23 ± 0.35 b	78.70 ± 0.36 b	83.33 ± 0.72 ab	84.80 ± 0.54 ab
CFP	45.23 ± 0.35 d	71.83 ± 0.25 c	77.03 ± 0.32 c	80.97 ± 0.31 b	82.63 ± 0.23 b
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.052)	(p.0.026)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

4.4.3. Seasonal variations of rice productions and effect of rice straw

Amounts of rice grain, rice straw, and rice residue produced in the wet and dry seasons have been compared in Table 3. 11. Statistically, there are no significant variations of rice grain yield between the WS 2003-04 and the DS 2004 ($p > 0.05$ see Table 3.11). However, the 1000-grain weights and number of rice grains per panicle in the DS 2004 were significantly greater than in the WS 2003-04 ($p < 0.05$ see Table 4. 9). This means that 1000-grains weight and number of rice grains per panicle are not the dominating factors controlling grain yield. Rice straw and rice residue productions were not statistically affected by seasons.

However, rice grain yields of the treatments in which rice straw was applied were significantly higher in the DS 2004 than in the WS 2003-04 (Table 4. 8). Moreover, the 1000-grain weights, the number of rice grains per panicle, and the number of filled grains per panicle were significantly higher in the DS 2004 compared to the WS 2003-04 (Table 4. 10).

Table 4. 8. Seasonal variations of biomass production as influenced by application of rice straw (mean ± standard deviation)

Treatment	Biomass production (t ha^{-1} $season^{-1}$)		
	Rice grain	Rice straw	Rice residue
+ RS (DS 2004)	5.01 ± 1.01 a	5.85 ± 0.90 a	5.93 ± 0.89 a
- RS (DS 2004)	4.08 ± 0.56 b	5.31 ± 0.63 a	5.42 ± 0.69 a
+ RS (WS 2003-04)	4.78 ± 1.16 ab	6.82 ± 1.05 b	5.76 ± 1.73 a
- RS (WS 2003-04)	3.67 ± 0.66 b	5.75 ± 0.72 a	4.62 ± 0.73 a
	(p = 0.050)	(p = 0.035)	(p = 0.198)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Comparing tables 4. 8 and 4. 10, it may be suggested that the number of filled grains per panicle is the most dominant factor controlling grain yield.

Significant seasonal variations were also observed in rice straw yield ($p < 0.05$). The production in the WS 2003-04 was statistically higher than in the DS 2004 due to significant differences in shoot weights during rice growth (Table 4. 11). However, the statistical differences were not observed in rice residue production, although significant variations of root weights during rice growth were detected. This suggests that variation in the cutting height may be the main reason, since the rice residue at harvest consists of roots and stubbles.

Table 4. 9. Seasonal variations of grain yield parameters (mean ± standard deviation)

Season	Grain yield parameters			
	Weight of 1000 rice grains (g)	Number of rice grains per panicle	Number of filled rice grains per panicle	Length of panicles (cm)
DS 2004	27.03 ± 0.99 a	97.69 ± 3.35 a	88.36 ± 5.56 a	21.03 ± 0.89 a
WS 2003-04	25.84 ± 1.17 b	96.00 ± 2.92 b	86.33 ± 2.67 a	20.75 ± 0.75 a
	(p = 0.014)	(p = 0.020)	(p = 0.268)	(p = 0.423)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Table 4. 10. Seasonal variations of grain yield parameters as influenced by application of rice straw (mean ± standard deviation)

Treatment	Grain yield parameters			
	Weight of 1000 rice grains (g)	Number of rice grains per panicle	Number of filled grains per panicle	Length of panicles (cm)
+ RS (DS 2004)	27.44 ± 0.82 a	99.00 ± 3.60 a	90.94 ± 5.91 a	21.34 ± 1.00 a
- RS (DS 2004)	26.62 ± 1.05 ab	96.39 ± 2.75 ab	85.78 ± 4.13 b	20.71 ± 0.70 a
+ RS (WS 2003-04)	26.19 ± 1.09 b	97.33 ± 3.27 ab	87.33 ± 3.01 b	21.00 ± 0.89 a
- RS (WS 2003-04)	25.49 ± 1.25 b	94.50 ± 1.97 b	85.33 ± 2.06 b	20.50 ± 0.55 a
	(p = 0.033)	(p = 0.050)	(p = 0.038)	(p = 0.321)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

The tremendous increase of rice straw production in the WS 2003-04 may be due to favourable external conditions for growing up of the vegetative parts during the ripening phase. This was indicated at harvest by more green leaves, unproductive tillers, and taller plants compared to the DS 2004. Indeed, significant seasonal variations of plant heights were detected at 60 DAT, 90 DAT and at harvest (see Table 4. 12).

Shoot and roots weights grown in the wet and dry season as influenced by addition of rice straw are compared in Table 4.11. Seasonal differences of shoot and root weights during rice growth were observed ($p < 0.05$), except for the shoot and root weights at 45 DAT ($p > 0.05$).

During rice growth, between 45 DAT and 90 DAT, shoot weights in the dry season were higher than in the wet season. However, at the harvest, shoot weight was higher in the wet season than in the dry season, proving the rice straw production in the wet season was higher than in the dry season.

Table 4. 11. Seasonal variations of shoot and root weights of rice plants as influenced by application of rice straw (mean ± standard deviation)

Treatment	Weight of rice plants (t ha^{-1})				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
Shoot weights:					
+ RS (DS 2004)	1.95 ± 0.14 a	2.97 ± 0.17 a	4.46 ± 0.07 a	5.68 ± 0.37 a	5.85 ± 0.90 a
- RS (DS 2004)	1.86 ± 0.12 a	2.79 ± 0.07 ab	4.39 ± 0.09 a	4.93 ± 0.29 b	5.31 ± 0.63 a
+ RS (WS 2003-04)	1.81 ± 0.15 a	2.64 ± 0.25 b	3.67 ± 0.32 b	5.25 ± 0.47 ab	6.82 ± 1.05 b
- RS (Ws 2003-04)	1.78 ± 0.17 a	2.60 ± 0.11 b	3.56 ± 0.34 b	4.92 ± 0.41 b	5.75 ± 0.72 a
	(p = 0.252)	(p = 0.009)	(p = 0.000)	(p = 0.011)	(p = 0.035)
Root Weights:					
+ RS (DS 2004)	0.68 ± 0.04 a	1.06 ± 0.07 a	1.70 ± 0.17 a	2.24 ± 0.17 a	5.93 ± 0.89 a
- RS (DS 2004)	0.62 ± 0.06 a	1.00 ± 0.07 b	1.59 ± 0.15 b	2.12 ± 0.18 b	5.42 ± 0.69 a
+ RS (WS 2003-04)	0.63 ± 0.07 a	0.95 ± 0.10 bc	1.22 ± 0.11c	1.83 ± 0.12 c	5.76 ± 1.73 a
- RS (Ws 2003-04)	0.62 ± 0.05 a	0.90 ± 0.05 c	1.20 ± 0.09 c	1.74 ± 0.14 c	4.62 ± 0.73 a
	(p = 0.260)	(p = 0.011)	(p = 0.000)	(p = 0.000)	(p = 0.198)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Table 4. 12. Seasonal variations of plant height as influenced by application of rice straw (mean ± standard deviation)

Treatment	Plant height (cm)				
	45 DAT	60 DAT	75 DAT	90 DAT	Harvest
+ RS (DS 2004)	50.24 ± 2.85 a	77.74 ± 2.76 a	81.42 ± 3.00 a	84.51 ± 8.62 a	86.24 ± 2.02 a
- RS (DS 2004)	47.23 ± 2.21a	75.75 ± 4.40 a	80.00 ± 3.94 a	83.32 ± 3.07 a	84.78 ± 2.94 a
+ RS (WS 2003-04)	52.52 ± 7.46 a	72.43± 4.98 b	84.45 ± 4.59 a	96.12± 2.77 b	103.8 ± 3.30 b
- RS (Ws 2003-04)	47.23 ± 6.43 a	67.12 ± 4.96 c	80.28 ± 4.16 a	94.08± 2.27 b	101.8 ± 1.09 b
	(p = 0.261)	(p = 0.002)	(p = 0.219)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

4. 5. Conclusions

The lowest yields were always observed for the Conventional Farmer Practices (CFP), illustrating that imbalanced fertilising could not supply enough nutrients to reach optimal yields.

Application of 33 % of straw produced ha^{-1} $season^{-1}$ significantly increased rice grain yields both in the wet and dry seasons.

Biomass production including rice grain, rice straw, and rice residue both in the wet and dry seasons was significantly higher for the improved technology + rice straw (IT + RS) treatments than for other treatments. This was also observed for grain yield parameters, shoot and root weights.

Significant seasonal variations were found for rice grain and rice straw yields when rice straw was applied. The rice grain yield, the 1000-grains weight, the number of grains $panicle^{-1}$, the number of filled grains $panicle^{-1}$ and shoot weights were significantly higher in the dry season 2004 compared to the wet season 2003-04.

Among the grain yield parameters, the number of filled grains $panicle^{-1}$ is the most dominant factor controlling grain yield.

Chapter 5

NUTRIENT BALANCES UNDER TRADITIONAL IRRIGATION IN TERRACED PADDY FIELD SYSTEMS

NUTRIENT BALANCES UNDER TRADITIONAL IRRIGATION IN TERRACED PADDY FIELD SYSTEMS

Abstract

This chapter presents nutrient balances of three major elements, N, P, and K, for rice farming in terraced paddy fields under traditional irrigation during the wet season 2003-04 and dry season 2004. The assessments were carried out for conventional farmer practices (CFP), conventional farmer practices + rice straw (CFP + RS), improved technology (IT), and improved technology + rice straw (IT + RS) treatments. Balances were computed based on differences between input and output. Nutrient originating from fertiliser (IN-1), recycled rice straw (IN-2), irrigation (IN-3), and precipitation (IN-4) were grouped as input. Nutrient removal by rice grains (OUT-1) and rice straw (OUT-2) was considered as output. The input-output analyses show negative N and K balances for all the treatments, both in the wet season 2003-04 and the dry season 2004. These mean that the nutrient inputs, particularly coming from inorganic fertilisers, are not sufficient to replace N and K removed by grains and straw. Positive P balances are observed in the improved technology and improved technology + rice straw treatments, proving the dominant contribution of P-fertiliser to the input.

5.1. Introduction

To meet growing rice demand and improve farmers' income, rice farming in terraced paddy field systems should be intensified and handled more efficiently by using inputs without reducing biomass production and soil fertility. At this time, the production in terraced paddy field systems is also confronted with less input and traditionalism. Inadequate or imbalanced nutrient inputs and decreasing soil organic matter contents are commonly identified. The results in Chapters 3 and 4 proved that application of only 50 kg of urea ha^{-1} $season^{-1}$ without returning rice straw was not sufficient to reach the optimal yield. There is a need, therefore, to develop agronomic strategies to properly utilise crop residues, besides balanced fertilising to manage rice farming in terraced paddy field systems.

In chapters 3 and 4, four treatments, including application of rice straw, have been examined in line with the nutrient (N, P, and K) concentrations, uptakes, and biomass productions. Assessment of nutrient balances based on these treatments, consequently, is also interesting to be done.

In the current chapter, nutrient balances of rice farming in terraced paddy field systems during the WS 2003-04 and DS 2004 are discussed. The objectives were (1) to study nutrient balances under conventional farmer practices and improved technologies and (2) to evaluate the effect of recycled rice straw on the balances of nutrients.

5.2. Literature Review

Recently, the need to protect environmental quality is a major concern in agricultural activities, besides improvement of crop production and farmers' income. The use of agro-chemicals has been recognised as an important non-point source of surface and subsurface water contamination (Lal *et al.,* 1998; Parry, 1998). Nutrients carried away by eroded sediments and water run-off do not only reduce fertility of soil, but also degrade surface water qualities (Duque *et al.*, 2003; Phomassack *et al.,* 2003; Sukristiyonubowo *et al.*, 2003; Toan *et al.*, 2003). Therefore, quantification of nutrient inputs and outputs is urgently needed for agronomical, economical and environmental analyses. According to Bationo *et al.* (1998) Hashim *et al.* (1998), Lefroy and Konboon (1999), Smaling *et al.* (1993), Stoorvogel *et al.*

(1993), Syers (1996), and Van den Bosch *et al.* (1998a; 1998b) , nutrient balances can be developed at different scales, including (1) plot, (2) field, farm or catchment, (3) district, province, and (4) country scale, and for different purposes.

On a theoretical basis, nutrient balances are computed according to the differences between nutrient gains and losses. The inputs include nutrients in fertilisers, returned crop residues, irrigation, rainfall, and biological nitrogen fixation (Lefroy and Konboon, 1999; Miller and Smith, 1976; Verloo, 2004; Wijnhoud *et al.,* 2003). According to Uexkull (1989), outputs include removal through harvested biomass (all nutrients), erosion (all nutrients), leaching (mainly nitrate, potassium, calcium and magnesium), fixation (mainly phosphate), and volatilisation (mainly nitrogen and sulphur). Furthermore, nutrient removed from cultivated land usually exceeds the natural rate of nutrient input. Hence, when the removals are not replaced by application of fertilisers or returning of biomass, soil mining takes place and finally crop production reduces.

Practically, a complete study of nutrient balances is very complicated. In a first approach, nutrient loss is mainly calculated based on removal by harvested products and unreturned crop residues, while the main inputs are organic and mineral fertilisers. So far, it is reported that most assessment is partial analysis of these in- and output data (Drechsel *et al.,* 2001; Lefroy and Konboon, 1998; Wijnhoud *et al.,* 2003).

Crop residue is a fundamental natural resource for conserving and sustaining soil productivity. It supplies essential plant nutrients, improves physical and biological conditions of the soil, and prevents soil degradation (Aulakh *et al.,* 2001; Jastrow *et al.,* 1998; Puget and Drinkwater, 2001; Tisdale and Oades, 1979; Walter *et al.,* 1992). However, the nutrients present in roots often have been ignored in assessment of cropping systems. Most attention was paid to cover crops since they are considered to be a potential source of nitrogen for the following crops (Harris and Hesterman, 1990; Kumar and Goh, 2000; Thomsen, 1993). Currently, it has been observed that the contribution of plant nutrients from roots is important, ranging between 13 and 40 % of total plant N (Chaves *et al.,* 2004; Kumar and Goh, 2000). This was also found to be the case for rice residues (Sukristiyonubowo *et al.,* 2004; 2003).

Many studies indicate that at plot, farm, district, province, and national levels, agricultural production is characterised by a negative nutrient balance. A long-term nitrogen experiment at plot scale in the sloping area of Kuamang Kuning (Jambi Province, Indonesia) provided confirmation that the balance in the plots without input was - 4 kg N ha^{-1} yr^{-1}. However, this did not happen in the plots treated with a combination of high fertiliser application rates and *Flemingia congesta* leaves planted in a hedge row system (Santoso *et al.,* 1995).

Studies at the farm level in the semi arid South Mali showed that nutrient balances for a cotton-based agro ecosystem were -25 kg N ha^{-1} yr^{-1}, 0 kg P ha^{-1} yr^{-1}, and -20 kg K ha^{-1} yr^{-1} (Van der Pol, 1992). Meanwhile, Van den Bosch *et al.* (1998b) found that the average balance for all farms in three different districts in Kenya were -71 kg N ha^{-1} yr^{-1}, +3 kg P ha^{-1} yr^{-1}, and -9 kg K ha^{-1} yr^{-1}. Similar results are found in northern Nigeria and in Uganda (Harris, 1998; Nkonya *et al.,* 2005; Wortmann and Kaizzi, 1998), and the negative balance is also found at terraced paddy field systems in the Ungaran Sub District, Indonesia (Sukristiyonubowo *et al.,* 2004; 2003).

At the district level, negative balances were also observed for major agricultural systems in the Kissi District of Kenya and amounted up to 112 N, 3 P, and 70 K kg ha^{-1} yr^{-1} (Smaling *et al.,* 1993). Meanwhile, the nutrient balance of rice farming in the Ubon Ratchathani Province (Thailand) was + 6.5 kg N ha^{-1}, + 5.2 kg P ha^{-1} and - 6.4 kg K ha^{-1} based on average yields and recommended fertiliser rates (Lefroy and Konboon, 1999).

At the national level, Jager *et al.* (1998) and Van den Bosch *et al.* (1998b) reported that agricultural production in Kenya is characterised by negative nutrient balances and a downward trend in food production. Similarly, Stoorvogel *et al.* (1993) observed negative N, P, and K balances in the arable land of some Sub Saharan African Countries. Studies in China using data from 1961 to 1997 confirmed that the N, P, and K balance were negative, both at national and provincial levels (Sheldrick *et al.,* 2003).

5.3. Materials and Methods

5.3.1. Data collection

Assessment of nutrient balances was done for rice farming in terraced paddy field systems. Nutrients coming into the rice fields were considered as input, whereas nutrients removed from the fields were classified as output. Data of nutrient losses and gains during rice growth are required to construct the nutrient balances. Nutrient originating from inorganic fertiliser (IN-1), organic fertiliser (IN-2), irrigation (IN-3) and rainfall (IN-4) were grouped as input. Losses through rice grains (OUT-1), rice straw (OUT-2) and erosion (OUT-3) were categorised as outputs.

Data on N, P and K were collected from twelve participating farmers (four treatments and three replicates), as presented in the previous chapters. They were subsequently extrapolated to a hectare basis (kg ha^{-1} $season^{-1}$). To quantify input, collected data included concentration of nutrients in inorganic fertiliser, rate of fertiliser application, amount of returned rice straw used as organic fertiliser, irrigation water supply, nutrient concentrations in irrigation waters, precipitation, and nutrient concentration in rainfall. The output parameters were rice grain yields, rice straw production, nutrient concentrations in rice grain and rice straw, and soil erosion. These data were measured during the wet season 2003-04 (WS 2003-04) and the dry season 2004 (DS 2004).

The rice residues were not taken into account either as an input nor an output in this balance assessment, as practically, they always remain in the field.

Nitrogen fixation, especially by *Azolla sp.* may contribute significant to N-input. However, it was not considered as an input, as practically, farmers have not grown *Azolla sp.* in the rice fields for more than 15 years.

Data and methods used to quantify each parameter for the assessment of nutrient balances of rice farming in terraced paddy field scale are presented in Tables 5. 1. and 5. 2.

Table 5. 1. Data collected and method of quantification for INPUTS in the assessment of N, P, and K balances

Input data	Code and Nutrients	Data required/collected	Method of quantification
Inorganic Fertilisers	IN-1: N, P, and K	• Type of fertiliser applied	• Field observation
		• Amount of fertiliser applied	• Field measurement
		• Nutrient concentration in fertiliser	• Laboratory analysis/ check from the label
Organic Fertilisers	IN-2: N, P, and K	• Amount of rice straw recycled	• Field measurement
		• Nutrient content in rice straw	• Laboratory analysis
Irrigation	IN-3: N, P, and K	• Discharge	• Field measurement
		▪ Water Input	• Transfer function
		▪ Nutrient concentration in irrigation water	• Laboratory analysis
Rainfall	IN-4: N, P, and K	• Daily, monthly and annual rainfall	• Field measurement
		• Nutrient concentration in rainfall	• Laboratory analysis

Table 5. 2. Data collected and method of quantification for OUTPUTS in the assessment of N, P, and K balances

Output data	Code and Nutrients	Data required/collected	Method of quantification
Harvested Product	OUT-1: N, P, and K	• Rice grain yield	• Field measurement
		• Nutrient concentration in rice grains	• Laboratory analysis
Rice straw	OUT-2: N, P, and K	• Rice straw production	• Field measurement
		• Nutrient concentration in rice straw	• Laboratory analysis
Erosion	OUT-3: N, P, and K	• Discharge at in- and outlet	• Field measurement
		• Nutrient concentration in suspended sediment	• Laboratory analysis
		• Sediment concentration	• Laboratory analysis

Ammonia (NH_3) volatilisation was not taken into account in the evaluation of the N balance, although it is considered as one of the important losses, affecting N-use efficiency in rice and the overall results. Many studies reported that NH_3 volatilisation is influenced by pH, CEC,

NH_4^+ concentration, ponding depth, when and how fertiliser is applied (Cho *et al.,* 2000; Chowdary *et al.,* 2006; Fan et al., 2006; Ghost and Bhat, 1998; Hayashi *et al.,* 2006; Manolov *et al.,* 2003; Xing and Zhu, 2000). In general, the loss ranges from 20.5 to 33.5 % of the amount of N applied, equivalent to 13 to 44.6 kg N ha^{-1}, and it is considered a significant loss (Cho *et al.,* 2000; Chowdary *et al.,* 2006; Fan *et al.,* 2006). However, other studies in China and Japan reported smaller losses, about 11 % and 1.4 $\pm$ 0.8 %, respectively (Hayashi *et al.,* 2006; Xing and Zhu, 2000). Ghost and Bhat (1998) reported the range of NH_3 losses to be about 2 – 30 %. As it was not feasible to measure N volatilisation during the field experiments, quantification of NH_3 losses was not done. The N outputs are thus expected to be a bit underestimated.

The nutrient inputs were the sum of nutrients coming from fertiliser (IN-1), recycled rice straw (IN-2), irrigation (IN-3), and precipitation (IN-4). Outputs were sum of nutrients removed by rice grains (OUT-1), rice straw (OUT-2), and erosion (OUT-3). See formulas 1, 2 and 3.

Nutrient Inputs (IN) = IN-1 + IN-2 + IN-3 + IN-4 ……………………. (1)
Nutrient Outputs (OUT) = OUT-1 + OUT-2 + OUT-3 ……………….. (2)
Nutrient Balance = IN – OUT ……………………..………………….. (3)

The materials to carry out the field experiment and to measure both input and output parameters have been described in chapters 2, 3, and 4.

IN-2 was calculated based on the recycling of 33 % of the previous season straw production. For the WS 2003-04, it was estimated according to 33 % of the straw production of the DS 2003, whereas it was derived from the production of the WS 2003-04 for the DS 2004.

IN-3 was estimated according to differences between incoming and outgoing nutrients. Nutrients trapped along the terraces were considered as input (see also chapter 2). The water added before puddling for land soaking was not taken into account. The sum of nutrients deposited during harrowing, before planting, during vegetative and generative phase were seen as the contribution of irrigation water to input.

IN-4 was estimated by multiplying monthly rainfall volume with nutrient concentrations in the rain water. To monitor rainfall events, data from seven rain gauges and an automatic weather station were considered. These devices were installed mainly for hydrological purposes related to watershed management. Rain waters were sampled once a month from every rain gauge in 600 ml plastic bottles and were also analysed according to the procedures of the Laboratory of the Soil Research Institute, Bogor.

As all rice grains are consumed, OUT-1 was estimated based on rice grain yield multiplied with nutrient concentration in the grains. OUT-2 was calculated according to the total rice straw produced multiplied with nutrient concentration in the straw.

As discussed in the section 2.4.2 of Chapter 2, erosion in the terraced paddy field system mainly occurs during harrowing both in the WS 2003-04 and the DS 2004. Moreover, total soil amounts displaced during the harrowing were low, both in the wet and dry season (see Figure 2. 2 of Chapter 2). Measurements from other participating farmers at the harrowing also confirm the same findings both in the WS 2003-04 and DS 2004 (see Appendix 5.1.). Therefore, OUT-3 was neglected.

5.4. Results and Discussion

Contributions of fertilisers, recycled rice straw, irrigation, and precipitation to the input are discussed in section 5.4.1, losses through removal by grain and straw are elaborated in section 5.4.2.

5.4.1. Input Parameters

5.4.1.1. Fertiliser (IN-1) and recycled rice straw (IN-2)

The contributions of fertilisers to inputs are given in Table 5. 3. For the CFP and CFP + RS treatments, only 50 kg of urea ha^{-1} $season^{-1}$ was regarded, while for the IT and IT + RS treatments 100 kg of urea, 100 kg of TSP, and 100 kg of KCl ha^{-1} $season^{-1}$ were taken into account. The IN-1 was 45 kg N, 20 kg P, and 50 kg K for the improved technologies in ha^{-1} $season^{-1}$, whereas it was only 22.5 kg N for the conventional farmer practices.

The contributions of recycled rice straw are also presented in Table 5. 3. Interestingly, the IN-2 for the CFP + RS treatment in the WS 2003-04 was higher than for the IT + RS treatment. This was due to higher rice straw production in the CFP + RS treatment compared to the IT + RS treatment in the DS 2003, although the concentrations of N, P, and K were lower. More information is given in Table 3. 1 of Chapter 3. However, the IN-2 for the IT + RS treatment was greater than for the CFP + RS treatment in the DS 2004, as in the WS 2003-04, the production and nutrient contents in rice straw for the IT + RS treatment were significantly superior over other treatments (see also Tables 3. 6 and 4. 2).

Table 5. 3. The contribution of fertilisers and recycled rice straw to input in the WS 2003-04 and the DS 2004

Treatment	IN-1: Fertiliser (kg ha^{-1} $season^{-1}$)			IN-2: Recycled rice straw (kg ha^{-1} $season^{-1}$)		
	N	P	K	N	P	K
WS 2003-04:						
IT + RS	45.0	20.0	50.0	26.4	3.2	46.2
IT	45.0	20.0	50.0	-	-	-
CFP + RS	22.5	-	-	28.4	2.2	52.5
CFP	22.5	-	-	-	-	-
DS 2004:						
IT + RS	45.0	20.0	50.0	29.0	1.9	58.8
IT	45.0	20.0	50.0	-	-	-
CFP + RS	22.5	-	-	19.8	1.6	39.8
CFP	22.5	-	-	-	-	-

It is also interesting to note that the average of IN-2 for the IT + RS and CFP + RS treatments was higher than IN-1 for the CFP treatment. This means that the contribution of 33 % rice straw recycling to the nutrient supply is greater than the contribution of the application of 50 kg urea.

5.4.1.2. Irrigation (IN-3)

The contribution of irrigation water to the input (IN-3) was computed according to the periods the farmers opened and closed the inlet and outlet, between land preparation and ripening stages. The results are given in Tables 5. 4 and 5. 5. More details are given in Appendices 5. 2 and 5. 3.

From the field monitoring and information given by the farmers, the total period of water inlet in the WS 2003-04 was found to be about 35 days and in the DS 2004 about 40 days. The difference was mainly due to the lower discharge and other external factors affecting water use in the DS 2004. During the wet season, opening inlet and outlet was aimed to control water level, to avoid dike damages and land slides, while irrigation of rice fields is most important during the dry season.

Depending on the treatment, the IN-3 varied between 7.20 and 13.62 kg N, 0.13 and 0.20 kg P, 7.25 and 13.42 kg K in the WS 2003-04 and 3.80 - 7.19 kg N, 0.06 - 0.09 kg P, and 6.43 - 8.32 kg K ha^{-1} $season^{-1}$ in the DS 2004. So far, it can be said that N and K input from irrigation water is equivalent to 16-30 kg of urea and 15-25 kg of KCl ha^{-1} $season^{-1}$ in the WS 2003-04 and about 8-16 kg of urea and 12-16 kg of KCl ha^{-1} $season^{-1}$ in the DS 2004.

Furthermore, the IN-3 in the WS 2003-04 was greater than in the DS 2004. This may be explained by: (1) the amounts of incoming dissolved nutrient was greater in the WS 2003-04 than in the DS 2004 (see also section 2.4.3 of Chapter 2); (2) there was nutrients contribution coming from rain waters, which is high, especially in nitrogen (see Figure 5. 1 of section 5.4.1.3); and (3) the decomposition product of organic matter and nitrates may be washed away from upstream locations during rain events. In addition, urea applied by farmers upstream and urea, TSP and KCl used in private plantations (rambutan, clove, tea, and coffee) may be washed away during rain events and that may increase N, P, and K in the irrigation water.

The results also indicate that net P-input by irrigation water is generally very low. This may be due to low solubility of P and thus P carried away through run off waters was also low. Ng Kee Kwong *et al.* (2002) also reported insignificant levels of P moving from plots and sub catchments during run off events. Cho *et al.* (2000) confirms the same finding, reporting that P coming from irrigation water is only 0.5 kg ha^{-1}.

Variations in nutrient inputs among the treatments were mainly due to the differences in water discharge, as the nutrient content variations of incoming irrigation water was relatively low.

5.4.1.3. Rainfall (IN-4)

The monthly rainfall and its contributions to nutrient input during the wet season 2003-04 are given in Figure 5. 1. In the WS 2003-04, the rainfall followed a normal pattern, from the end of October 2003 to May 2004. The annual precipitation was 3 395 mm, with the highest monthly rainfall in January 2004 being 856 mm.

The total nutrient gains from the rainfall (IN-4) were about 20.6 kg N, 2.6 kg P, and 6.1 kg K ha^{-1}. These values were about two times higher than in the WS 2002-03 (Sukristiyonubowo *et al.,* 2003). The rainfall water supplied relatively high N amounts, almost equivalent to 45 kg of urea. In Belgium, N-input from rainfall is about 25 kg N ha^{-1} (Demyttenaere, 1991) and in South Korea, N and P input from rainfall are 39.5 kg N and 0.7 kg P ha^{-1}. The P and K contents on the rainwater are low.

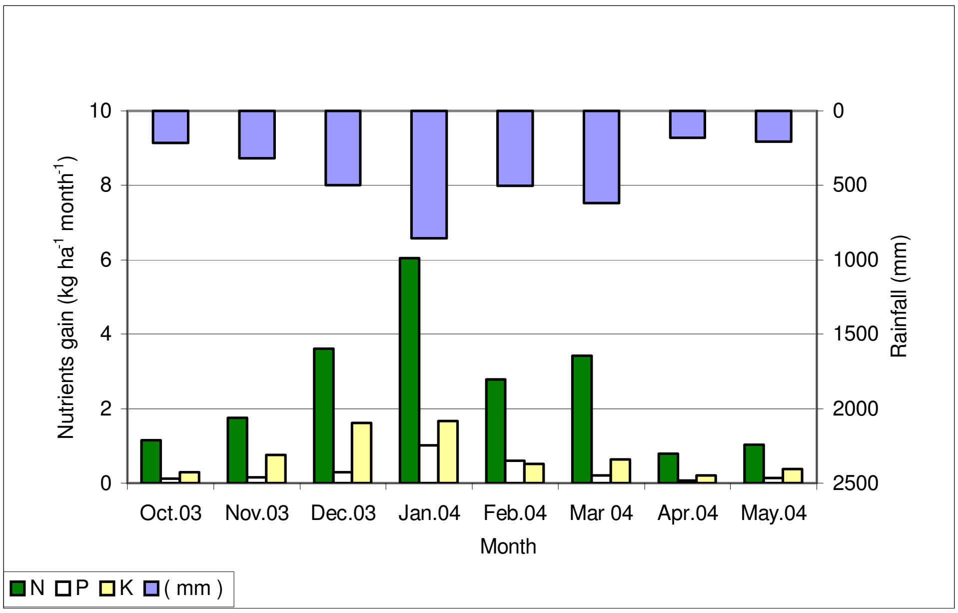


Figure 5. 1. Monthly rainfall and its contribution to nutrient inputs in the WS 2003-04

Table 5. 4. Contribution of irrigation water to the nutrient input during rice growth in the WS 2003-04

Stage	Incoming nutrient (kg ha^{-1} season^{-1})			Outgoing nutrient (kg ha^{-1} season^{-1})			Net input (kg ha^{-1} season^{-1})		
	N	P	K	N	P	K	N	P	K
CFP:									
Puddling	0.58	0.002	1.06	0.36	0.002	0.55	0.22	0	0.51
Puddling to planting	4.20	0.060	4.26	3.06	0.018	2.64	1.20	0.018	1.62
Vegetative	22.50	0.270	16.20	12.96	0.126	10.80	9.90	0.144	6.84
Generative	9.50	0.070	8.40	7.20	0.040	6.00	2.30	0.030	2.40
Total	36.78	0.402	29.92	23.58	0.186	19.99	13.62	0.192	11.37
CFP + RS:									
Puddling	1.20	0.020	1.57	0.86	0.040	0.93	0.33	0	0.640
Puddling to planting	6.48	0.060	6.60	5.64	0.030	3.90	0.90	0.030	2.70
Vegetative	29.52	0.288	22.86	19.98	0.162	14.58	9.54	0.126	8.28
Generative	12.50	0.090	11.00	10.20	0.050	9.10	2.30	0.040	1.80
Total	49.70	0.458	42.03	36.68	0.282	28.51	13.07	0.196	13.42
IT:									
Puddling	0.52	0.002	0.87	0.34	0.003	0.46	0.18	0	0.41
Puddling to planting	3.24	0.060	3.30	2.16	0.030	1.92	1.08	0.030	1.38
Vegetative	12.60	0.144	9.90	8.46	0.072	5.76	4.14	0.090	3.96
Generative	6.60	0.050	5.80	4.80	0.040	4.10	1.80	0.010	1.50
Total	22.96	0.256	19.87	15.76	0.145	12.24	7.20	0.130	7.25
IT + RS:									
Puddling	0.68	0.002	1.13	0.56	0.008	0.80	0.12	0	0.33
Puddling to planting	6.36	0.060	6.42	4.48	0.030	4.62	1.50	0.030	1.80
Vegetative	25.56	0.270	20.70	15.66	0.180	12.42	9.90	0.090	8.28
Generative	12.30	0.090	10.80	10.30	0.080	9.90	2.00	0.010	0.90
Total	44.90	0.422	39.05	31.32	0.298	27.74	13.52	0.130	11..31

Table 5. 5. Contribution of irrigation water to the nutrient input during rice growth in the DS 2004

Stage	Incoming nutrient (kg ha^{-1} season^{-1})			Outgoing nutrient (kg ha^{-1} season^{-1})			Net input (kg ha^{-1} season^{-1})		
	N	P	K	N	P	K	N	P	K
CFP:									
Puddling	0.29	0.017	1.13	0.14	0.011	0.70	0.15	0.006	0.43
Puddling to planting	3.48	0.048	3.66	2.16	0.036	1.92	1.32	0.012	1.74
Vegetative	3.99	0.147	7.56	2.52	0.105	4.41	1.47	0.042	3.15
Generative	6.96	0.084	7.92	3.84	0.060	5.16	3.12	0.024	2.76
Total	14.72	0.296	20.27	8.66	0.212	12.19	6.06	0.084	8.08
CFP + RS:									
Puddling	0.41	0.015	1.42	0.18	0.011	0.93	0.23	0.004	0.49
Puddling to planting	5.40	0.084	5.64	3.66	0.066	3.66	1.74	0.018	1.98
Vegetative	6.30	0.210	12.60	5.04	0.168	9.03	1.26	0.042	3.57
Generative	10.44	0.120	11.88	6.48	0.096	9.60	3.96	0.024	2.28
Total	22.55	0.429	31.54	15.36	0.341	23.22	7.19	0.088	8.32
IT:									
Puddling	0.38	0.015	1.04	0.30	0.009	0.58	0.08	0.006	0.46
Puddling to planting	2.52	0.036	2.64	1.26	0.024	1.08	1.26	0.012	1.56
Vegetative	2.52	0.126	5.46	2.10	0.084	3.57	0.42	0.042	1.89
Generative	5.04	0.060	5.64	3.00	0.048	3.12	2.04	0.012	2.52
Total	10.46	0.237	14.78	6.66	0.165	8.35	3.80	0.072	6.43
IT + RS:									
Puddling	1.12	0.017	1.47	0.93	0.017	1.00	0.19	0.000	0.47
Puddling to planting	5.10	0.078	5.34	3.54	0.072	3.06	1.56	0.006	2.28
Vegetative	5.67	0.210	10,08	4.62	0.168	7.14	1.05	0.042	2.94
Generative	10.08	0.120	11.40	8.40	0.108	9.24	1.68	0.012	2.16
Total	21.97	0.425	28.29	17.49	0.365	20.44	4.48	0.060	7.85

5.4.2. Output Parameters

5.4.2.1. Crop Removal: rice grains (OUT-1) and rice straw (OUT-2)

The nutrients removed through rice grains (OUT-1) in the WS 2003-04 and the DS 2004 are presented in Table 5. 6. Statistically, the data indicated that the variations of grain yields within treatment were small, meaning that soil properties variability within the farmers is small. This was illustrated by the low standard deviations, varying between 0.33 and 0.62, 0.57 and 0.59, 0.22 and 0.45, 0.10 and 0.29 kg ha^{-1} for the IT + RS, IT, CFP + RS, and CFP treatments, respectively.

Table 5. 6. Nutrient output through rice grains in the WS 2003-04 and in the DS 2004

Treatment	Rice grains (t ha^{-1} $season^{-1}$)	OUT-1: output via rice grains (kg ha^{-1} $season^{-1}$)		
		N	P	K
WS 2003-04				
IT + RS	5.73 ± 0.62 a	76.48 ± 6.25 a	10.84 ± 3.03 a	20.27 ± 2.38 a
IT	4.14 ± 0.57 b	51.87 ± 11.25 b	5.99 ± 0.25 b	13.47 ± 4.28 b
CFP + RS	3.82 ± 0.45 b	48.70 ± 10.11 b	4.54 ± 0.46 b	11.74 ± 1.83 b
CFP	3.19 ± 0.29 b	38.63 ± 6.89 b	3.86 ± 0.93 b	9.46 ± 0.79 b
DS 2004				
IT + RS	5.91 ± 0.33 a	82.78 ± 7.19 a	12.01 ± 1.11 a	21.72 ± 2.95 a
IT	4.45 ± 0.59 b	58.77 ± 9.56 b	7.09 ± 0.53 b	15.74 ± 2.12 b
CFP + RS	4.12 ± 0.22 bc	51.47 ± 3.54 bc	5.50 ± 0.54 c	12.50 ± 0.91bc
CFP	3.69 ± 0.10 c	44.99 ± 1.89 c	4.56 ± 0.58 c	10.36 ± 1.09 c

Since rice grain yields and nutrient contents of the rice grains for the IT + RS treatments were significantly higher than for other treatments, the OUT-1 values also were significantly higher, both in the wet and dry season. Depending on the treatment and season, OUT-1 in kg ha^{-1} $season^{-1}$ ranged from 38.6 to 76.5 for N, 3.9 to 10.8 for P, and 9.5 to 20.3 for K in the WS 2003-04 and from 45 to 82.8 for N, 4.6 to 12.0 for P, and 10.4 to 21.7 for K in the DS 2004. These losses are equivalent to 75 - 180 kg of urea (45 % N), 25 - 50 kg of TSP (46 % P_2O_5), and 20 - 42 kg of KCl (60 % K_2O). It is also noted that the nitrogen losses are higher than the nitrogen applied as urea in all treatments.

The nutrients removed by rice straw in the WS 2003-04 and the DS 2004 are given in Table 5. 7. The results indicated that the variations of straw yields within treatments were small. The standard deviations varied between 0.30 and 0.91, 0.37 and 0.79, 0.77 and 1.05, 0.48 and 0.63 kg ha^{-1} for the IT + RS, IT, CFP + RS, and CFP treatments, respectively. The variations may be due to the variable cutting heights.

The highest OUT-2 was observed for the IT+ RS treatments both in the wet and dry season. Depending on the treatment and season, the OUT-2 in kg ha^{-1} $season^{-1}$ ranged from 49.2 to 87.8 for N, 4.4 to 5.8 for P, and 94.9 to 178.0 for K in the WS 2003-04 and from 48.6 to 81.7 for N, 3.8 to 6.0 for P, and 97.1 to 157.1 for K in the DS 2004. These outputs are equivalent to 110 - 185 kg of urea, 19 - 30 kg of TSP, and 190 - 356 kg of KCl. Potassium (K) loss was especially very high and as well agronomically as economically very significant. Therefore, rice straw should be properly managed to reduce K loss from rice fields.

Table 5. 7. Nutrient output through rice straw in the WS 2003-04 and in the DS 2004

Treatment	Rice straw ($t\ ha^{-1}\ season^{-1}$)	OUT-2: output via rice straw ($kg\ ha^{-1}\ season^{-1}$)		
		N	P	K
WS 2003-04				
IT + RS	7.50 ± 0.91 a	87.77 ± 12.17 a	5.78 ± 0.82 a	178.04 ± 22.08 a
IT	6.25 ± 0.38 ab	54.43 ± 8.50 b	5.40 ± 0.22 ab	133.41 ± 13.86 ab
CFP+RS	6.16 ± 0.77 ab	60.08 ± 6.25 b	4.76 ± 1.19 b	120.59 ± 30.14 b
CFP	5.25 ± 0.63 b	49.17 ± 17.80 b	4.40 ± 0.83 b	94.86 ± 37.30 b
DS 2004				
IT + RS	6.37 ± 0.30 a	81.72 ± 6.44 a	5.95 ± 0.43 a	157.07 ± 12.81 a
IT	5.52 ± 0.79 b	59.22 ± 11.36 b	4.77 ± 0.61 b	123.50 ± 19.13 b
CFP+RS	5.33 ± 1.05 b	55.29 ± 12.98 b	4.00 ± 0.27 b	103.92 ± 21.20 b
CFP	5.10 ± 0.48 b	48.62 ± 7.00 b	3.76 ± 0.67 b	97.10 ± 12.02 b±

From the results both in the WS 2003-04 and the DS 2004, we may learn that rice straw on the one hand may be an important nutrient source for improving soil fertility when it is managed properly. On the other hand, it shows the greatest nutrient loss, when it is removed from the field for animal feeding.

5.4.3. Nutrient Balances

The N, P, and K balances in the WS 2003-04 and the DS 2004 are presented in Tables 5. 8 to 5.11. In general, the results indicate that inorganic fertiliser (IN-1) contributes considerably to N, P and K input in all treatments. The amounts varied depending on the treatment and season. In the improved technology (IT + RS and IT) treatments, IN-1 covered from 43 to 92 % of total N, 79 to 99 % of total P and 43 to 89 % of total K inputs, while in the conventional practices (CFP + RS and CFP) treatments, it contributed from 27 to 79 % of the total N inputs. Therefore, it can be said that inorganic fertilisers are the most important nutrient sources to manage rice field. It is also interesting to note that the ratio of contribution of inorganic fertiliser (IN-1) to the total amount of inputs was greater in the dry season than in the wet season. This means that the needs for mineral fertilisers may be greater in the dry season than in the wet season, as less nutrient sources were found in the dry season.

With respect to P input, P fertiliser (IN-1 see Table 5. 10) was the most dominant factor contributing for 79 to 99 % to the total P-inputs.

Recycled straw (IN-2) was also an important nutrient source, covering from 25 to 40 % of total N, 9 to 94 % of total P, and 41 to 83 % of total K inputs, depending on the treatment and season. The IN-2 inputs are getting more important, when no or less inorganic fertilisers are applied like in the CFP + RS treatments. The N and K inputs were equivalent to 45 to 65 kg of urea and 80 to 110 kg of KCl.

Table 5. 8. The N balance at terraced paddy fields under traditional irrigation systems, in the WS 2003-04 and the DS 2004

Parameter	Nitrogen Balance (kg ha^{-1} season^{-1})							
	IT + RS		I T		CFP + RS		CFP	
	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004
Gains:								
IN-1: Fertiliser	45.0	45.0	45.0	45.0	22.5	22.5	22.5	22.5
	(43%)	*(57%)*	*(62%)*	*(92%)*	*(27%)*	*(45%)*	*(40%)*	*(79%)*
IN-2: Recycled straw	26.4	29.0	-	-	28.4	19.8	-	-
	(25%)	*(37%)*			*(34%)*	*(40%)*		
IN-3: Irrigation	13.5	4.5	7.2	3.8	13.1	7.2	13.6	6.1
	(13%)	*(6%)*	*(10%)*	*(8%)*	*(15%)*	*(15%)*	*(24%)*	*(21%)*
IN-4: Rainfall	20.6	-	20.6	-	20.6	-	20.6	-
	(19%)		*(28%)*		*(24%)*		*(36%)*	
Total Gains	105.5	78.5	72.8	48.8	84.6	49.5	56.7	28.6
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Losses:								
Removal by harvest								
▪ OUT-1: Rice grains	76.5	82.8	51.9	58.7	48.7	51.5	38.6	45.0
	(47%)	*(50%)*	*(49%)*	*(50%)*	*(45%)*	*(48%)*	*(44%)*	*(48%)*
▪ OUT-2: Rice straw	87.8	81.7	54.4	59.2	60.1	55.3	49.2	48.6
	(53%)	*(50%)*	*(51%)*	*(50%)*	*(55%)*	*(52%)*	*(56%)*	*(52%)*
Total Loss	164.3	164.5	106.3	117.9	108.8	106.8	87.8	93.6
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Balance	- 58.8	- 86.0	- 33.5	- 69.1	- 24.2	- 57.3	- 31.1	- 65.0

Although the amounts of nutrients coming from IN-3 were smaller compared to the amounts of nutrients originating from inorganic fertilisers (IN-1) and returning rice straw (IN-2), the contributions of IN-3, especially to N and K inputs were still important, covering between 6 % and 24 % of the total N input and between 7 % and 100 % of the total K input. In the CFP treatments, IN-3 was the main K input source, as in these treatments both inorganic and organic fertilisers were not applied.

IN-4 was also an important nutrient source, particularly for N during the wet season, covering from 19 to 36 % of the total of N input.

With respect to the output, depending on the treatment and season, around 44 % - 50 % of total N, 47 % - 67 % of total P and 10 % - 12 % of total K were taken up by rice grains and the rest by rice straw. This means that N was equally removed by rice straw and rice grains; P was mainly removed via rice grains and K mainly through straw.

Comparison of N input and output shows a negative balance for all treatments both in the WS 2003-04 and in the DS 2004 (Table 5. 8). The negative balances ranged between 24.2 and 86.0 kg N ha^{-1} $season^{-1}$, depending on the treatment and season. The N balance in the DS 2004 was more negative than in the WS 2003-04. This may be explained by increased rice grain and straw productions and no additional input from precipitation, having an input of 20.6 kg ha^{-1}. It should also be noted that the N output will even be higher, when NH_3 volatilisation is taken into account and rice residues would be removed from the rice field.

The data showed that rice residue productions both in the WS 2003-04 and DS 2004 were high, ranging from 4.57 to 6.93 t ha^{-1} $season^{-1}$, and rich in N and K, thus being important nutrient sources (Table 5.9). Depending upon the treatment and season, the contribution to the nutrient pool in the soil ranged from 21.0 to 43.1 kg N, 2.3 to 5.2 kg P, and 72.1 to 152.8 kg K ha^{-1} $season^{-1}$ in the WS 2003-04 and from 24.3 to 42.6 kg N, 3.6 to 5.2 kg P, and 87.7 to 143.1 kg K ha^{-1} $season^{-1}$ in the DS 2004, respectively. It is also interesting to note that the N input by rice residue is higher than that the N amount in 50 kg of urea, as applied in the CFP; also the input of K is higher than the K amount in 100 kg of KCl ha^{-1} $season^{-1}$, as applied in the Improved Technology treatments. Therefore, it can be said that the presence of rice residues in terraced paddy field systems may be considered as an important natural nutrient investment. However, as practically the residues always remain in the field, they may be regarded as an organic pool in the soils and they are not regarded as an input or an output. The overall balances would be lower, if the rice residues would be removed from the rice field. In that case, the rice residues should be regarded as an output.

The negative N balances in all treatments also demonstrated that the application rates of inorganic and organic fertilisers were not sufficient to balance N removed by grains and straw. Therefore, to avoid nutrient mining and sustain a high rice yield, nitrogen fertiliser application rate must be between 200 to 250 kg of urea ha^{-1} $season^{-1}$, which implies an increase of about 100 – 150 kg of urea compared to the current application rate of improved technology (IT+RS and IT) treatments.

Table 5. 9. Rice residue production and their contributions to the nutrient pool in the soil in the WS 2003-04 and in the DS 2004

Treatment	Rice residue (t $ha^{-1}season^{-1}$)	Contribution to the nutrient pool in the soil (kg ha^{-1} $season^{-1}$)		
		N	P	K
WS 2003-04				
I T + R S	6.93 ± 1.17 a	43.13 ± 7.29 a	5.21 ± 0.94 a	152.81 ± 59.10 a
I T	4.67 ± 0.97 b	23.35 ± 6.46 b	3.27 ± 0.67 b	88.00 ± 21.90 b
CFP + R S	4.58 ± 1.39 b	22.90 ± 7.28 b	2.29 ± 0.60 b	72.05 ± 32.99 b
CFP	4.57 ± 0.60 b	21.02 ± 1.58 b	2.74 ± 0.78 b	81.84 ± 16.47 b
DS 2004				
I T + R S	6.55 ± 0.21 a	42.60 ± 3.98 a	5.23 ± 0.55 a	143.05 ± 6.40 a
I T	5.69 ± 0.68 b	32.46 ± 6.60 ab	3.99 ± 0.48 b	111.94 ± 13.10 b
CFP + R S	5.31 ± 0.88 b	27.23 ± 5.09 b	3.72 ± 0.61 b	91.32 ± 16.71 b
CFP	5.16 ± 0.71 b	24.34 ± 7.12 b	3.61 ± 0.49 b	87.66 ± 12.11 b

Analysis of P input and output only shows positive balances both in the wet and dry season for the IT + RS and IT treatments (Table 5. 10). The excess P ranged from 4.0 to 9.3 and from 9.2 to 11.3.6 kg P ha^{-1} $season^{-1}$, respectively. The excess P in the DS 2004 was lower than in the WS 2003-04. This was due to in fact that the grain yields and P contents in the grain were higher in the DS 2004 than in the WS 2003-04. The positive P balances demonstrated the dominant contribution of P fertiliser.

The negative P balance of the CFP treatment both in the WS 2003-04 and DS 2004 confirms that this practice is not sustainable.

Table 5. 10. The P balance at terraced paddy fields under traditional irrigation systems, in the WS 2003-04 and the DS 2004

Parameter	Phosphorus Balance (kg ha^{-1} season^{-1})							
	IT + RS		I T		CFP + RS		CFP	
	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004
Gains:								
IN-1: Fertiliser	20.0	20.0	20.0	20.0	-	-	-	-
	(79%)	*(91%)*	*(88%)*	*(99%)*				
IN-2: Recycled straw	3.2	1.9	-	-	2.2	1.6	-	-
	(12%)	*(9%)*			*(44%)*	*(94%)*		
IN-3: Irrigation	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1
	(0%)	*(0%)*	*(1%)*	*(1%)*	*(4%)*	*(6%)*	*(7%)*	*(100%)*
IN-4: Rainfall	2.6	-	2.6	-	2.6	-	2.6	-
	(10%)		*(11%)*		*(52%)*		*(93%)*	
Total Gains	25.9	22.2	22.7	20.1	5.0	1.7	2.8	0.1
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Losses:								
Removal by harvest								
▪ OUT-1: Rice grains	10.8	12.0	6.0	7.1	4.5	5.5	3.9	4.6
	(65%)	*(67%)*	*(53%)*	*(60%)*	*(48%)*	*(58%)*	*(47%)*	*(55%)*
▪ OUT-2: Rice straw	5.8	6.0	5.4	4.8	4.8	4.0	4.4	3.8
	(35%)	*(33%)*	*(47%)*	*(40%)*	*(52%)*	*(42%)*	*(53%)*	*(45%)*
Total Loss	16.6	18.0	11.4	11.9	9.3	9.5	8.3	8.4
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Balance	+ 9.3	+ 4.0	+ 11.3	+ 9.2	- 4.3	- 7.8	- 5.5	- 8.3

Analysis of K input and output also shows negative K balances for all treatments both in the WS 2003-04 and in the DS 2004. The deficits varied between 62.2 and 99.4 kg K ha^{-1} season^{-1}, depending on the treatment and season (Table 5. 11).

So far, these results also confirm that more rice straw recycling and/or K fertilisers are needed to meet K removals from the fields. As in this village the rice straw was also used for cattle feeding, the most realistic way is just increase the inorganic fertiliser application rate. Therefore, it is recommended to apply about 200 kg of KCl ha^{-1} season^{-1} provided that 33 % rice straw production is recycled to maintain minimal rice grain yields of about 6 tons ha^{-1}

season^{-1}. It is also important to note that the balance of K will be more negative, if rice residues would be removed from the field.

Table 5. 11. The K balance at terraced paddy fields under traditional irrigation systems, in the WS 2003-04 and the DS 2004

Parameter	Potassium Balance (kg ha^{-1} season^{-1})							
	IT + RS		I T		CFP + RS		CFP	
	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004	WS 2003-04	DS 2004
Gains:								
IN-1: Fertiliser	50.0	50.0	50.0	50.0	-	-	-	-
	(44%)	*(43%)*	*(79%)*	*(89%)*				
IN-2: Recycled straw	46.2	58.8	-	-	52.5	39.8	-	-
	(41%)	*(50%)*			*(73%)*	*(83%)*		
IN-3: Irrigation	11.3	7.8	7.3	6.4	13.4	8.3	11.4	8.1
	(10%)	*(7%)*	*(12%)*	*(11%)*	*(19%)*	*(17%)*	*(65%)*	*(100%)*
IN-4: Rainfall	6.1	-	6.1	-	6.1	-	6.1	-
	(5%)		*(9%)*		*(8%)*		*(35%)*	
Total Gains	113.6	116.6	63.4	56.4	72.0	48.1	17.5	8.1
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Losses:								
Removal by harvest								
▪ OUT-1: Rice grains	20.3	21.7	13.5	15.7	11.7	12.5	9.5	10.4
	(10%)	*(12%)*	*(9%)*	*(11%)*	*(9%)*	*(11%)*	*(9%)*	*(10%)*
▪ OUT-2: Rice straw	178.0	157.1	133.4	123.5	120.6	103.9	94.9	97.1
	(90%)	*(88%)*	*(91%)*	*(89%)*	*(91%)*	*(89%)*	*(91%)*	*(90%)*
Total Loss	198.3	178.8	146.9	139.2	132.3	116.4	103.1	107.5
	(100%)	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*	*(100%)*
Balance	- 84.7	- 62.2	- 83.5	- 82.8	- 60.3	- 68.3	- 85.6	- 99.4

5.5. Conclusions

The negative N and K balances in all treatments, both in the wet and dry season, demonstrate that the rates of mineral fertilisers (100 kg of urea and 100 kg of KCl ha^{-1} $season^{-1}$) applications are not enough to meet N and K removals by rice grains and straw. Towards sustainable rice farming, more nitrogen and potassium fertilisers have to be applied. About 200 – 250 kg of urea ha^{-1} $season^{-1}$ and 200 kg of KCl ha^{-1} $season^{-1}$ are recommended.

Application of P fertiliser results in equilibrated balances of P. Therefore, an application rate of 100 kg of TSP ha^{-1} $season^{-1}$ is recommended to meet P requirement and secure rice yield.

Although the N, P, and K balances are still negative, the addition of rice straw reduces the negative balances (see CFP + RS treatment). Practically (in terms of technical, environmental, and economical points of view), returning of at least 33 % rice straw production to the fields is recommended.

Chapter 6

NUTRIENT BALANCES OF WETLAND RICE FARMING SYSTEMS FOR THE SEMARANG DISTRICT

NUTRIENT BALANCES OF WETLAND RICE FARMING SYSTEMS FOR THE SEMARANG DISTRICT

Abstract

Data from 1978 to 2003 were analysed to evaluate N, P, and K balances of wetland rice farming systems for the Semarang District. Data from the Statistic Agency at province and district levels, the Food Crop Service at district level, field experiments, and the farmers were compiled. Data were grouped according to the five-year development plans executed in Indonesia called PELITA (*Pembangunan Lima Tahun*). Balances were computed according to the differences between input and output. Different recommended fertiliser application rates and farmer rate as well with and without recycling rice straw were used to evaluate the balances.

Compared to 1978, rice yield, producing area, and total production during every five-year development plan increased. The highest average rice yield, about 5.10 t ha^{-1}, was reached during the PELITA V which coincided with the economic crisis era. In general, the N, P, and K balances for the control fertiliser application rates are more negative compared to all levels of recommended fertiliser application rates. When application of rice straw was taken into account and a minimal of rice yield of 5.10 t ha^{-1} is expected, only P balances were positive for all levels of recommended P fertiliser application rates. A positive N balance was observed for the high level of recommended N fertiliser application rate (250 kg of urea ha^{-1} $season^{-1}$), when the rice straw was recycled. However, when the rice straw was not considered, only P balances were consistently positive for all recommended fertiliser application rates, demonstrating the dominant contribution of P fertiliser.

6.1. Introduction

Up to now, Jawa Tengah or the Central Java Province is one of the main national Indonesian rice producers. Improving rice yield is one of the main targets in the food sector development. In 2002, the rice yield reached 5.14 t ha^{-1}, an increase of about 2.41 % compared to the previous year, whereas the rice producing area enhanced about 0.17 %. Furthermore, the total rice production reached 8.50 million tons. Almost 97 % of the total rice production in this province comes from wetland rice (BPS, 2003a).

Among the rice growing centres in this province, the Semarang District was evaluated for the following reasons: (i) it has mainly terraced paddy field areas, for which research has been scarce; (ii) the average rice yield is lower than the average yield of the Province; (iii) agriculture activities are still dominant, although the industrialisation is also growing fast; (iv) input-output assessments for rice farming on the district level have not yet been done; (v) Keji Village, where the field experiments were located, is situated in this district and scaling up of nutrient balances for rice farming from farm to district level is interesting to be studied.

As for chapter 5, nutrient coming from mineral fertiliser, returning rice straw, irrigation, rainfall waters and losses through rice grains and straw are considered to construct nutrient balances. The objectives are to study the effect of coincidental events on rice production data between 1978 and 2003 and to evaluate nutrient balances of wetland rice farming systems using inorganic and organic fertilisers on a district level.

6.2. Location

The Semarang District is one of the twenty-nine districts and six municipalities of the Central Java Province. The capital is Ungaran city. Administratively, it is divided into 17 sub districts with a total area of about 95 021 ha or about 2.92 % of the total province area (BPS, 2002). The administrative boundaries are given in Figure 6. 1.

Figure 6. 1. Administrative map of the Semarang District, Central Java Province

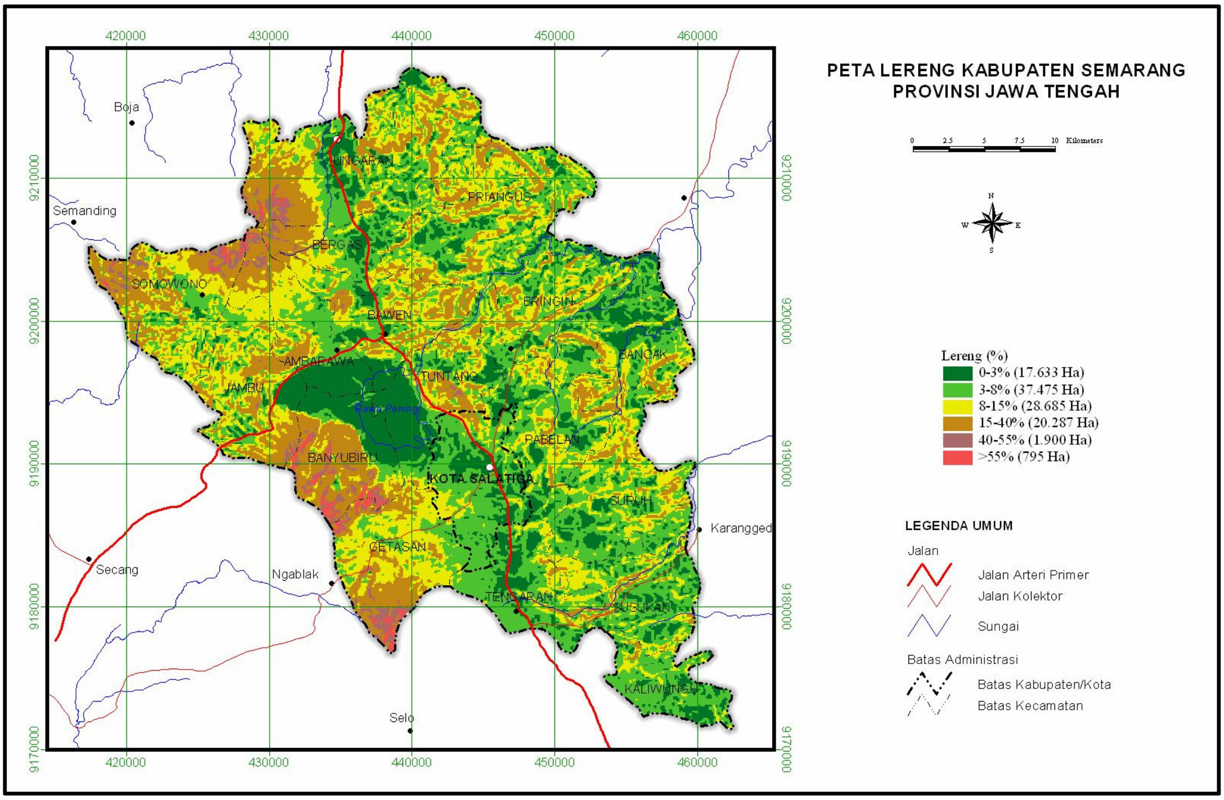


Figure 6. 2. Slope map of the Semarang District

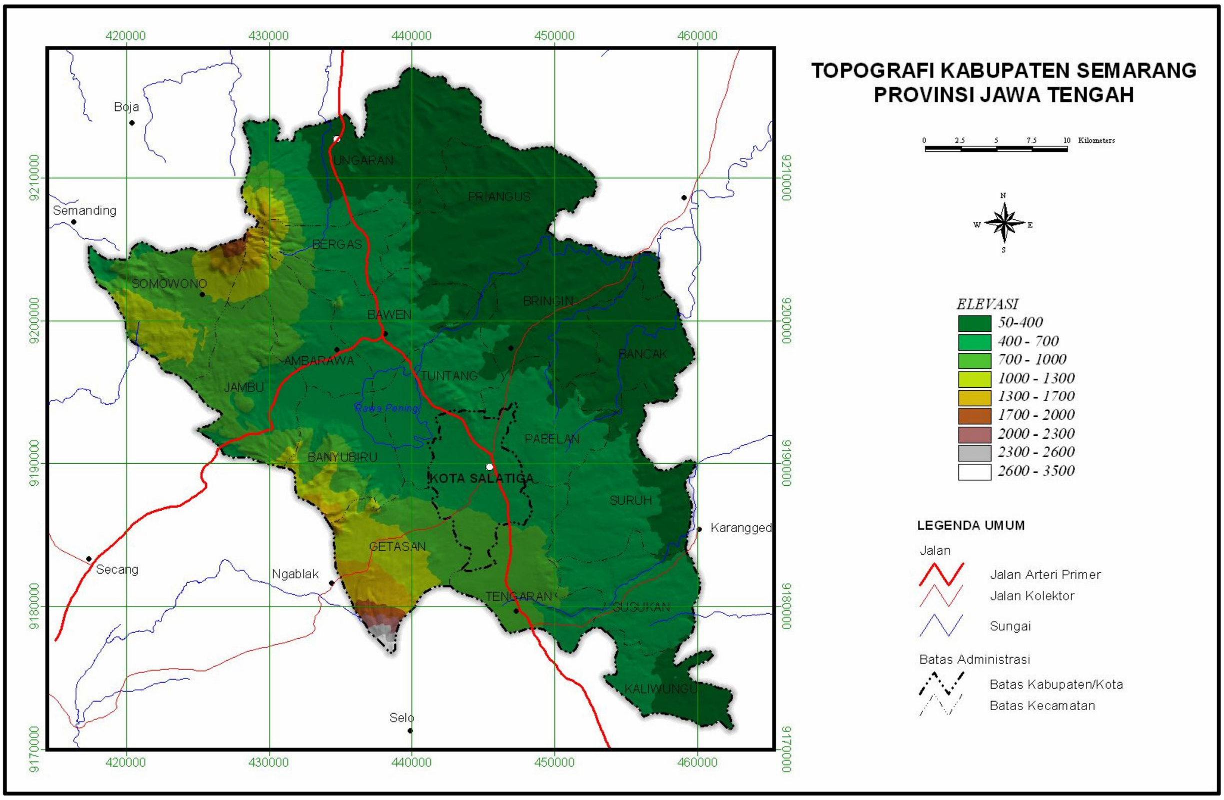


Figure 6. 3. Topographic map of the Semarang District

6.3. Biophysical setting

Geographically, the Semarang District stretches out from 110° 14' 54.75" to 110° 39' 3" South Latitude and from 7° 3' 57" to 7° 30' 00" East Longitude. The area is predominantly mountainous consisting mainly of hills, steep and very steep slopes (8 to more than 55 %), occupying about 55 %, and flat to gentle slopes (0 to less than 8 %) representing 45 % of the area. The Soil Research Institute of Bogor classifies the area into six regions based on the slope classes (Table 6. 1). More details are presented in Figure 6. 2. The elevation varies from 318 to 1 450 m above sea level. The completed topographic situation is given in Figure 6. 3.

Table 6. 1. The area of the Semarang District according to slope classes

No	Slope (%)	Area (Ha)
1	0 – 3	17 633
2	3 – 8	37 475
3	8 – 15	28 685
4	15 – 40	20 287
5	40 – 55	1 900
6	> 55	795

The climate is characterised by two distinct seasons, wet and dry periods. The wet or rainy season normally occurs from November to April and the dry period from May to October. According to ten years climatic data, the average annual precipitation is about 2 402 mm, ranging from 1 924 to 3 196 mm, with the highest annual rainfall taking place in 1998 (Figure 6. 4).

Approximately, 26.12 % or 24 823 ha of the lands are granted to wetland rice (*sawah*) production. Around 15 764 ha can be planted two times a year. Regarding the irrigation network system constructed in the field, the paddy fields can be classified into four groups, as presented in Table 6. 2.

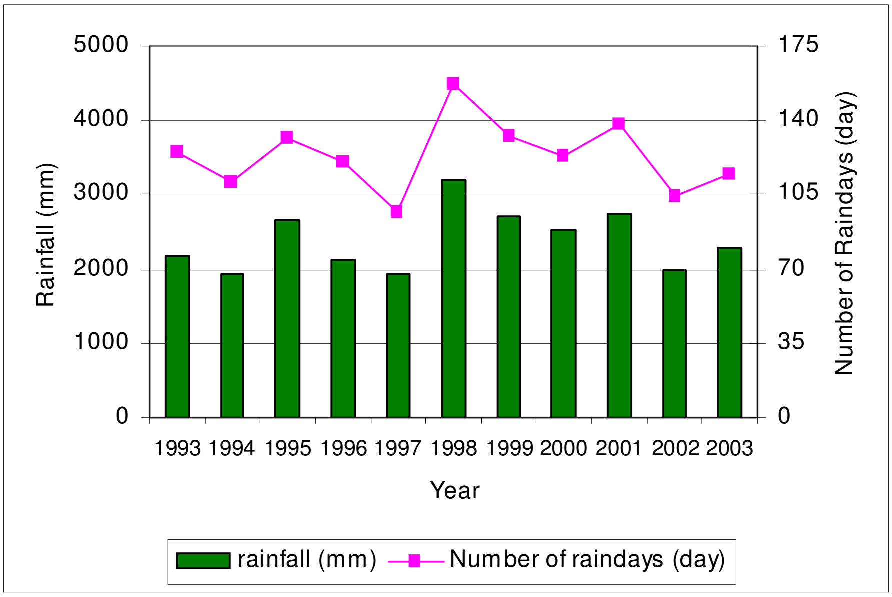


Figure 6. 4. Annual rainfall and rain days during ten years, from 1993 to 2002, of the Semarang District, Central Java Province

Technically, the data in Table 6. 2 also provide confirmation that the facilities of irrigation could be enhanced, from rain-fed irrigation (6 017 ha) and simple irrigation systems (8 910 ha) to half or fully regulated technical irrigation systems to produce more rice. This indeed depends on the available budget proposed by the Irrigation Division of the Public Work Services in the annual planning programme. Compared to 2002, the fully regulated technical irrigation system in 2004 increased about 82 ha. This enlargement is very important in terms of rice production, food security, and wetland rice protection. As previously noted, land conversion from agriculture to non-agriculture has occurred in many rice growing centres in Indonesia, resulting in the shrinking of paddy field areas used to cultivate rice.

Table 6. 2. Wetland rice areas classified according to their irrigation system in the Semarang District, Central Java Province

No.	Type of rice field	Area (ha)	Area (%)
1	Wetland rice with fully regulated technical irrigation system	5 525.1	22.6
2	Wetland rice with half regulated technical irrigation system	4 003.9	16.4
3	Wetland rice with simple irrigation system, including traditional	8 910.6	36.4
4	Wetland rice with rain-fed irrigation system	6 017.0	24.6

Source: BPS Semarang District (2004)

Next to the rice fields, the agro forestry (a mix of perennial trees and annual food crops), housing, forestry, and plantation are dominating land use types of the Semarang District (Table 6. 3; BPS, 2002).

Table 6. 3. Land use system, excluding wetland rice, in the Semarang District, Central Java Province

No.	Land use type	Area (ha)	Area (%)
1	Agro forestry	28 062.70	39.98
2	Housing	19 680.61	28.04
3	Forestry	11 329.00	16.14
4	Plantation	5 976.00	8.51
5	Swamp	2 637.00	3.76
6	Fresh water pond	10.00	0.01
7	Others	2 502.81	3.56

6.4. Socio-economic setting

Data in Tables 6. 2 and 6. 3 also illustrate that agriculture is an important sector at the district level, assisting in the economic development of the Semarang District. Although the industrialisation has also been growing fast during the last two decades and contributes very significantly to off-farm income, providing off-farm works finally supports the economic development of the district.

Furthermore, rice shows very valuable food crop commodities. The importance of rice is not only expressed in terms of staple food, but also in generating on-farm income and creating on-farm occupation. In 2000, there were about 265 648 persons working in the agricultural sector as farmers, farm workers, and rice traders. Compared to other sources of employment, this number is ten times higher than that of civil servants and about four times higher than in industrial sectors (BPS, 2000).

The demographic characteristics between 1998 and 2002 are given in Table 6. 4. Compared to 1998, the number of inhabitants, head of household, and population density increased in 2002, except for the growth rate. This may be due to migration from other districts when looking for employment. The increases were about 7 %, 19 % and 7 % for number of inhabitants, head of household, and population density, respectively. Consequently, land demands for housing, industries, and for infrastructures also enhanced and rice fields have been sacrificed. It may be concluded that land pressures due to land conversion from agriculture to non agriculture purposes are important challenges for sustaining rice production and food security in this district.

Table 6. 4. Demographic information of the Semarang District between 1998 and 2002

No.	Year	Area (Km^2)	Number of Inhabitants	Growth rate (%)	Head of household	Density (People km^{-2})
1.	1998	950.21	785 097	0.57	185 442	826
2.	1999	950.21	788 149	0.39	189 200	829
3.	2000	950.21	834 826	5.92	214 976	879
4.	2001	950.21	838 022	0.38	217 875	882
5.	2002	950.21	841 137	0.37	220 117	885

6.5. Materials and Methods

To assess nutrient balances of wetland rice farming on a district level, nutrients inputs and outputs have to be known. Data obtained mainly from the Statistic Agency of the Semarang District (*BPS*), covering the period between 1978 and 2003, were used to construct the balances, besides information gathered from the Food Crop Services, field experiments and field monitoring, including interviews with the farmers.

The procedures to evaluate nutrient balances for a district level is the same as for the field scale, as described in chapter 5 (see section 5.3). The nutrient balances were computed according to the differences between input and output. The nutrients originating from inorganic fertilisers (IN-1), recycling of rice straw (IN-2), irrigation (IN-3), and rainfall waters (IN-4) were the inputs. The nutrients removed by rice grains (OUT-1) and rice straw (OUT-2) were grouped as the outputs. Losses through NH_3-volatilisation and erosion were not taken into account. Output by NH_3-volatilisation may be considered significant as discussed in the previous chapter. However, because of practical restrictions, we could not collect data to estimate it at the district level. Erosion mainly occurs at harrowing and the values are small, besides variations in land preparation among villages.

Recommended fertiliser application rates provided by the Food Crop Services of the Semarang District and fertiliser application rates recently used by the farmers (called farmer rates) were used to estimate IN-1. The farmers applied imbalanced fertilisation due to financing difficulties. 33 % of the rice straw production and the nutrient content in the straw were used to estimate IN-2. The rice straw productions at the district level were computed based on their relation with rice grain yields and rice residues, as measured in the field experiments. IN-3 was calculated by multiplying the deposited nutrient during rice growth in the field experiments (previous chapter) with the producing area at district level. The sum of nutrients deposited between puddling and the generative phase were seen as the input coming from the irrigation water. Data from the field scale showed that the nutrient contributions to input from irrigation waters were small, ranging from 4 to 13 kg N, 0.1 to 0.2 kg P, and 6 to 13 kg K ha^{-1} $season^{-1}$. IN-4 was estimated taking into account the annual rainfall by multiplying rain volume with nutrient concentrations in the rainwater.

OUT-1 was calculated according to rice production multiplied with nutrient concentration in the grains. Data of the rice production between 1978 and 2003 were used to estimate removed nutrients by rice grains. The nutrient concentrations were adopted from the nutrient concentrations measured during the field experiments, between the WS 2001-02 and DS 2004. OUT-2 was computed based on rice straw production multiplied with nutrient concentration in the straw. Rice straw production for the district level was estimated from the relation with rice grain and residue yields, measured at field level between the WS 2001-02 and DS 2004. The nutrient concentrations in rice straw were compiled from the field experiments between the WS 2001-02 and DS 2004.

The period of 1978 to 2003 represents three distinct situations in Indonesia including the New Order Government or *ORBA* (1978-1993), the New Order Government with the economic crisis period (1994-1998), and the Reform Order Government with the economic recovery period, from 1999 to 2003 (National Information Agency, 2003).

During the *ORBA* (*Orde Baru* means the New Order Government), the national development programme was designed for 25 years, from 1969 to 1993, and was called the First Long-term Development Programme. This was executed through the Five-Year Development Plan called PELITA (*Pembangunan Lima Tahun*). Data were grouped and analysed in accordance with the Five-Year Development Plan. The mean producing area of the Five-Year Development Plan was considered as the unit area for the district level analysis.

The following assumptions and limitations were recognised to evaluate nutrient balances of wetland rice farming at district scale:

- Fertilising recommendation rates provided by the Food Crop Services of the Semarang District were considered. The fertiliser application rates were classified into high, medium, and low levels,
- The application of 50 kg of urea ha^{-1} $season^{-1}$ was considered as farmer rate and added as the control,
- As the management of rice straw differs among farmers, evaluation of nutrient balances with and without recycling of rice straw was considered,
- The mean nutrient contents measured from the experiment at Keji village were used to estimate input and output at district scale

6.6. Results and Discussion

6.6.1. Rice production, from 1978 to 2003

A better understanding of annual rice yields during the PELITA periods and the strategic implementation to reach the target of rice production set in every PELITA is essential to refine wetland rice management making it more profitable and sustainable with less negative impacts to the environment.

Rice yield, producing area, and total production from 1978 to 2003 in the Semarang District are given in Table 6. 5. Compared to 1978, rice yield, producing area and total rice production during every five-year development plan increased. The highest improvement for rice yield, about 48 %, was shown in the PELITA V and in the economic crisis era. The producing area increased about 14 % during the PELITA IV and the total production about 67% during PELITA V. Changing rice varieties from local to high yielding and developing irrigation networks greatly contributed to the increase of production intensity, leading to higher total rice production.

Looking to the PELITA III, from 1979 to 1983, rice yield, producing area, and total rice production were 3.73 t ha^{-1}, 28 753 ha yr^{-1}, and 107 625 t yr^{-1}, showing an increase of 8 %, 2 %, and 10 %, respectively compared to 1978. Planting new HYV and applying recommended fertilising rates in the rice producing areas successfully increased rice yields, resulting in enhancement of the total production of the district. Furthermore, introduction of HYV was focused on the improvement of quantitative and qualitative aspects of rice production. In addition, the shorter live cycle of HYV compared to local varieties increased the planting intensity.

In the PELITA IV, from 1984 to 1988, successful enhancement of rice yield, producing area and total production still took place. In general, compared to the previous PELITA, the enhancements were around 24 %, 12 %, and 39 % for grain yield, producing area, and total production, respectively. Interestingly, during the PELITA IV Indonesia has been recognised to be self-sufficient in rice. The end of PELITA IV was marked by the highest total production, 180 146 t yr^{-1}, and the largest producing area, 35 057 ha yr^{-1}. Successfully planting new HYV and applying recommended fertiliser rates in major producing areas were the main reason, besides other efforts, like providing credit, developing irrigation networks, and improving farmer's knowledge through training and farmer groups meeting.

Table 6. 5. Rice yield, producing area, and total rice production of the Semarang District, from 1978 to 2003

Period-Development Plan	Year	Rice Yield ($t\ ha^{-1}$)	Producing Area ($ha\ yr^{-1}$)	Production ($t\ yr^{-1}$)
ORBA:				
PELITA II	1978	3.45	28 215	97 364
PELITA III	1979	3.18	24 244	77 462
	1980	3.56	29 284	104 280
	1981	3.61	32 217	116 092
	1982	3.91	29 356	114 593
	1983	4.39	28 664	125 698
Mean		*3.73 ± 0.45*	*28 753 ± 2 872*	*107 625 ± 18 492*
PELITA IV	1984	4.76	31 199	148 620
	1985	4.36	28 435	123 979
	1986	4.61	34 692	159 817
	1987	4.28	31 865	136 446
	1988	5.14	35 057	180 146
Mean		*4.63 ± 0.35*	*32 250 ± 2 723*	*149 802 ± 21 608*
PELITA V	1989	5.34	32 121	172 138
	1990	5.42	30 702	166 305
	1991	4.64	32 148	145 134
	1992	5.14	32 497	167 124
	1993	4.95	33 140	164 040
Mean		*5.10 ± 0.31*	*32 122 ± 894*	*162 948 ± 10 389*
The Economic crisis:	1994	4.66	29 204	136 091
	1995	5.36	31 986	171 340
	1996	5.09	32 693	166 382
	1997	5.33	31 338	159 536
	1998	5.08	34 541	175 606
Mean		*5.10 ± 0.28*	*31 952 ± 1 948*	*161 791 ± 15 562*
The Economic	1999	4.78	32 332	154 482
recovery:	2000	5.28	32 804	173 314
	2001	4.93	29 624	146 021
	2002	5.19	33 062	171 694
	2003	4.82	30 285	146 047
Mean		*5.00 ± 0.22*	*31 621 ± 1 562*	*158 312 ± 13 419*

During the PELITA V, from 1989 to 1993, average rice yields reached 5.10 t ha^{-1}, varying between 4.64 and 5.42 t ha^{-1}. It was the highest average rice yield of this district. This coincides with the highest total production. Compared to the PELITA IV, rice yield and total rice production increased about 10 % and 8 %, respectively. However, in 1991, the rice yield and total production decreased about 14 % and 13 %, respectively compared to the rice yield and total production in 1990. This was attributed to a drought period, diseases, and pest attacks.

After the First Long-term Development Programme passing through the PELITA, the Indonesian Government has incessantly started a Second Long-term Development Programme to continue rising economic goals and improving standard of living. However, this programme was not successful because of political, social and economical crises. During the economic crisis, 1994 - 1998, the average rice yield remained about 5.10 t ha^{-1}, indicating that rice yield in this district was generally not directly affected by the crises. Although producing area and total production decreased about 1 %.

The rice yield and total rice production during the economic recovery, from 1999 to 2003, varied between 4.78 and 5.28 t ha^{-1} and between 146 021 and 173 314 t yr^{-1}, respectively. These variations were mainly due to differences in fertiliser application rates, as the farmers were facing financial difficulties. Efforts as done in the period of 1978 to 1993 were not yet well overseen and implemented.

6.6.2. Nutrient Balance

6.6.2.1. Input Data

IN-1: Inorganic Fertilisers

The contribution of inorganic fertilisers to the input (IN-1) is given in Table 6. 6. Fertilising rates recommended by the Food Crop Services for the Semarang District range between 100 - 250 kg of urea, 100 – 200 kg of TSP, and 100 kg of KCl ha^{-1} $season^{-1}$. Recent farmer practices, using only 50 kg of urea are added as control. So, for the practical reason, rates ranging from 50 to 250 kg of urea, 0 to 200 kg of TSP and 0 to 150 kg of KCl were evaluated and classified into high, medium, low, and control. The average contribution of mineral fertilisers varied as the average producing area differs in every five-year development plan. The highest IN-1 was found in the PELITA IV (see also Table 6. 5).

Table 6. 6. Contribution of inorganic fertiliser to input in the wetland rice farming system in the Semarang District

Fertiliser ($kg\ ha^{-1}\ season^{-1}$)		IN-1: Contribution of fertiliser to input ($t\ yr^{-1}\ district^{-1}$)					
Kind	Rate	1978	PELITA III	PELITA IV	PELITA V	1994-1998	1999-2003
Urea:							
High	250	3 174	3 235	3 628	3 614	3 595	3 557
Medium	175	2 222	2 264	2 540	2 530	2 516	2 490
Low	100	1 270	1 294	1 451	1 445	1 438	1 423
Control	50	635	647	726	723	719	711
TSP:							
High	200	1 129	1 150	1 290	1 285	1 278	1 265
Medium	150	846	863	968	964	959	949
Low	100	564	575	645	642	639	632
Control	0	0	0	0	0	0	0
KCl:							
High	150	2 116	2 157	2 420	2 409	2 397	2 371
Medium	100	1 411	1 438	1 613	1 606	1 598	1 581
Low	50	705	719	807	803	799	790
Control	0	0	0	0	0	0	0

IN-2: Recycling rice straw

Estimated productions of rice straw and rice residues during every five-year development plan and their contributions to the nutrient input (IN-2) are presented in Tables 6. 7 and 6. 8. The productions ranged from 127 005 to 213 745 and 112 836 to 189 898 $t\ yr^{-1}\ district^{-1}$ for rice straw and rice residue, respectively. IN-2 is estimated according to average nutrient contents in rice straw of the WS 2001-02, DS 2002, WS 2002-03, DS 2003, WS 2003-04 and DS 2004. The average ($\pm$ standard deviation) nutrient concentrations were 1.05 $\pm$ 0.10 % N, 0.10 $\pm$ 0.02

% P, and 2.05 ± 0.19 % K in rice straw and 0.64 ± 0.11 % N, 0.07 ± 0.01 % P, and 1.90 % ± 0.17 K in rice residues. During the PELITA V, the highest IN-2 was observed (Table 6. 8).

Table 6. 7. The average production of rice grain, estimated rice straw and rice residue between 1978 and 2003 in the Semarang District

Period	Average yield (t ha^{-1})			Estimated mean production (t $yr^{-1}district^{-1}$)		
	Rice grain	Rice straw	Rice residue	Rice grain	Rice straw	Rice residue
1978 (end of PELITA II)	3.45	4.50 ± 0.44	4.00 ± 0.34	97 364	127 005 ± 12 257	112 836 ± 9 647
PELITA III	3.73	4.87 ± 0.47	4.32 ± 0.37	107 625	139 931 ± 13 505	124 320 ± 10 629
PELITA IV	4.63	6.04 ± 0.58	5.37 ± 0.46	149 802	194 820 ± 18 802	173 085 ± 14 798
PELITA V	5.10	6.65 ± 0.64	5.91 ± 0.51	162 948	213 745 ± 20 628	189 898 ± 16 236
1994-1998	5.10	6.65 ± 0.64	5.91 ± 0.51	161 791	212 613 ± 20 520	188 893 ± 16 150
1999-2003	5.00	6.52 ± 0.63	5.80 ± 0.49	158 312	206 285 ± 19 909	183 271 ± 15 669

IN-3: Irrigation

IN-3 for the Semarang District ranged from 216 to 246 t N yr^{-1}, 3 to 4 t P yr^{-1}, and 232 to 265 t K yr^{-1} showing the smallest contribution of P to input.

Table 6. 8. The nutrient contribution of rice straw to the nutrient input, rice residues to the nutrient pool, and of rice grains to the output in the Semarang District

Period	Estimated nutrient contribution to input , or nutrient pool, or output (t yr^{-1} $district^{-1}$)								
	IN-2: Returned Rice straw			Rice residue			OUT-1: Rice grain		
	N	P	K	N	P	K	N	P	K
1978	441	40	858	720 ± 43	77 ± 6	2 128±101	1 419 ± 72	190 ± 22	294 ± 22
PELITA III	486	41	946	793 ± 48	85 ± 7	2 344±111	1 568 ± 79	210 ± 25	325 ± 25
PELITA IV	676	61	1 317	1 104±66	119 ± 9	3 264±155	2183 ± 110	292 ± 35	452 ± 34
PELITA V	742	67	1 445	1 211±73	130 ± 9	3 581±170	2375 ± 120	318 ± 38	492 ± 36
1994-1998	738	67	1 437	1 205±73	129±10	3 562±167	2358 ± 119	316 ± 38	489 ± 37
1999-2003	716	65	1 394	1 169±71	126 ± 9	3 456±164	2307 ± 117	309 ± 37	478 ± 36

The presence of rice residues in the rice fields is not considered either as an input or as an output. However, it should be noted that although the N, P, and K concentrations in rice residues were lower than in recycled rice straw, the nutrient pool in rice residues was higher, as all rice residues remained in the field and only 33 % of the rice straw production returned to the field (Table 6. 8). The data show that the N and K pool in rice residues ranged from 720 to 1 211 t N yr^{-1} and from 2 128 to 3 158 t K yr^{-1}. These amounts are higher than IN-2, ranging from 441 to 742 t N yr^{-1} and 856 to 1 445 t K yr^{-1}.

IN-4: Precipitation

IN-4 is given in Figure 6. 5 and annual rainfall is given in Appendix 6. 1. The contribution of rainfall to nutrients input was the highest for N. Depending on the period, the contributions ranged from 303 to 372 t N yr^{-1}, 26 to 32 t P yr^{-1}, and 107 to 131 t K yr^{-1}. Economically, these contributions were equivalent to 700 - 825 t of urea yr^{-1}, 125 - 150 t of TSP yr^{-1}, and 200 - 260 t of KCl yr^{-1}.

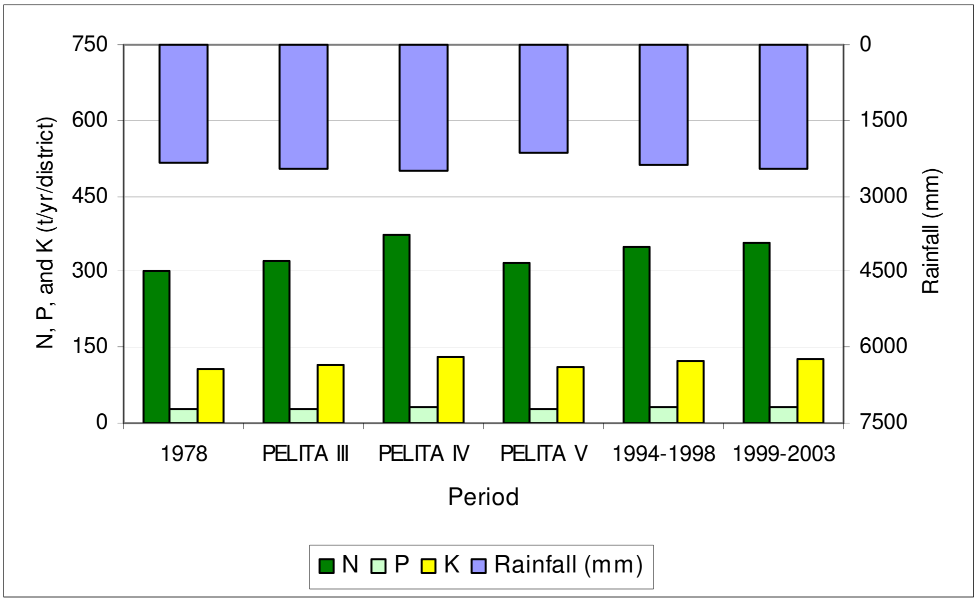


Figure 6. 5. Contribution of rainfall to N, P, and K input in the Semarang District

6.6.2.2. Output Data

OUT-1: Rice grain

Total nutrient amounts taken up by rice grains are given in Table 6. 8. OUT-1 was estimated according to the average total rice production and average nutrient contents during every five-year development plan. Average nutrient contents in grains were estimated from the nutrient contents in the WS 2001-02, DS 2002, WS 2002-03, DS 2003, WS 2003-04, and DS 2004. The means were 1.46 $\pm$ 0.22 % N, 0.20 $\pm$ 0.05 % P, and 0.30 $\pm$ 0.04 % K. The OUT-1 ranged between 1 419 and 2 375 t N, 190 and 318 t P, 294 and 492 t K yr^{-1} $district^{-1}$, depending on grain yields as reached in every period of development.

OUT-2: Rice straw

Total nutrient amounts removed by rice straw are given in Table 6. 9. OUT-2 was estimated according to average total rice straw production and nutrient contents in every five-year development plan. The nutrient contents were estimated from data of the WS 2001-02, DS 2002, WS 2002-03, DS 2003, WS 2003-04, and DS 2004. The values were 1.05 $\pm$ 0.10 % N, 0.10 $\pm$ 0.02 % P, and 2.05 $\pm$ 0.19 % K.

Table 6. 9. Nutrients removal through rice straw in the Semarang District by the period of development plan

Period	Nutrients removal (t yr^{-1} $district^{-1}$)		
	N	P	K
1978	1 335 $\pm$ 109	120 $\pm$ 22	2 601 $\pm$ 239
PELITA III	1 471 $\pm$ 120	133 $\pm$ 24	2 866 $\pm$ 259
PELITA IV	2 049 $\pm$ 167	185 $\pm$ 33	3 990 $\pm$ 367
PELITA V	2 248 $\pm$ 177	203 $\pm$ 37	4 378 $\pm$ 403
1994-1998	2 236 $\pm$ 182	202 $\pm$ 36	4 355 $\pm$ 400
1999-2003	2 169 $\pm$ 177	196 $\pm$ 35	4 225 $\pm$ 389

6.6.2.3. Input-output analysis with application of rice straw

The N, P, and K balances in every five-year development plan are given in Tables 6.10 to 6. 12. When application of rice straw (33 % of production) was considered, positive N balances were mainly observed for the high fertiliser application rates. Depending on the period of the development, the positive N balances ranged between 330 and 1 380 t N yr^{-1} $district^{-1}$. The medium level (175 kg of urea ha^{-1} $season^{-1}$) also showed positive N balances, when the rice production was up to 107 625 t yr^{-1} $district^{-1}$ or 3.73 t ha^{-1}. Increasing biomass production reduces the positive balances (Table 6. 10). Since the Semarang District is one of the centres producing rice, a minimal average rice yield of about 5.10 t ha^{-1}, as reached in the PELITA V and in the economic crisis, was more important to meet the growing rice demand than that having higher N positive balance with lower rice grain yield, as observed in the PELITA III. Moreover, the positive N balances of about 330 – 336 t N yr^{-1} $district^{-1}$, as observed in the PELITA V and in the economic crisis, are equivalent to 25 kg of urea. Consequently, for the economical and environmental reasons, application rates of urea up to 225 kg ha^{-1} $season^{-1}$ are required to substitute the N removed by grains and straw.

As the P content of rice straw is low and the output by grains is very high, the balance is mainly influenced by the application of P fertiliser. In all levels of recommended fertiliser application rates, positive P balances were observed (Table 6.11). To fit the P removal, application of 100 kg of TSP ha^{-1} $season^{-1}$ may be recommended.

A negative potassium (K) balance, between 617 and 3 692 t K yr^{-1} $district^{-1}$, was observed for all levels of inorganic fertiliser application rates, when the minimal rice yield of 5.10 t ha^{-1} $season^{-1}$ is targeted (Table 6. 12). The input by rice straw helped reducing the negative balance, but it is not adequate to completely meet the K removals. Hence, potassium fertiliser application rates should be increased to avoid K mining. To improve soil fertility and to secure rice yield, application of 200 kg of KCl ha^{-1} $season^{-1}$ may be advised.

For the control fertiliser application rate (farmer rate), the most negative N, P, and K balances were observed, ranging from 1 159 to 2 661 t N, from 241 to 429 t P, and from 1 693 to 3 178 t K yr^{-1} $district^{-1}$. This means that conventional farmer practices using only 50 kg of urea ha^{-1} $season^{-1}$ are not sustainable and not longer recommended.

It may be concluded that to reach a grain yield higher than 5 t ha^{-1} and when 33 % of rice straw is recycled, about 250 kg of urea, 100 kg of TSP, and 200 kg of KCl ha^{-1} $season^{-1}$ should be applied to replace the removed N, P, and K.

6.6.2.4. Input-output analysis without application of rice straw

On the contrary, when all rice straw is removed and when the highest rice yields were considered, as reached during the PELITA V and the economic crisis era, only P balances were consistently positive provided TSP was applied (see also Tables 6. 10 to 6. 12). The negative N and K balances were observed for all inorganic fertiliser application rates. This means that application rates of urea up to 250 kg and KCl up to 150 kg ha^{-1} $season^{-1}$ were not sufficient to balance N and K removal through grains and straw. These N and K balances were more negative compared to when recycling rice straw was taken into account. Furthermore, to equilibrate the negative balances around 446 t N and 2 086 t K yr^{-1} $district^{-1}$, about 280 kg of urea and 300 kg of KCl ha^{-1} $season^{-1}$ have to be applied.

The positive P balances are demonstrating the dominant contribution of P fertiliser. So far, environmentally and economically, application of 100 kg of TSP ha^{-1} $season^{-1}$ seems sufficient to substitute P removal by rice grain production.

For the control fertiliser application rate, N, P, and K balances were negative proving that application of only 50 kg of urea ha^{-1} is not sustainable and profitable. Hence, it is no longer recommended.

Therefore, it may be concluded that applications of 280 kg of urea, 100 kg of TSP, and 300 kg of KCl ha^{-1} $season^{-1}$ are needed to restore the nutrient removal by wetland rice when a minimal yield of 5 t ha^{-1} rice grains is needed and no rice straw is recycled.

Table 6. 10. The N balances for wetland rice farming with (+ RS) and without (- RS) returning rice straw, in the Semarang District

Parameter and Period of Development	Nitrogen Balance (t yr^{-1} $district^{-1}$)							
	High		Medium		Low		Control	
	+ RS	- RS	+ RS	- RS	+ RS	- RS	+ RS	- RS
1978:								
Total Input	4 134	3 693	3 182	2 741	2 220	1 789	1 595	1 154
Total Output	2 754	2 754	2 754	2 754	2 754	2 754	2 754	2 754
Balance	+ 1 380	+ 939	+ 428	- 13	- 534	- 965	- 1 159	- 1 600
PELITA III:								
Total Input	4 219	3 878	3 248	2 807	2 278	1 837	1 631	1 190
Total Output	3 039	3 039	3 039	3 039	3 039	3 039	3 039	3 039
Balance	+ 1 180	+ 838	+ 209	- 232	- 716	- 1 202	- 1 408	- 1 849
PELITA IV:								
Total Input	4 733	4 247	3 645	3 159	2 556	2 070	1 831	1 345
Total Output	4 232	4 232	4 232	4 232	4 232	4 232	4 232	4 232
Balance	+ 501	+ 15	- 587	- 1 073	- 1 676	- 2 162	- 2 401	- 2 887
PELITA V:								
Total Input	4 953	4 177	3 769	3 093	2 684	2 008	1 962	1 286
Total Output	4 623	4 623	4 623	4 623	4 623	4 623	4 623	4 623
Balance	+ 330	- 446	- 854	- 1 530	- 1 939	- 2 615	- 2 661	- 3 337
1994 – 1998:								
Total Input	4 930	4 188	3 851	3 109	2 773	2 031	2 054	1 312
Total Output	4 594	4 594	4 594	4 594	4 594	4 594	4 594	4 594
Balance	+ 336	- 406	- 743	- 1 485	- 1 821	- 2 563	- 2 540	- 3 282
1999 – 2003:								
Total Input	4 893	4 155	3 826	3 088	2 659	2 021	2 047	1 309
Total Output	4 476	4 476	4 476	4 476	4 476	4 476	4 476	4 476
Balance	+ 417	- 321	- 650	- 1 388	- 1 817	- 2 455	- 2 429	- 3 167

Table 6. 11. The P balances for wetland rice farming with (+ RS) and without (- RS) returning rice straw, in the Semarang District

Parameter and Period of Development	Phosphorus Balance (t yr^{-1} $district^{-1}$)							
	High		Medium		Low		Control	
	+ RS	- RS	+ RS	- RS	+ RS	- RS	+ RS	- RS
1978:								
Total Input	1 198	1 158	915	875	633	593	69	29
Total Output	310	310	310	310	310	310	310	310
Balance	+ 888	+ 848	+ 605	+ 565	+ 323	+ 283	- 241	- 281
PELITA III:								
Total Input	1 221	1 175	934	894	646	606	71	31
Total Output	343	343	343	343	343	343	343	343
Balance	+ 878	+ 832	+ 591	+ 551	+ 303	+ 263	- 272	- 312
PELITA IV:								
Total Input	1 370	1 326	1 048	1 004	725	681	80	36
Total Output	477	477	477	477	477	477	477	477
Balance	+ 893	+ 849	+ 571	+ 527	+ 248	+ 204	- 397	- 441
PELITA V:								
Total Input	1 377	1 316	1 056	995	734	673	92	31
Total Output	521	521	521	521	521	521	521	521
Balance	+ 856	+ 795	+ 535	+ 474	+ 213	+ 152	- 429	- 490
1994 – 1998:								
Total Input	1 379	1 312	1 060	993	740	673	101	34
Total Output	518	518	518	518	518	518	518	518
Balance	+ 861	+ 794	+ 542	+ 475	+ 222	+ 155	- 417	- 484
1999 – 2003:								
Total Input	1 367	1 300	1 051	984	734	667	102	35
Total Output	505	505	505	505	505	505	505	505
Balance	+ 862	+ 795	+ 546	+ 479	+ 229	+ 162	- 403	- 470

Table 6. 12. The K balances for wetland rice farming with (+ RS) and without (- RS) returning rice straw, in the Semarang District

Parameter and Period of Development	Potassium Balance (t yr^{-1} $district^{-1}$)							
	High		Medium		Low		Control	
	+ RS	- RS	+ RS	- RS	+ RS	- RS	+ RS	- RS
1978:								
Total Input	3 313	2 455	2 608	1 750	1 903	1 045	1 197	339
Total Output	2 895	2 895	2 895	2 895	2 895	2 895	2 895	2 895
Balance	+ 418	- 440	- 287	- 1 145	- 992	- 1 850	- 1 698	- 2 556
PELITA III:								
Total Input	3 365	2 507	2 646	1 788	1 839	1 069	1 208	350
Total Output	3 191	3 191	3 191	3 191	3 191	3 191	3 191	3 191
Balance	+ 174	- 684	- 545	- 1 403	- 1 352	- 2 122	- 1 983	- 2 841
PELITA IV:								
Total Input	3 862	2 816	3 055	2 009	2 248	1 202	1 442	396
Total Output	4 452	4 452	4 452	4 452	4 452	4 452	4 452	4 452
Balance	- 590	- 1 636	- 1 397	- 2 243	- 2 204	- 3 250	- 3 010	- 4 056
PELITA V:								
Total Input	4 101	2 784	3 298	1 981	2 495	1 178	1 692	375
Total Output	4 870	4 870	4 870	4 870	4 870	4 870	4 870	4 870
Balance	- 769	- 2 086	- 1 572	- 2 889	- 2 375	- 3 692	- 3 178	- 4 495
1994 – 1998:								
Total Input	4 227	2 782	3 428	1 983	2 629	1 184	1 830	385
Total Output	4 844	4 844	4 844	4 844	4 844	4 844	4 844	4 844
Balance	- 617	- 2 062	- 1 416	- 2 861	- 2 215	- 3 660	- 3 014	- 4 459
1999 – 2003:								
Total Input	4 193	2 756	3 403	1 986	2 613	1 176	1 822	385
Total Output	4 703	4 703	4 703	4 703	4 703	4 703	4 703	4 703
Balance	- 510	- 1 947	- 1 300	- 2 717	- 2090	- 3 527	- 2 881	- 4 318

6.7. Conclusions

1. There was a significant increase of rice yield in the Semarang District between the end of PELITA II (178) and PELITA V, from 3.45 to 5.10 t ha^{-1}, because of the application of recommended fertiliser rates and planting of high yielding rice varieties. From the economic crisis to the economic recovery periods, rice yield levelled of at 5.10 t ha^{-1} because of improper rice straw management and imbalanced fertilising.

2. During the economic crisis rice yield remained 5.10 t ha^{-1}, showing that in the Semarang District rice yield was not directly affected by the crises occurring in Indonesia.

3. In the era of economic recovery, 1999-2003, rice yield reached 5 tons ha^{-1} and total production decreased about 1%, which can be due to land use changes.

4. When 33 % of rice straw production is recycled and the expected grain yield is 5 t ha^{-1}, applications of 225 kg of urea, 100 kg of TSP, and 200 kg of KCl ha^{-1} $season^{-1}$ are economically and environmentally recommended. However, when rice straw is not recycled, applications of 280 kg urea, 100 kg TSP, and 300 kg KCl ha^{-1} $season^{-1}$ are needed.

5. Recycling of rice straw may result in a saving of 1 580 t of urea and 3 162 t of KCl $district^{-1}$ yr^{-1}, representing an amount of 1.11 million euro (the price of urea is 0.20 euro and KCl is 0.25 euro kg^{-1}).

GENERAL CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSSIONS AND RECOMMENDATIONS

The study on sediment and nutrient movement behaviour in terraced paddy field under traditional irrigation systems indicate that sediment was displaced mainly during harrowing, both in the wet and dry seasons. Contrary, sediments were deposited on every terrace a week before and after fertilising. Both at harrowing and fertilising, the amounts of incoming dissolved nutrients were higher than outgoing as well in the wet season as in the dry season. Terraces having greater surfaces trapped higher amounts of sediments and nutrients than terraces with smaller sizes. It may be concluded that terraced paddy field system is not only the way for producing rice, but also provides environmental services, like sediment trapping and nutrients conservation. It is strongly recommended to protect these areas to reduce erosion and other downstream negative effects. The terraced paddy fields with high productivities and good facilities should be intensified to meet increasing rice demands and to support food security programmes.

The studies on nutrient uptake during rice growth and effects of rice straw addition on rice production demonstrate that applications of 100 kg ha^{-1} $season^{-1}$ of urea, Triple Super Phosphate (TSP), and Potassium Chloride (KCl) along with 33% of rice straw production always show the highest nutrient (N, P, and K) concentrations in shoots and roots of rice plants, nutrient uptakes and significantly enhance rice yields both during the wet and dry season. However, the study of nutrient balances demonstrates that application rates of 100 kg ha^{-1} $season^{-1}$ of urea, TSP, and KCl along with 33% of the rice straw production present negative N and K balances. These negative balances, both in the wet and dry season, illustrate that the mineral fertilisers (urea and KCl) application rates are not sufficient to replace N and K removals by rice grains and straw. On the other hand, application of P fertiliser results in equilibrated balances of P both in the wet season and in the dry season. Towards sustainable rice farming in terraced paddy field systems, more nitrogen and potassium fertilisers have to be applied. Therefore, application rates of 200 kg of urea ha^{-1} $season^{-1}$, 100 kg of TSP ha^{-1} $season^{-1}$, and 200 kg of KCl ha^{-1} $season^{-1}$ are highly recommended to manage the rice fields. As in the dry season the N balance is more negative, it is recommended to apply 250 kg ha^{-1} (about 50 kg ha^{-1} of urea more) to equilibrate the balance in the dry season.

Conventional farmer practices with a urea application of 50 kg ha^{-1} $season^{-1}$ always show the lowest nutrient concentration, rice yield and negative nutrient balances. Hence, this practice may not longer be recommended to avoid wetland degradation.

Although the N, P, and K balances are still negative, the recycling of rice straw reduces the negative balances. In terms of technical, environmental, and economical points of view, returning rice straw should be continuously practiced. Realising that intensification of livestock through the cattle fattening programme in this village also needs rice straw, the use of 67 % of rice straw production as cattle feed and returning 33 % of rice straw production to the rice field may be a realistic recommendation.

As the prices of inorganic fertilisers are getting higher and the farmers face financial difficulties, dependency on inorganic fertiliser in dry land farming may be minimised by cattle dung produced from the cattle fattening programme. Practically, the farmers do not apply cattle dung to the wetland rice fields. So far, providing credit for agricultural input with no or low interest is also highly justified.

Scaling up of this study from farm level to district level shows that when a minimal rice yield of 5 t ha^{-1} is expected and 33 % of rice straw is applied, the recommended fertilisation rates given before (200-250 kg of urea, 100 kg of TSP and 200 kg of KCl ha^{-1} $season^{-1}$) remain economically and environmentally valid. However, at expected rice yield of 5 t ha^{-1} and when rice straw is not recycled, application rates of 280 kg of urea, 100 kg of TSP, and 300 kg of KCl ha^{-1} $season^{-1}$ are needed.

It is important to note that the overall N balances would be lower, when the rice residues would be removed from the field and NH_3 losses through volatilisation are taken into account. With respect to K balances, they will be more negative, when rice residues would be removed from the rice fields.

For future research, measurement of N volatilisation in wetland rice cultivation and nutrients in eroded sediments to have a more reliable N balance is recommended. As in general terraced paddy fields is located at high place (in average higher than 400 m above sea level), many agronomic aspects are still interesting to be researched to increase rice yield and farmers income.

Strategy of achievement

From the studies of nutrient balances, it is observed that soil fertility may be improved, sustained, or declined depending on the inorganic and organic fertiliser application rates and expected rice production. To improve soil fertility and to secure rice yields, the following strategies are proposed:

At the farmer level: application of 200-250 kg of urea, 100 kg of TSP, and 200 kg of KCl ha^{-1} $season^{-1}$ together with returning of 33 % of rice straw is practised. The strategy is farmer to farmer transfer through some activities:

1. Organise regular meeting with the farmers
2. Carry out demonstration plots, focusing on balanced fertilising along with returning of 33% of rice straw production
3. Conduct field days
4. Organise cross-farm visits
5. Provide credit for agricultural inputs

At the village/community level: activate farmer groups to improve awareness in managing wetland rice is put into priority supported by several activities:

1. Organise group meetings attended by village leaders, key persons, extension workers, and the leaders of farmer groups
2. Carry out demonstration plots in different farmer group sites
3. Conduct field days
4. Organise cross-farm visits

At the district level/policy makers: increasing awareness that wetland resources are shrinking and rice demand is increasing, good policies are required. Consequently, strict policies and regulations to provide certain sites as *protected wetland rice areas* in the rice growing centres must be enforced. The wetland rice fields with good irrigation facilities and high productivities should not be converted. Current situations, in which agricultural inputs and daily needs are getting more expensive resulting in imbalanced fertiliser application and reducing of living standards. This should be anticipated by giving credit for agricultural purposes to maintain better wetland rice farming systems (more profitable and sustainable). Conducting training and regular meetings to improve farmers' knowledge are also advised.

REFERENCES

REFERENCES

Adachi, K. 1990. Effect of rice-soil puddling on water percolation. *In:* Proceedings of the transactions of the 14th international congress on soil science. I: 146-151.

Adimihardja, A., Wahyunto, and Shafiyati, R. 2004. Advocacy for controlling sawah conversion for improvement of the national food security. In: Agus, F., Pawitan, H., and Husen, E. (Eds.), Multifungsi pertanian dan konservasi sumber daya lahan. pp: 47-63 (in Indonesian)

Agus, F., Kurnia, U., and Nurmanaf, A.R. (Eds.). 2006. Proceeding, national seminar on the multifunction of sawah. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat, Bogor, Indonesia. 147p. (In Indonesian)

Agus, F., Wahyunto, Watung, R.L., Tala'ohu, S.H., and Sutono. 2004. Land use changes and their effects on environmental functions of agriculture. In: Agus, F., Pawitan, H., and Husen, E. (Eds.), Multifungsi pertanian dan konservasi sumber daya lahan. pp: 1-21 (in Indonesian)

Agus, F., Vadari, T., Watung, R.L., Sukristiyonubowo, and Valentin, C. 2003. Effects of land use and management systems on water and sediment yields: Evaluation from several micro catchments in Southeast Asia. In: Maglinao, A.R., Valentin, C., and Penning de Vries, F.W.T. (Eds.), From soil research to land and water management: Harmonising People and Nature. Proceedings of the IWMI-ADB Project Annual Meeting and 7th MSEC Assembly. pp: 135-149

Agus, F., and Sukristiyonubowo. 2003. Nutrient loss and onsite cost of soil erosion under different land uses systems in South East Asia. In: Wani, S.P., Maglinoa, A.R, Ramakrisna, A., and Rego, T.J. (Eds.), Integrated catchment management for land and water conservation and sustainable agricultural production in Asia. pp. 186-193

Agus, F., Sukristiyonubowo, Vadari, T., and Setiani, C. 2001. Catchment approach to managing soil erosion in Kaligarang Catchment of Java, Indonesia. In: Maglinoa, A.R., and Leslie, R.N. (Eds.), Soil erosion management research in Asia catchment: Methodological approach and initial results. Proceeding of the 5th Management of Soil Erosion Consortium

(MSEC) assembly organised by the Centre for Soil and Agroclimate Research and Development (CSARD) Bogor Indonesia and the International Water Management Institute (IWMI), Colombo, Sri Lanka with support from the Asian Development Bank (ADB), Manila, Philippines. pp. 129-151

Aksoy, H., and Kavvas, H.L. 2005. A review of hillslope and watershed scale erosion and sediment transport model. Catena. 64: 247-271

Akonde, T.P., Leihner A.E., and Kuhne, R. 1999. Nutrient balance in agroforestry systems. Plant Research and Development. Institute for Scientific Co-operation, Tubingen, Federal Republic of Germany. 50: 7-17

Alberts, E.E., Schuman, G.E., and Burwell, R.E. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri Valley loess watershed. Journal of Environmental Quality. 7: 203-208

Alice, J., Sujeetha, R.P., and Venugopal, M.S. 2003. Effect of organic farming on management of rice brown plant hopper. IRRN. 28 (2): 36 - 37

Anbumozhi, V., Yamaji, E., and Tabuchi, T. 1998. Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertigation level. Agricultural Water Management. 37: 241-253

Anonymous. 2004. Rencana Pembangunan Jangka Menengah Nasional 2004-2009 (National Mid-term Development Plan 2004-2009). 515 p (in Indonesian)

Anonymous. 1977. General practices for rice, cash crops and vegetables. BIMAS, Ministry of Agriculture of the Republic of Indonesia. 280 p. (in Indonesian)

Aulakh, M.S., Khera, T.S., Doran, J.W., and Bronson K.F. 2001. Managing crop residue with green, urea, and tillage in a rice-wheat rotation. Soil Science Society of America Journal. 65: 820-827

Bationo, A., Lompo, F., and Koala, S. 1998. Research on nutrient flows and balances in West Africa: State-of-the-art. Agricultural Water Management. 71: 19-35

Bhagat, R.M., Bhuiyan, S.I., and Moody, K. 1996. Water, tillage and weed interactions in lowland tropical rice: a review. Agricultural Water Management. 31: 165-184

Bhuiyan, S.I., Sattar, M.A., and Tabbal, D.F. 1994. Wet seeded rice: water use efficiency, productivity and constraints to wider adoption. Paper presented at the International Workshop on constrains, opportunities, and innovations for wet seeded rice, Bangkok, May 31 – June 3, 1994, 19 pp.

Bhuiyan, S.I. 1992. Water management in relation to crop production: case study on rice. Outlook Agriculture. 21: 293-299

Bouman, B.A.M., Peng, S., Castaneda, A.R., and Visperas, R.M. 2005. Yield and water use of irrigated tropical aerobic rice systems. Agricultural Water Management. 74: 87-105

Bouman. B.A.M., and Tuong, T.P. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agricultural Water Management. 49: 11-30

BPS. 2004a. Statistic of Indonesia. Biro Pusat Statistik. (in Indonesian)

BPS. 2004b. Semarang Regency in figures 2004. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 2003a. Jawa Tengah in figure 2003. Collaboration Regional Development Planning Board of Jawa Tengah (BAPPEDA Jawa Tengah) with Statistics Agency of Jawa Tengah Province. 587 pp (in Indonesian)

BPS. 2003b. Semarang Regency in figures 2003. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 2002a. Statistic of Indonesia. Biro Pusat Statistik (in Indonesian).

BPS. 2002b. Semarang Regency in figures 2002. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 2001. Semarang Regency in figures 2001. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 2000. Semarang Regency in figures 2000. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1999. Semarang Regency in figures 1999. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1998. Semarang Regency in figures 1998. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1997. Semarang Regency in figures 1997. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1996. Semarang Regency in figures 1996. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1995. Semarang Regency in figures 1995. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1994. Semarang Regency in figures 1994. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1993. Semarang Regency in figures 1993. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1992. Semarang Regency in figures 1992. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1991. Semarang Regency in figures 1991. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1990. Semarang Regency in figures 1990. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1989. Semarang Regency in figures 1989. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1988. Semarang Regency in figures 1988. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1987. Semarang Regency in figures 1987. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1986. Semarang Regency in figures 1986. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1985. Semarang Regency in figures 1985. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1984. Semarang Regency in figures 1984. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1983. Semarang Regency in figures 1983. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1982. Semarang Regency in figures 1982. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1981. Semarang Regency in figures 1981. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1980. Semarang Regency in figures 1980. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1979. Semarang Regency in figures 1979. Statistics Agency of Semarang Regency (in Indonesian)

BPS. 1978. Semarang Regency in figures 1978. Statistics Agency of Semarang Regency (in Indonesian)

Bridgit, A.T., and Potty, N.N. 2002. Influence of root characteristics on rice productivity in iron-rich lateritic soils of Kerala, India. IRRN. 27 (1): 45-46

Cabangon, R.J., Tuong, T.P., and Abdullah, N.B. 2002. Comparing water input and water productivity of transplanted and direct-seeded rice production systems. Agricultural Water Management. 57: 11-31

Cabangon, Romeo J., and Tuong, T.P. 2000. Management of cracked soils for water saving during land preparation for rice cultivation. Soil and Tillage Research. 56: 105-116

Campbell, C.A., and Zentner, R.P. 1993. Soil organic matter as influenced by crop rotations and fertilisation. Soil Science Society of America Journal. 57: 1034-1040

Casanova, D., Goudriaan, J., Catala Forner, M.M., and Withagen, J.C.M. 2002. Rice yield prediction from yield components and limiting factors. European Journal of Agronomy. 17: 41 - 61

Ceisiolka, C.A.A., and Rose, C.W. 1998. The measurement of soil erosion. In: Penning de Vries, F.W.T., Agus, F., and Kerr, J. (Eds.), Soil Erosion at Multiple Scale. Principles and Methods for Assessing Causes and Impacts. CABI Publishing in Association with IBSRAM. pp. 287-302

Chandler, R. F. 1970. Overcoming physiological barriers to higher yields through plant breeding. In: International Potash Institute (Eds.), Symposium role of fertilisation in the intensification of agricultural production. Proceedings of the 9th Congress of the International Potash Institute. Antibes. pp. 421-434

Chaves, B., De Neve, S., Hofman, G., Boeckx, P., and Clemput, O. V. 2004. Nitrogen mineralisation of vegetables roots residues and green manures as related to their (bio) chemical composition. European Journal of Agronomy. 21: 161-170

Chowdary, V.M., Rao, N.H., and Sarma, P.B.S. 2004. A coupled soil water and nitrogen balance model for flooded rice fields in India. Agriculture Ecosystems and Environment. 103: 425-441

Cho, J.Y., Han K.W., and Choi, J.K. 2000. Balance of nitrogen and phosphorus in a paddy field of central Korea. Soil Science and Plant Nutrition. 46: 343-354

Clark, M.S., Horwath, W.R., Shennan, C., and Scow, K.M. 1998. Changes in soil chemical properties resulting from organic and low-input farming practices. Agronomy Journal. 90: 662-671

Cooke. 1970. Soil fertility problems in cereal growing in temperate zones. In: International Potash Institute (Eds.), Symposium role of fertilisation in the intensification of agricultural production. Proceedings of the 9th Congress of the International Potash Institute. Antibes. pp. 123-133

Daniels, T.C., Sharpley, A.N., and Lemunyon, J.L. 1998. Agricultural phosphorus and eutrophication a symposium overview. Journal of Environmental Quality. 27: 251-257

De Datta, S.K., Buresh, R.J., Samson, M.I., Obcemea, M.N., and Real, J.G. 1991. Direct measurement of ammonia and denitrification fluxes from urea applied to rice. Soil Science Society of America Journal. 55: 543-548

De Datta, S.K. 1981. Principles and practices of rice production. IRRI, Los Banos, Philippines. 618 p.

Demyttenaere, P. 1991. Stikstofdynamiek in de bodems van de westvlaamse groentestreek. Doctorate Thesis. 203p

Drechsel, Pay, Dagmar Kunze, and de Vries, F.P. 2001. Soil nutrient depletion and population growth in Sub-Saharan Africa: A Malthusian Nexus? Population and Environment: A Journal of Interdisciplinary Studies. 22 (4): 411-423

Douglas, Jr. C.L., King, K.A., and Zuzel, J.F. 1998. Nitrogen and phosphorus in surface runoff and sediment from a wheat-pea rotation in Northeastern Oregon. Journal of Environmental Quality. 27: 1170-1177

Duque Sr, C.M., Ilao, R.O., Tiongco, L.E., Quita, R.S., Carpina, N.V., Santos, B., and de Guzman, T. 2003. Management of soil erosion consortium: An innovative approach to sustainable land management in the Philippines. MSEC-Philippines Annual Report. In: Wani, S.P., Maglinoa, A.R, Ramakrisna, A., and Rego, T.J. (Eds.), Integrated catchment management for land and water conservation and sustainable agricultural production in Asia. CD-Rom (one CD).

El-Swaify, S.A. 1989. Monitoring of weather, runoff, and soil loss. *In* Soil management and smallholder development in the Pacific Islands. IBSRAM-Thailand proceedings. 8: 163-178

Eneji, A.E., Yamamoto, S., and Honna, T. 2001. Rice growth and uptake as affected by livestock manure in four Japanese soils. Journal of Plant Nutrient. 123: 333-343

Fan, X.H., Song, Y.S., Lin, D.X., Yang, L.Z., and Lou, J.F. 2006. Ammonia volatilisation losses and N-15 balance from urea applied to rice on a paddy soil. Journal of Environmental Science China. 18 (2): 299-303

Ferwerda, J.D. 1970. Soil fertility in the tropics as affected by land use. The International Potash Institute (Eds.), Proceedings of the 9th congress of the International Potash Institute. pp. 317-329

F F T C. 2000. Food and Fertiliser Technology Centre. Newsletter 129. 8 p.

Food and Agriculture Organisation. 1994. Food and Agricultural Organisation Statistics Series. FAO Yearbook. Vol 38. No 63.

Gajri, P.R., Gill, K.S., Rachhpal Singh, and Gill, B.S. 1999. Effect of pre-planting tillage on crop yields and weeds biomass in a rice-wheat system on a sandy loam soil in Punjab. Soil and Tillage Research. 52: 83-89

Ghildyal, B. P. 1971. Soil and water management for increased water and fertiliser use efficiency for rice production. In: Kanwar, J.S., Datta, N.P., Bains, S.S., Bhumbla, D.R., and Biswas, T.D. (Eds.), Proceedings of international symposium on soil fertility evaluation. 1: 499-509

Ghosh, B.C. and Bhat, R. 1998. Environmental hazards of nitrogen loading in wetland rice fields. Environmental pollution. 102: 123-126

Gill, H.S., and Meelu, O.P. 1982. Studies on the substitution of inorganic fertilisers with organic manure and their effect on soil fertility in rice wheat rotation. Fertiliser Research. 3: 303-313

Harris, F.M.A. 1998. Farm-level assessment of the nutrient balance in northern Nigeria. Agriculture, Ecosystems and Environment 71: 201-214

Harris, G.H., and Hesterman, O.B. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. Agronomy Journal. 82: 129-134

Hartfield, J.l., Jayness, D.D., Burkat, M.R., Cambardella, C.A., Moorman, T.B., Prueger, J.H., and Smith, M.A. 1999. Water quality in Walnut Creek Watershed: Setting and farm practices. Journal of Environmental Quality. 28: 11 – 24

Hasegawa, H., Furukawa, Y., and Kimura, S.D. 2005. On-farm assessment of organic amendments effects on nutrient status and nutrient use efficiency of organic rice fields in Northern Japan. Agriculture, Ecosystems and Environment. 108: 350-362

Hashim, G.M., Caughlan, K.J., and Syers, J.K. 1998. On-site nutrient depletion: An effect and a cause of soil erosion. In: Penning de Vries, F.W.T., Agus, F., and Kerr, J. (Eds.), Soil Erosion at Multiple Scale. Principles and Methods for Assessing Causes and Impacts. CABI Publishing in Association with IBSRAM. pp. 207-222

Hayashi, K., Nishimura, S., and Yagi, K. 2006. Ammonia volatilisation from the surface of a Japanese paddy field during rice cultivation. Soil Science and Plant Nutrition. 52: 545-555

International Rice Research Institute. 2005. World Rice Statistic. F:\WES2005\WRS2005-Table01.doc

IWMI (International Water Management Institute). 2004. Water facts. IWMI Brochure.

Jastrow, J.D., Miller, R.M., and Lussenhop, J. 1998. Contributions of interacting biological mechanisms to soil aggregate stabilisation in restored prairie. Soil Biology Biochemistry. 30: 905-916

Kaleeswari, R.K., and Subramanian, S. 2004. Impact of organic manure and inorganic phosphatic fertiliser on yield and nutrient uptake in a rice-rice cropping system. IRRN. 29 (2): 57 – 60

Kemmler, G. 1971. Response of high yielding paddy varieties to potassium: Experimental results from various rice growing countries. In: Kanwar, J.S., Datta, N.P., Bains, S.S., Bhumbla, D.R., and Biswas, T.D. (Eds.), Proceedings of international symposium on soil fertility evaluation. 1: 391-406

Kirchhof, G., Priyono, S., Utomo, W.H., Adisarwanto, T., Dacanay, E.V., and So, H.B. 2000. The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. Soil and Tillage Research. 56: 37-50

Kissel, D.E., Richardson, C.W., and Burnett, E. 1976. Losses of nitrogen in surface runoff in the Black Prairie of Texas. Journal of Environmental Quality 5: 288-293

Kukal, S.S., and Sidhu, A.S. 2004. Percolation losses of water in relation to pre-puddling tillage and puddling intensity in a puddle sandy loam rice (*Oryza sativa* L.) field. Soil and Tillage Research. 78: 1-8

Kukal, S.S., and Aggarwal, G.C. 2003. Puddling depth and intensity effects in rice-wheat system on a sandy loam soil. I. Development of subsurface compaction. Soil and Tillage Research. 72:1-8

Kumar, K., and Goh, K. M. 2000. Biological nitrogen fixation, accumulation of soil nitrogen, and nitrogen balance for white clover (*Trifolium repens* L.) and field pea (*Pisum sativum* L.) grown for seed. Field Crop Research. 68: 49-59

Laegrid, M., Bockman, O.C., and Kaarstad, O. 1999. Agriculture, fertilisers and the environment. CABI Publishing in Association with Norsk Hydro ASA. 294p.

Lal, R., Miller, F.P., and Logan, T.J. 1998. Are intensive agricultural practices environmentally and ethically sound? Journal of Agriculture Ethics. 1: 193-210

Landa, J. K., Pareek, R.P., Becker, M. 1992. Stem-nodulating legume-*Rhyzobium* symbiosis and its agronomic use in lowland rice. Advance Soil Science. 20

Lefroy, R.D.B., and Konboon, J. 1999. Studying nutrient flows to assess sustainability and identify areas of nutrient depletion and imbalance: an example for rainfed rice systems in Northeast Thailand. In: Ladha (Eds.), Rainfed Lowland Rice: Advances in Nutrient Management Research. IRRI, pp. 77-93

Mandal, Uttam K., Singh, G., Victor, U.S., and Sharma, K.L. 2003. Green Manuring: its effect on soil properties and crop growth under rice-wheat cropping system. European Journal of Agronomy. 19: 225-237

Manolov, I.G., Ikeda M., and Yamakawa, T. 2003. Effect of methods of nitrogen application on nitrogen recovery from N-15-labeled urea applied to paddy rice (*Oryza sativa* L.). Journal of the Faculty of Agriculture Kyushu University. 48: 1-11

Mikkelsen, D.S., Jayaweera, G.R., and Rolston, D.E. 1995. Nitrogen fertilisation practices of lowland rice culture. p: 171-223

Miller, R.J., and Smith, R.B. 1976. Nitrogen balance in the Southern San Joaquin Valley. Journal of Environmental Quality. 5 (3): 274-278

Mohammad, S. Z., Mohamad, M., Muhammad, A., and Maqsood, A. G. 1992. Integrated used of organic manure and inorganic fertilisers for cultivation of lowland rice in Pakistan. Soil Science and Plant Nutrition. 38: 331-338

Naphade, J. D., and Ghildyal, B.P. 1971. Influences of puddling and water regimes on soil characteristics, ion uptake and rice growth. In: Kanwar, J.S., Datta, N.P., Bains, S.S., Bhumbla, D.R., and Biswas, T.D. (Eds.), Proceedings of international symposium on soil fertility evaluation. 1: 510-517

National Information Agency. 2003. Indonesia 2003: An official handbook. National Information Agency, Republic of Indonesia. 180p

Ng Kee Kwong, K.F., Bholah, A., Volcy, L., and Pynee, K. 2002. Nitrogen and phosphorus transport by surface runoff from a silty clay loam soil under sugarcane in the humid tropical environment of Mauritius. Agriculture, Ecosystem and Environment. 91: 147-157

Nkonya, E., Kaizzi, C., and Pender, J. 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. Agricultural System. 85: 155-182

Phommassack, T., Chanthavongsa, A. Sihavong, C., Thonglatsamy, C., Valentine, C., de Rouw, A., Marchand, P., and Chaplot, V. 2003. An innovative approach to sustainable land management in Lao PDR. MSEC-Lao PDR Annual Report. In: Wani, S.P., Maglinoa, A.R, Ramakrisna, A., and Rego, T.J. (Eds.), Integrated catchment management for land and water conservation and sustainable agricultural production in Asia. CD-Rom (one CD).

Prakhas, Y.S., Bhadoria, P.B.S., and Rakshit, A. 2002. Relative efficacy of organic manure in improving milling and cooking quality of rice. IRRN. 27 (1): 43 - 44

Puget, P., and Drinkwater, L.E. 2001. Short-term dynamics of root- and shoot- derived carbon from a leguminous green manure. Soil Science Society of America Journal. 65: 771-779

Puserglove, J.W. 1968. Tropical Crops: Monocotyledons. Longman, London.

Rasmussen, P.E., and Parton, W.J. 1994. Long-term effects of residue management in wheat-fallow: I. Inputs, yields, and soil organic matter. Soil Science Society of America Journal. 58: 523-530

Ray, S.S., and Gupta, R.P. 2001. Effect of green manuring and tillage practices on physical properties of puddled loam soil under rice-wheat cropping system. Journal of Indian Society Soil Science. 49 (4): 670 - 678

Robichaud, P.R., Lillybridge, T.R., and Wagenbrenner, J.W. 2006. Effect of post fire seeding and fertilising on hill slope erosion in north-central Washington, USA. Catena. 67: 56 - 67

Sanchez, P.A. 1973. Puddling tropical rice soils: 1. Growth and nutritional aspects. Soil Science. 115: 303 – 308

Sanchez, P.A., and Calderon, M. de. 1971. Timing of nitrogen application for rice grown under intermittent flooding in the coast of Peru. In: Kanwar, J.S., Datta, N.P., Bains, S.S., Bhumbla, D.R., and Biswas, T.D. (Eds.), Proceedings of international symposium on soil fertility evaluation. 1: 595-602

Santoso, D., Wigena, I.G.P., Eusof, Z., and Chen, X.H. 1995. The ASIALAND management of sloping lands network: Nutrient balance study on sloping lands. *In*: International Workshop on Conservation Farming for Sloping Uplands in Southeast Asia: Challenges, Opportunities, and Prospects. IBSRAM-Thailand Proceedings. 14: 93-108

Schuman, G.E., and Burwell, R.E. 1974. Precipitation nitrogen contribution relative to surface runoff discharge. Journal of Environmental Quality. 4: 366-369

Senapati, H.K., Sahoo, S.S., Jena, B., and Sahoo, D. 2004. Impact of integrated plant nutrient management on upland rainfed rice cultivation. IRRN. 29 (2): 56 - 57

Sharma, P., Tripathi, R.P., and Singh, S. 2005. Tillage effects on soil physical properties and performance of rice-wheat-cropping under shallow water table conditions of Tarai, Northern India. European Journal of Agronomy. 23: 327-335

Sharma, P.K., and De Datta, S.K. 1986. Physical properties and processes of puddled rice soils. Advance Soil Science. 5: 139-178

Sharpley, A.N., Chapr, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C., and Reddy, K.R. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and Options. Journal of Environmental Quality. 23: 437-451

Sheldrick, W.F., Keith Syers, J., and Lingard, John. 2003. Soil nutrient audits for China to estimate nutrient balance and output/input relationships. Agriculture, Ecosystems and Environment. 94: 341-354

Singh, B., Niranjan, R.K., and Pathak, R.K. 2001. Effect of organic matter resources and inorganic fertilisers on yield and nutrient uptake in the rice-wheat cropping system. IRRN. 26 (2): 57 - 58

Singh, M., Singh, V.P., and Reddy, K. S. 2001. Effect of integrated use of fertiliser nitrogen and farmyard manure on transformation of N, K and S and productivity of rice-wheat system on a vertisol. Journal of Indian Society Soil Science. 49: 430-435

Siswanto, Agus Bambang. 2006. Profile description of wet land rice in Babon Catchment. Field trip report. 3 p.

Smaaling, E.M.A., Stoorvogel, J.J., and Wiindmeijer, P.N. 1993. Calculating soil nutrient balances in Africa at different scales II. District scale. Fertiliser Research. 35 (3): 237-250

So, H.B., and Ringrose-Voase, A.J. 2000. Management of clay soils for rainfed lowland rice-based cropping systems: an overview. Soil and Tillage Research. 56: 3-14

Soil Research Institute. 2004. Penuntun analisis air irigasi (*Procedure to measure irrigation water*). Soil Research Institute, Bogor. 9 p. (in Indonesian)

Sommerfeldt, T.G., Chang, C., and Entz, T. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Science Society of America Journal. 52: 1668-1672

Sojka, R.E., Carter, D.L., and Brown, M.J. 1992. Imhoff cone determination of sediment in irrigation runoff. Soil Science Society of America Journal. 56 (3): 884-890

Stoorvogel, J.J., Smaaling, E.M.A., and Janssen, B.H. 1993. Calculating soil nutrient balances in Africa at different scales. I. Supra-national scale. Fertiliser Research. 35 (3): 227-236

Stroosnijder, L. 2005. Measurement of erosion: Is it possible? Catena. 64: 162-173

Sudhakar, P.C., Singh, J.P., and Singh, K. 2004. Effect of silicon sources and fertility levels on transplanted rice. IRRN. 29 (2): 61-63

Sukristiyonubowo, Agus, F., Gabriels, D., and Verloo, M. 2004. Sediment and nutrient balances under traditional irrigation at terraced paddy field systems. Paper presented at the second International Symposium on Land Use Change and Soil and Water processes in Tropical Mountain Environments held in Luang Prabang, Lao PDR on 14-17 December 2004. Organised by Ministry of Agriculture and Forestry, Lao PDR and sponsored by National Agriculture and Forestry Research Institute (NAFRI), International Water Management Institute (IWMI) and Institut de Recherche pour le Développement (IRD)

Sukristiyonubowo, Watung, R.L., Vadari, T., and Agus, F. 2003. Nutrient loss and the on-site cost of soil erosion under different land use systems. In: Maglinao, A.R, Valentin, C., and Penning de Vries, F.W.T. (Eds.), From soil research to land and water management: Harmonising People and Nature. Proceedings of the IWMI-ADB Project Annual Meeting and 7th MSEC Assembly. pp. 151-164

Sukristiyonubowo, Vadari, T., Watung, R.L., Sidik, H.T., and Agus, F. 2002. Impact assessment of MSEC Project in Indonesia. Paper presented at the training workshop on Impact Assessment organised by IWMI, Bangkok, Thailand.

Syers, J.K. 1996. Nutrient budgets: uses and abuses. *In* Soil data for sustainable land uses: A training workshop for Asia. IBSRAM-Thailand Proceedings. 15: 163-168

Sys, C. 1989. Land evaluation and land use planning, with special reference to steep lands. *In* Soil management and smallholder development in the Pacific Islands. IBSRAM-Thailand Proceedings. 8: 77-95.

Taball, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B., and Sattar, M.A. 2002. On-farm strategies for reducing water input in irrigated rice; case study in the Philippines. Agricultural Water Management. 56: 93-112

Takahashi, E. 1995. Uptake mode and physiological function of silica. Science of Rice Plant. 2: 58-71

Tarigan, S.D., and Sinukaban, N. 2001. The role of paddy fields as sediment filter: Case study in Way Besai Watershed, Lampung. Prosiding Seminar Nasional Multifungsi Lahan Sawah. Bogor 1 May 2001: 29-37 (in Indonesian).

Thomsen, I.K. 1993. Nitrogen uptake in barley after spring incorporation of 15N labelled Italian ryegrass into sandy soils. Plant Soil. 150: 193-201

Tisdall, J.M., and Oades, J.M. 1979. Stabilisation of soil aggregates by the root systems of ryegrass. Austrian Journal of Soil Research. 29: 729-743

Toan, T.D., Phien, T., Phai, D.D., and Nguyen, L. 2003. Managing soil erosion for sustainable agriculture in Dong Cao Catchment. MSEC-Vietnam Annual Report. In: Wani, S.P., Maglinoa, A.R, Ramakrisna, A., and Rego, T.J. (Eds.), Integrated catchment management for land and water conservation and sustainable agricultural production in Asia. CD-Rom (one CD).

Udawatta, R.P., Motavalli, P.P., Garrett, H.E., and Krstansky, J.J. 2006. Nitrogen losses in runoff from three adjacent agricultural watersheds with clay pan soils. Agriculture Ecosystems and Environment. 117: 39 – 48

Uexkull, H.R. von. 1989. Nutrient cycling. *In* Soil Management and Smallholder Development in the Pacific Islands. IBSRAM-Thailand Proceedings. 8: 121-132

Uexkull, H.R. von. 1970. Role of fertiliser in the intensification of rice cultivation. In: The International Potash Institute (Eds.), Proceedings of the 9th congress of the International Potash Institute. pp. 391-402

Uexkull, H.R. von. 1970b. Some notes on the timing of potash fertilisation of rice (nitrogen-potash balance in rice nutrition). In: The International Potash Institute (Eds.), Proceedings of the 9th congress of the International Potash Institute. pp. 413 - 416

Van den Bosch, H., Joger, A. de, and Vlaming, J. 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool Development. Agriculture, Ecosystems and Environment. 71: 49-62

Van den Bosch, H., Gitari, J.N., Ogoro, V.N., Maobe, S., and Vlaming, J. 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture, Ecosystems and Environment. 71: 63-80

Varennes, A. de, Melo-Arbreu, J.P. de, and Ferreira, M.E. 2002. Predicting the concentration and uptake of nitrogen, phosphorus, and potassium by field-grown green beans under non-limiting conditions. European Journal of Agronomy. 17: 63-72

Verma, A.K., Pandey, N., and Tripathi, S. 2002. Effect of transplanting spacing and number of seedling on productive tillers, spikelet sterility, grain yield, and harvest index of hybrid rice. IRRN. 27 (1): 51

Vigiak, O., Okaba, B.O., Sterk, G., and Stroosnijder, L. 2005. Water erosion assessment using farmers' indicators in the West Usambawa Mountains, Tanzania. Catena. 64: 307-320

Visser, S.M., Stroosnijder, L., and Chardon, W.J. 2005. Nutrient losses by wind and water, measurements and modelling. Catena. 64: 1-22

Walters, D.T., Aulkh, M.S., and Doran, J.W. 1992. Effect of soil aeration, legume residue and soil texture on transformations of macro and micronutrients in soils. Soil Science. 153: 100-107

Wander, M.M., Traina, S.J., Stinner, B.R., and Peters, S.E. 1994. Organic and conventional management effects on biologically active organic matter pools. Soil Science Society of America Journal. 58: 1130-1139

Whitbread, Anthony M., Blair, Graeme J., and Lefroy, Rod D.B. 2000. Managing legume leys, residues and fertilisers to enhance the sustainability of wheat cropping system in Australia. 1. The effects on wheat yields and nutrient balance. Soil and Tillage Research. 54: 63 - 75

Wijnhoud, J.D., Konboon, Y., and Lefroy, R.D.B. 2003. Nutrient budgets: Sustainability assessment of rainfed lowland rice-based systems in northeast Thailand. Agriculture, Ecosystems and Environment. 100: 119-127

W M O (World Meteorological Organisation). 1994. Guide to hydrological practices. Data acquisition and processing, analysis, forecasting and other applications. Fifth ed. WMO-No.168. 735p.

Wortmann, C.S., and Kaizzi, C.K. 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. Agriculture, Ecosystems and Environment. 71: 115-129

Xing, G.X. and Zhu, Z.L. 2000. An assessment of N loss from agricultural fields to the environment in China. Nutrient Cycling in Agroecosystems. 57: 67-73

Xu, Y., Zhang, F., Ho, X., Wang J., Wang R., and Kong, X. 2006. Influence of management practices on soil organic matter changes in the northern China plain and northeast China. Soil and Tillage Research. 86: 230-236

Yang, Changming, Yang, Linzhang, Yang, Yongxing, and Ouyang, Zhu. 2004. Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. Agricultural Water Management. 70: 67-81

Yoshida, S. 1981. Fundamentals of rice crop science. IRRI, Los Banos, Philippines. 269p.

Zhang, Mingkui and Zhenli, He. 2004. Long-term changes in organic carbon and nutrients of an Ultisol under rice cropping in southeast China. Geoderma. 118: 167-179

SUMMARY

In Indonesia, rice is not only a staple food, but also a source of income, providing jobs for the villagers. Increasing rice production to improve farmer's income, to meet growing rice demand and to support food security programmes is one of the priorities in agricultural development. On the other hand, land demands for non-agricultural purposes, such as housing, industry, road facilities and other infrastructural developments are increasing in the lowland rice areas, resulting in shrinking total surfaces for cultivating rice. Hence, intensifying other wetland rice systems, such as terraced paddy fields, is very important. Increasing prices of agricultural inputs, lack of capital to purchase fertilisers and reducing standards of living caused imbalanced fertilising in many rice growing areas. Consequently, improving rice production in these systems is also confronted with socio-economic and biophysical problems. Terraced paddy field systems at Keji Village located in the Semarang District was selected to conduct research during the wet season 2003-04 and the dry season 2004. Field experiments and a secondary data analysis were set up to achieve the objectives mentioned for every chapter.

In Chapter 2, sediment and nutrient movement behaviour was studied in a terraced paddy field system under traditional irrigation. The aims were to evaluate inflowing and outgoing sediments and nutrients and to study sediment and nutrient mobility at harrowing and fertilising. At harrowing, the amounts of outgoing sediment were higher than incoming, both in the wet season 2003-04 and dry season 2004. However, a week before and after fertilising both in the wet season 2003-04 and dry 2004 the incoming sediment amounts were higher than the outgoing. In the wet season 2003-04 incoming sediment amounts were even three to four times higher than outgoing. Contrary to sediment movement at harrowing, the amounts of incoming soluble nutrients were higher than the outgoing, except for P in the wet season 2003-04. However, at fertilising incoming nutrient amounts were higher than the outgoing both during the wet season 2003-04 and dry season 2004. This was similar to the sediment behaviour. A net input of N and K was observed at harrowing during the wet season 2003-04 and dry season 2004. This also occurred at fertilising, but gained amounts of N, P, and K were greater than at harrowing. Every terrace presented a different behaviour in transporting and trapping sediments and nutrients. In terraces having greater surface areas, more total sediment and nutrients were deposited than terraces with smaller sizes. These results demonstrate that terraced paddy field systems are not only useful to produce rice, but also provide

environmental services like trapping sediment and conserving nutrients, which otherwise may have negative impacts downstream.

Nutrient concentrations and uptakes during rice growth and development in terraced paddy field systems were studied in Chapter 3. The aims were to study nutrient uptake during rice growth under different treatments and to evaluate the seasonal nutrient uptake variations during the wet and dry season. Four treatments were applied, namely 1) Conventional Farmer Practices, 2) Conventional Farmer Practices + Rice Straw, 3) Improved Technology, and 4) Improved Technology + Rice Straw. Each treatment was replicated three times. In the conventional farmer practices treatments, only 50 kg of urea ha^{-1} $season^{-1}$ was applied. In the improved technology treatments, about 100 kg of urea, 100 kg of Triple Super Phosphate (TSP), and 100 kg of Potassium Chloride (KCl) ha^{-1} $season^{-1}$ were applied. About 33 % of rice straw produced in the previous season was recycled in the treatments of conventional farmer practices + rice straw and improved technology + rice straw. Plants were sampled five times, at 45, 60, 75, 90 and 105 days after transplanting. Both in the wet season 2003-04 and dry season 2004 concentrations of N, P, and K in shoots and roots decreased during rice growth. The highest nutrient concentrations were observed 45 days after transplanting. The nutrient concentrations both in shoots and roots were higher in the dry season than in the wet season, but statistical evidences were not consistent. Contrary to the concentrations, the N, P, and K uptakes increased during the rice growth. The highest N, P, and K concentrations and uptakes in shoots and roots always occur in Improved Technology + Rice Straw treatments.

The effect of rice straw and fertilisers addition on rice productions in terraced paddy fields were studied in Chapter 4. Four treatments, as in the previous chapter, were applied and replicated three times. The objectives were (1) to compare the effects of improved technologies and conventional farmer practices on biomass production, (2) to assess the effect of 33 % rice straw recycling on rice yield, and (3) to evaluate seasonal variations of biomass production and grain yield parameters. The Improved Technology + Rice Straw treatments were found to be significantly superior over other treatments, both in the wet season 2003-04 and dry season 2004. Significant increases of rice grain yields both in the wet and dry seasons were related to significant improvements of 1000-grains weight, the number of grains $panicle^{-1}$, number of filled grains $panicle^{-1}$, and length of panicles. In general, there were no significant differences among treatments for the plant height. Seasonal variations were observed for rice grains and rice straw yields when rice straw was recycled, as well as variation for the 1000-grains weight, the number of grains panicle^{-1}, the number of filled grains and shoot weights.

Nutrient balances of N, P, and K for rice farming in terraced paddy fields under traditional irrigation were evaluated in Chapter 5. Assessment was carried out for Conventional Farmer Practices, Conventional Farmer Practices + Rice Straw, Improved Technology, and Improved Technology + Rice Straw treatments. The objectives were (1) to study nutrient balances under conventional farmer practices and improved technologies and (2) to evaluate the effect of recycled rice straw on the nutrient balances. Balances were computed based on the differences between input and output. Nutrients originating from fertiliser (IN-1), recycling of 33 % rice straw (IN-2), irrigation (IN-3), and precipitation (IN-4) were grouped as input. Nutrient removal by rice grains (OUT-1) and rice straw (OUT-2) was considered as output. Negative N and K balances, and thus a net outflow, were observed in all the treatments, both in the wet and dry season. Positive P balances were found in the Improved Technologies treatments, proving the dominant contribution of P-fertilisers to input. The N balance would be even more negative, if NH_3 losses through volatilisation are taken into account, whereas the N and K output would also be higher, when rice residues would also be removed from the fields at harvest. For attaining sustainable rice farming in terraced paddy fields, application rates of 200 – 250 kg of urea, 100 kg of TSP, and 200 kg of KCl ha^{-1} season^{-1} along with recycling of rice straw of at least 33% of the production are recommended.

In Chapter 6, nutrient (N, P, and K) balances of wetland rice farming systems for the whole Semarang District were evaluated using data from 1978 to 2003. The objectives were (1) to study the effect of coincidental events on rice production data between 1978 and 2003 and (2) to evaluate nutrient balances of wetland rice farming systems using inorganic and organic fertilisers on a district level. Data were grouped according to the Five-Year Development Plan (PELITA) executed in Indonesia. In every period of five year development plan, rice yield, producing area, and total rice production in the Semarang District have increased compared to 1978. The highest average rice yield was reached in the PELITA V and in the Economic crisis era, indicating that wetland rice farming was not directly affected by the crises. From the economic crisis to the economic recovery, the yield levelled of at 5.10 t ha^{-1} because of improper rice straw management and imbalanced fertilising. In general, N, P, and K balances for the control fertiliser application rates are more negative than for the recommended fertiliser application rates. When application of rice straw was taken into account and a

minimal of rice yield of 5.10 t ha^{-1} is targeted, only P balances were positive for all recommended P fertiliser application rates, while positive N balances were observed for the high level of recommended N fertiliser application rate. Moreover, when the rice straw was not considered, only P balances were consistently positive for all recommended fertiliser application rates, demonstrating the dominant contribution of P fertiliser. To reach grain yields higher than 5 t ha^{-1}, and when 33% of rice straw is recycled, about 225 kg of urea, 100 kg of TSP, and 200 kg of KCl ha^{-1} $season^{-1}$ should be applied to replace the removed N, P, and K. However, an even higher fertiliser application rate of 250 kg urea and 300 kg KCl ha^{-1} $season^{-1}$ should be applied to replenish N and K deficits when no rice straw is recycled. From agronomical and economical points of view, recycling rice straw may result in a saving of 1 580 t of urea and 3 162 t of KCl $district^{-1}$ yr^{-1}. This represents an amount of 1.11 million euros, taking into account the price of urea is 0.20 euro kg^{-1} and the price of KCl is 0.25 euro kg^{-1}.

SAMENVATTING

In Indonesië is rijst niet enkel een belangrijke voedingsbron, maar ook een inkomensbron, welke werkgelegenheid voor dorpsbewoners creëert. Een toename van de rijstproductie om het inkomen van de landbouwers te verbeteren, te voldoen aan de groeiende vraag en de voedselveiligheid te garanderen is één van de prioriteiten van de landbouwontwikkeling. Anderzijds is er een toenemende vraag naar landgebruik voor niet-agrarische doeleinden, zoals huisvesting, industrie, wegenbouw en overige infrastructuurwerken in de laaggelegen rijstvlaktes, wat resulteert in een afname van de oppervlakte beschikbaar voor rijstproductie. Als dusdanig is het belangrijk andere wetland rijstproductiesystemen, zoals in terrassen aangelegde rijstvelden, te intensiveren. Toename van de prijs van landbouw-inputs, een tekort aan kapitaal om meststoffen aan te kopen en een afnemende levensstandaard heeft in vele gebieden geleid tot een ongebalanceerde bemesting. Bijgevolg wordt de rijstproductie in dergelijke systemen tevens geconfronteerd met socio-economische en biofysische problemen. In terrassen aangelegde rijstvelden in het dorp Keji, gesitueerd in het Semarang district, werden geselecteerd om onderzoek uit te voeren tijdens het natte seizoen 2003-2004 en het droge seizoen 2004. Veldexperimenten en secundaire data-analyse werden opgezet om de objectieven te halen die hierna geformuleerd worden bij de besprekingen van de hoofdstukken.

In het tweede hoofdstuk werd de mobiliteit van sedimenten en nutriënten bestudeerd in rijstveldsystemen onder traditionele irrigatie, die in terrassen werden aangelegd. De doelstellingen waren het evalueren van in- en uitstromende sediment- en nutriënthoeveelheden en het inschatten van de mobiliteit van sedimenten en nutriënten tijdens het eggen en bemesten. Tijdens het eggen waren de instromende sedimenthoeveelheden hoger dan de uitstromende, zowel in het natte seizoen 2003-2004 als in het droge seizoen 2004. Een week voor en na de bemesting waren de instromende hoeveelheden echter hoger dan de uitstromende, tevens in beide seizoenen. In het natte seizoen 2003-2004 waren instromende sedimenthoeveelheden zelfs 3 tot 4 keer hoger dan uitstromende. In tegenstelling tot de sedimentverplaatsing tijdens het eggen, was de hoeveelheid instromende opgeloste nutriënten hoger dan de hoeveelheid uitstromende, met uitzondering van P in het natte seizoen 2003-2004. Tijdens het eggen waren instromende nutriënthoeveelheden echter hoger dan uitstromende, zowel in het natte seizoen 2003-2004 als in het droge seizoen 2004, wat overeenstemde met het gedrag van de sedimenten. Een netto instroom van N en K werd waargenomen bij het eggen, zowel tijdens het natte seizoen 2003-2004 als het droge seizoen 2004. Dit werd tevens waargenomen bij de bemesting, maar de instromende hoeveelheden van N, P en K waren groter tijdens het eggen. Elk terras vertoonde een verschillend gedrag met betrekking tot het transporteren en opvangen van sedimenten en nutriënten. Op terrassen met grotere oppervlaktes, werden meer sedimenten en nutriënten afgezet dan op terrassen met kleinere afmetingen. Deze resultaten tonen aan dat in terrassen aangelegde rijstveldsystemen niet enkel nuttig zijn voor de productie van rijst, maar dat ze ook het milieu een dienst verlenen door het wegvangen van sedimenten en nutriënten, welke anders stroomafwaarts een negatieve impact zouden kunnen hebben.

De concentraties en opname van nutriënten tijdens de groei en ontwikkeling van rijst in rijstvelden die in terrassen aangelegd zijn, werden bestudeerd in hoofdstuk 3. De doelstellingen waren het bestuderen van de nutriëntopname tijdens rijstgroei onder verschillende behandelingen en het evalueren van seizoensgebonden variaties in nutriëntopname in een nat en een droog seizoen. Vier behandelingen werden toegepast, met name: 1) Conventionele Landbouwpraktijken, 2) Conventionele Landbouwpraktijken + Rijststrohergebruik, 3) Verbeterde Technologie, 4) Verbeterde Technologie + Rijststrohergebruik. Elke behandeling werd 3 keer herhaald. Bij de "Conventionele Landbouwpraktijken" werd enkel een bemesting van 50 kg ureum per hectare per seizoen toegepast. In de "Verbeterde Technologie" behandelingen werd ongeveer 100 kg ureum, 100 kg tripel superfosfaat en 100 kg kaliumchloride (KCl) per hectare per seizoen toegediend. Ongeveer 33 % van het rijststro geproduceerd in het voorgaande groeiseizoen werd als meststof hergebruikt in de behandelingen met "Rijststrohergebruik". De rijstplanten werden 5 keer bemonsterd, 45, 60, 75, 90 en 105 dagen na het overplanten. Zowel in het natte seizoen 2003-2004 als in het droge seizoen 2004 namen de concentraties van N, P, en K in scheuten en wortels af tijdens de rijstgroei. De hoogste nutriëntconcentraties werden waargenomen 45 dagen na overplanten. Zowel in de scheuten als in de wortels leken de nutriëntconcentraties hoger te zijn in het droge seizoen dan in het natte seizoen, maar dit kon niet eenduidig statistisch bewezen worden. In tegenstelling tot de concentraties, namen de opnames van N, P en K toe tijdens de rijstgroei. De hoogste concentraties en opname van N, P en K in scheuten en wortels werden steeds waargenomen in de behandeling waarin de "Verbeterde Technologie" gecombineerd werd met rijststrohergebruik.

Het effect van de toediening van rijststro op de rijstproductie in rijstvelden die in terrassen werden aangelegd, werd bestudeerd in hoofdstuk 4. Dezelfde 4 behandelingen als in het voorgaande hoofdstuk werden toegepast en 3 keer herhaald. De doelstellingen waren: 1) het vergelijken van de effecten van verbeterde technologieën en conventionele landbouwpraktijken op de biomassaproductie, 2) het inschatten van het effect van het hergebruik van rijstro op de rijstopbrengst, 3) het evalueren van seizoensgebonden variaties van de biomassaproductie en rijstopbrengst. De behandeling waarin "Verbeterde Technologie" gecombineerd werd met het hergebruik van rijststro bleek significant beter te presteren dan de overige behandelingen, zowel in het natte seizoen 2003-2004 als in het droge seizoen 2004. Significante toenames van rijstopbrengst konden toegeschreven worden aan de significante toename van het duizendkorrelgewicht, het aantal korrels per pluim, het aantal gevulde korrels per pluim en de lengte van de pluimen. Algemeen werden voor de lengte van de planten geen significante verschillen waargenomen tussen de behandelingen. Seizoensgebonden variaties werden waargenomen voor rijstkorrels and opbrengst van de rijststroproductie wanneer rijststro werd hergebruikt, en voor het duizendkorrelgewicht, het aantal korrels per pluim, het aantal gevulde korrels en het gewicht van de scheuten.

Nutriëntenbalansen van N, P en K in rijstvelden onder traditionele irrigatie, die in terrassen werden aangelegd, werden geëvalueerd in hoofdstuk 5. Dezelfde behandelingen als in de 2 voorgaande hoofdstukken werden vergeleken. De doelstellingen waren: 1) het bestuderen van nutriëntenbalansen onder conventionele landbouwpraktijken en verbeterde technologieën en 2) het evalueren van het effect van het hergebruik van rijststro op de nutriëntenbalansen. De balansen werden berekend op basis van de verschillen tussen instroom en uitstroom. Nutriënten afkomstig van meststoffen (IN-1), het hergebruik van rijststro (IN-2), irrigatie (IN-3), en neerslag (IN-4) werden gegroepeerd als instroom. Nutriëntverwijdering door rijstkorrels (OUT-1) en rijststro (OUT-2) bij oogst werden gegroepeerd als uitstroom. Negatieve N en K balansen – en dus een netto uitstroom - werden geobserveerd voor alle behandelingen, zowel in het natte als in het droge seizoen. Positieve P-balansen werden waargenomen in de "Verbeterde Technologie" behandeling, wat een dominante bijdrage van P-meststoffen tot de input suggereert. De N-balans zou zelfs nog negatiever zijn wanneer verliezen van NH_3 door vervluchtiging tevens in rekening gebracht zouden worden, terwijl de uitstromen van N en K nog groter zouden zijn wanneer ook de rijstresidu's van het veld verwijderd zouden worden bij de oogst. Om te komen tot een duurzame rijstproductie in rijstvelden die in terrassen aangelegd zijn, worden bemestingsdosissen van 200-250 kg ureum, 100 kg tripel superfosfaat en 200 kg KCl per hectare per seizoen aanbevolen, dit in combinatie met het hergebruik van rijststro (33 % van de productie).

In hoofdstuk 6 werden nutriëntenbalansen (N, P, K) geëvalueerd voor de wetland rijstproductiesystemen van het gehele Semarang district, gebruik makend van analysegegevens verzameld tussen 1978 tot 2003. De objectieven waren: 1) het bestuderen van de invloed van occasionele gebeurtenissen op de rijstproductie tussen 1978 en 2003 en 2) het evalueren van de nutriëntenbalansen van wetland rijstproductiesystemen gebruik makend van anorganische en organische meststoffen op districtniveau. De data werden gegroepeerd in overeenstemming met de 5-jaarlijkse Indonesische ontwikkelingsplannen (PELITA). Tijdens elk 5-jaarlijks ontwikkelingsplan, bleken de rijstopbrengst, de oppervlakte gebruikt voor rijstproductie en de totale rijstproductie toegenomen te zijn in vergelijking met 1978. De hoogste gemiddelde rijstopbrengst werd bereikt in de PELITA V periode en tijdens de economische crisis, wat aantoont dat de rijstproductie in wetlands niet beïnvloed wordt door economische crisissen. Algemeen waren de N-, P- en K-balansen nog meer negatief voor de controle bemestingsdosis dan voor de aanbevolen dosissen. Wanneer het hergebruik van rijststro in rekening gebracht wordt en er gestreefd wordt naar een minimale rijstopbrengst van 5.10 ton ha^{-1}, zijn alleen de P-balansen positief voor alle aanbevolen P-bemestingsdosissen, terwijl positieve N-balansen enkel waargenomen werden voor de hoogste aanbevolen N-bemestingsdosissen. Als bovendien het hergebruik van rijststro niet in rekening gebracht wordt, blijven enkel de P-balansen positief, wat weerom de dominante bijdrage van P-bemesting illustreert. Om korrelopbrengsten hoger dan 5 ton per hectare te behalen, moet een bemesting van ongeveer 225 kg ureum, 100 kg tripel superfosfaat, en 200 kg KCl ha seizoen toegepast worden om de verwijderde N, P en K te vervangen, in de veronderstelling dat 33 % van het rijststro hergebruikt wordt. Er moet echter een nog hogere bemesting van ongeveer 280 kg ureum en 300 kg KCl per hectare per seizoen toegepast worden om de N- en K-tekorten aan te vullen ingeval geen rijststro hergebruikt wordt. Vanuit een agronomisch en economisch perspectief, kan het hergebruik van rijststro resulteren in een besparing van 1580 ton ureum en 3162 ton KCl per district per jaar. Dit stemt overeen met investering van 1.11 miljoen euro, rekening houdend met een prijs van 0.20 euro per kg voor ureum en 0.25 euro per kg voor KCl.

APPENDICES

APPENDICES

Appendix 3. 1. Profile no: AB02/CSAR/03-06

Classification*:* Aquandic Epiaquepts, medial, isohyperthermic.

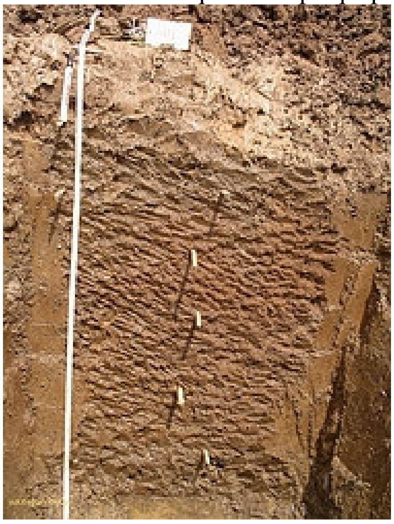
Location: Dusun Suruhan, Desa. Keji, Kecamatan Ungaran, Semarang District, Central-Java. Profile is situated in a sawah of Pak Jono represented IT treatment; approx. Longitude 431.404 m, latitude 9.212.806 m (UTM zone M49), and altitude 435 m above sea level. ***Geomorphic surface:*** Lower slope of Ungaran volcano with tuffaceous ash and lapili layers underlain by dacitic materials deposited on basaltic lava. ***Parent material:*** Mature andesite-dacitic tuff. ***Topography:*** Rolling (8-15%) with surrounding landscape is hilly. ***Drainage:*** Imperfect drained. ***Permeability:*** Slightly slow. ***Land Use:*** Terraced paddy field with traditional irrigation systems. ***Described by:*** Agus B Siswanto, Marc 17, 2006. ***Remarks:*** soil was moist when described.

Horizons		**Depth**	**Descriptions**
No	**Symbol**	(cm)	
1	Ap	0 - 13	Dark brown (7,5YR 4/4) and dark yellowish brown (10YR 4/6) silty clay; common fine distinct red (2,5YR 4/8) mottles; weak, fine and medium, sub angular blocky structure; friable, slightly sticky and slightly plastic; many very fine and fine roots; many fine and medium pores, slightly acid; clear smooth boundary.
2	Bg1	13 - 38	13 to 38 cm; dark brown (7,5YR 4/4) silty clay; yellowish red (5YR 4/6) clods, dark grey (10YR 4/1) coating on faces of peds; weak, medium and moderate fine, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic; common very dark grey (5YR 3/1) manganese concretions; common fine roots; many fine and common medium pores; slightly acid; gradual smooth boundary.
3	Bg2	38 - 54/70	Brown (7,5YR 4/2) and light brown (7,5YR 6/4) silty clay; dark grey (10YR 4/1) coating on faces of peds, common fine distinct red (2,5YR 4/6) mottles; weak, medium, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic, slightly thixotropic; common very dark grey (5YR 3/1) manganese concretions; few fine roots; common fine and few medium; slightly acid; abrupt irregular boundary.
4	2BC	54/70 - 90	Strong brown (7,5YR 4/6) and light brown (7,5YR 6/4) silty clay loam; weak, medium, sub angular blocky structure; firm, slightly sticky and slightly plastic, thixotropic; many fine and medium pores; slightly acid; gradual smooth boundary.
5	2BC	90 - 120	Strong brown (7,5YR 5/6) and pink (7,5YR 7/4) silty clay loam; weak, medium to coarse, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; many fine and common medium pores; slightly acid.

Note: Epipedon: ochric; sub horizon: cambic; other properties: aquic soil conditions

Appendix 3. 2. Profile no: AB01/CSAR/03-06

Classification: Aquandic Epiaquepts, medial, isohyperthermic.



Location: Dusun Suruhan, Desa Keji, Kecamatan Ungaran, Semarang District, Central-Java. Profile is situated in a sawah of Pak Ngainin represented CFP+RS treatment; approx. longitude 431.439 m, latitude 9.212.742 m (UTM zone M49), and altitude 451 m above sea level. ***Geomorphic surface:*** Lower slope of Ungaran volcano with tuffaceous ash and lapili layers underlain by dacitic materials deposited on basaltic lava. ***Parent material:*** Mature andesite-dacitic tuff. ***Topography:*** Rolling (8-15%) with surrounding landscape is hilly. ***Drainage:*** Imperfect drained. ***Permeability:*** Slightly slow. ***Land Use:*** Terraced paddy field with traditional irrigated systems. ***Described by:*** Agus B Siswanto, Marc 17, 2006. ***Remarks:*** soil was wet when described.

Horizons No	**Horizons** Symbol	**Depth** (cm)	**Descriptions**
1	Ap1	0 - 13	Olive grey (5Y 4/2) and dark grey (5Y 4/1) silty clay; few fine faint red (2,5YR 4/8) mottles; moody; massive, slightly sticky and slightly plastic; many very fine and fine roots; acid; abrupt smooth boundary.
2	Ap2	17 - 27/32	Dark grey (5Y 4/1) clay; common fine faint strong brown (7,5YR 5/6) mottles; weak, medium, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic; few fine roots; common fine, few medium and coarse pores; acid; clear wavy boundary.
3	Bg1	27/32 - 43	Dark yellowish brown (10YR 4/4) clay; greyish brown (10YR 5/2) coating on faces of peds, common fine distinct strong brown (7,5YR 5/6) mottles; moderate, medium, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic; many fine, common medium, and few coarse pores; acid; gradual smooth boundary.
4	Bg2	43 - 58	Dark brown (7,5YR 4/4) silty clay loam; greyish brown (10YR 5/2) coating on faces of peds, many fine distinct red (2,5YR 4/6) mottles; moderate, medium, sub angular blocky structure; firm, slightly sticky and slightly plastic, thixotropic; many fine and medium pores; slightly acid; gradual smooth boundary.
5	Bg3	58 - 77	Dark brown (7,5YR 4/4) silty clay loam, greyish brown (10YR 5/2) coating on faces of peds, common fine faint yellowish red (5YR 4/6) mottles; moderate, fine and medium, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; common very dark grey (5YR 3/1) manganese concretions; many fine and medium, few coarse pores; slightly acid; clear smooth boundary.
6	Bg4	77 - 96	Brown (7,5YR 4/2) silty clay; common fine faint yellowish red (5YR 4/6) and many fine distinct red (2,5YR 4/6) moderate; medium and coarse, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; common fine and medium pores; slightly acid; abrupt smooth boundary.
7	2Bg5	96 - 108	Dark brown (10YR 4/3) clay; this horizon is sometimes broken with pockets of very dark grey (10YR 3/1) coated sandy scoria material (II layer), dark greyish brown (10YR 4/2) coating on faces of peds; common fine faint yellowish red (5YR 4/6) mottles; weak, medium to coarse, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; common fine and few medium pores; slightly acid; clear smooth boundary.
8	2BC2	108 - 126	Dark brown (7,5YR 4/4) and dark yellowish brown (10YR 4/6) silty clay loam; few fine distinct red (2,5YR 4/6) mottles; massive breaking to weak, medium to coarse, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; common fine and few medium pores; slightly acid.

Note: Epipedon: ochric; sub horizon: cambic; other properties: andic soil properties (?), aquic soil conditions

Appendix 3. 3. Profile no*:* AB03/CSAR/03-06

Classification: Aquandic Epiaquepts, medial, isohyperthermic

Location: Dusun Suruhan, Desa. Keji, Kecamatan Ungaran, Semarang District, Central-Java. Profile is situated in a sawah of Pak Mardi represented CFP treatment; approx. longitude 431.593 m, latitude 9.212.864 m (UTM zone M49), and altitude 421 m above sea level. ***Geomorphic surface:*** Lower slope of Ungaran volcano with tuffaceous ash and lapili layers underlain by dacitic materials deposited on basaltic lava. ***Parent material:*** Mature andesite-dactic tuff. ***Topography:*** Rolling (8-15%) with surrounding landscape is hilly. ***Drainage:*** Imperfect drained. ***Permeability:*** Slightly slow. ***Land Use:*** Terraced paddy field with traditional irrigation systems. ***Described by:*** Agus B Siswanto, Marc 17, 2006. ***Remarks:*** soil was moist when described

Horizons		**Depth**	**Descriptions**
No	**Symbol**	(cm)	
1	Ap	0 - 17	Dark yellowish brown (10YR 3/4) silty clay; weak, fine and medium, sub angular blocky structure; friable, slightly sticky and slightly plastic; many very fine and fine roots; many fine and medium pores, slightly acid; clear smooth boundary.
2	Bg1	17 - 30/38	Dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/4) silty clay; dark grey (10YR 4/1) coating on faces of peds; common fine distinct yellowish red (5YR 4/6) and dark reddish brown (2,5YR 3/4) mottles; moderate, fine and medium, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic; few very dark grey (2,5YR 3/0) manganese concretions; few fine roots; many fine and medium, few coarse pores; slightly acid; clear wavy boundary.
3	Bg2	30/38 - 60	Dark yellowish brown (10YR 4/4) and dark brown (7,5YR 4/4) silty clay; dark grey (10YR 4/1) coating on faces of peds, few fine faint reddish brown (5YR 4/4) and common fine distinct red (2,5YR 4/6) mottles; moderate, medium, sub angular blocky structure; friable to firm, slightly sticky and slightly plastic; common very dark grey (2,5YR 3/0) manganese concretions; few fine roots; many fine, common medium, and few coarse pores; slightly acid; clear smooth boundary.
4	Bg3	60 - 72	Dark brown (7,5YR 4/4) and reddish brown (5YR 4/4) silty clay; dark grey (5YR 4/1) coating on faces of peds; moderate, fine medium, sub angular blocky structure; firm, slightly sticky and slightly plastic; few very dark grey (2,5YR 3/0) manganese concretions; many fine and medium, few coarse pores; slightly acid; gradual smooth boundary.
5	Bg4	72 - 85/90	Dark yellowish brown (10YR 3/4) and brown (5YR 4/3) silty clay; few fine distinct red (2,5YR 4/6) mottles; weak, medium, sub angular blocky structure; firm, slightly sticky and plastic, thixotropic; few very dark grey (7,5YR 3/0) manganese concretions; common fine and medium, few coarse pores; slightly acid; clear wavy boundary
6	2BC2	85/90-108	Yellowish red (5YR 4/6) and red (2,5YR 4/6) clay; few fine faint dark red (10R 3/6) and brown (5YR 4/3) mottles; weak, medium, sub angular blocky structure; firm, slightly sticky and slightly plastic, thixotropic; common fine and medium pores, slightly acid.

Note: Epipedon: ochric; sub horizon: cambic; other properties: aquic soil conditions.

Appendix 3. 4. Concentration of exchangeable cation and exchangeable calcium, magnesium and potassium percentages (mean ± standard deviation)

Treatment	Terrace	Exchangeable cation (cmol+ kg^{-1})				Exchangeable percentage (%)		
		Ca	Mg	K	Na	Ca	Mg	K
IT + RS	T1	5.02± 0.47	1.95± 0.03	0.33± 0.09	0.16± 0.04	34.89 ± 2.04	13.57 ± 0.51	2.31 ± 0.56
	T2	4.95± 0.20	2.04± 0.19	0.30± 0.07	0.19± 0.02	34.48 ± 0.82	14.18 ± 1.10	2.09 ± 0.46
	T3	5.17± 0.24	1.94± 0.18	0.25± 0.06	0.16± 0.02	36.03 ± 1.63	13.53 ± 0.78	1.78 ± 0.52
	T4	5.03± 0.98	2.03± 0.31	0.25± 0.06	0.16± 0.03	36.14 ± 1.45	14.53 ± 1.95	1.82 ± 0.47
	T5	4.61± 0.72	1.84± 0.09	0.32± 0.12	0.09± 0.01	33.83 ± 1.88	13.72 ± 2.09	2.36 ± 0.81
	T6	4.61± 0.23	1.88± 0.12	0.23± 0.04	0.17± 0.03	33.94 ± 1.64	13.86 ± 1.00	1.67 ± 0.31
	T7	5.24± 0.18	1.99± 0.01	0.20± 0.05	0.10± 0.01	35.92 ± 1.15	13.63 ± 0.08	1.35 ± 0.35
	T8	5.30± 0.15	2.03± 0.03	0.20± 0.00	0.10± 0.00	36.33 ± 0.31	13.89 ± 0.21	1.37 ± 0.03
I T	T1	6.26± 0.68	2.41± 0.40	0.17± 0.03	0.08± 0.00	43.14 ± 4.02	16.61 ± 2.47	1.14 ± 0.20
	T2	6.05± 0.10	2.23± 0.03	0.23± 0.05	0.12± 0.01	41.70 ± 0.66	15.36 ± 0.16	1.56 ± 0.32
	T3	6.57± 0.65	2.77± 0.11	0.33± 0.08	0.04± 0.02	43.20 ± 2.66	18.27 ± 0.20	2.16 ± 0.43
	T4	6.57± 0.62	2.75± 0.11	0.30± 0.05	0.06± 0.04	43.18 ± 2.46	18.11 ± 0.54	1.95 ± 0.23
	T5	6.85± 0.10	2.58± 0.09	0.20± 0.04	0.11± 0.04	41.88 ± 0.64	15.79 ± 0.39	1.24 ± 0.25
	T6	6.45± 0.12	2.78± 0.35	0.25± 0.01	0.11± 0.01	39.36 ± 0.21	16.98 ± 0.02	1.52 ± 0.09
	T7	6.54± 0.32	2.78± 0.40	0.29± 0.66	0.11± 0.01	39.90 ± 1.64	16.99 ± 0.22	1.77 ± 0.37
	T8	6.65± 0.18	2.82± 0.03	0.29± 0.06	0.11± 0.01	40.21 ± 0.78	17.04 ± 0.19	1.75 ± 0.36
CFP + RS	T1	4.40± 0.13	1.94± 0.02	0.33± 0.09	0.16± 0.04	25.10 ± 0.84	11.05 ± 0.14	1.90 ± 0.53
	T2	4.50± 0.15	1.95± 0.05	0.26± 0.02	0.19± 0.03	25.66 ± 0.65	11.14 ± 0.20	1.46 ± 0.13
	T3	4.55± 0.20	1.89± 0.09	0.22± 0.05	0.15± 0.01	26.08 ± 0.75	10.85 ± 0. 64	1.26 ± 0.30
	T4	4.63± 0.08	1.90± 0.09	0.19± 0.01	0.16± 0.03	26.55 ± 0.28	10.87 ± 0.57	1.07 ± 0.06
	T5	6.42± 0.08	2.03± 0.10	0.20± 0.05	0.10± 0.00	38.50 ± 1.08	12.17 ± 0.39	1.22 ± 0.33
	T6	6.12± 0.21	2.12± 0.03	0.21± 0.04	0.16± 0.02	36.67 ± 0.93	12.73 ± 1.26	1.26 ± 0.23
	T7	6.46± 0.18	2.07± 0.07	0.20± 0.05	0.12± 0.06	37.71 ± 0.91	12.06 ± 0.29	1.15 ± 0.29
	T8	4.95± 0.09	1.84± 0.02	0.20± 0.05	0.10± 0.00	28.89 ± 0.32	10.74 ± 0.17	1.17 ± 0.30
CFP	T1	5.83± 0.15	2.00± 0.13	0.11± 0.03	0.08± 0.00	40.83 ± 0.73	14.00 ± 0.08	0.82 ± 0.19
	T2	5.57± 0.16	2.16± 0.04	0.19± 0.01	0.13± 0.01	38.99 ± 0.46	15.11 ± 0.12	1.36 ± 0.10
	T3	5.70± 0.10	2.07± 0.08	0.24± 0.01	0.04± 0.03	39.88 ± 0.61	14.46 ± 0.49	1.70 ± 0.04
	T4	6.77± 0.28	2.27± 0.08	0.28± 0.02	0.09± 0.01	42.87 ± 1.43	14.39 ± 0.63	1.79 ± 0.17
	T5	6.68± 0.06	2.53± 0.07	0.20± 0.04	0.09± 0.01	42.34 ± 0.14	16.03 ± 0.52	1.29 ± 0.30
	T6	4.63± 0.24	2.74± 0.08	0.25± 0.02	0.11± 0.01	28.57 ± 1.28	16.92 ± 0.47	1.54 ± 0.09
	T7	5.65± 0.18	1.88± 0.13	0.20± 0.08	0.11± 0.01	34.89 ± 0.74	11.63 ± 0.83	1.26 ± 0.52
	T8	6.78± 0.21	1.91± 0.25	0.25± 0.01	0.11± 0.01	46.48 ± 0.79	13.71 ± 0.47	1.71 ± 0.05

Appendix 3. 5. N uptake by shoots as influenced by treatments and sampling time in the WS 2003-04 (mean + standard deviation)

Treatment	N uptake by shoots (kg ha^{-1} $season^{-1}$)			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	60.03 + 4.58 a	68.24 + 7.34 a	68.47 + 12.11 a	72.75 + 12.27 a
I T	47.33 + 9.96 b	58.70 + 5.28 b	56.32 + 8.73 b	54.87 + 10.19 b
CFP + RS	33.41 + 5.50 c	41.65 + 8.33 c	46.60 + 8.59 b	48.25 + 4.22 b
CFP	37.54 + 5.16 bc	40.89 + 6.55 c	46.04 + 9.77 b	44.58 + 8.55 b
	(p = 0.004)	(p = 0.001)	(p = 0.007)	(p = 0.007)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 6. P uptake by shoots as influenced by treatments and sampling time in the WS 2003-04 (mean + standard deviation)

Treatment	P uptake by shoots (kg ha^{-1} $season^{-1}$)			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	3.82 + 0.67 a	4.92 + 0.47 a	5.15 + 0.55 a	6.41 + 0.55 a
I T	3.59 + 0.62 a	4.45 + 0.81 a	5.26 + 1.30 a	4.30 + 0.24 a
CFP + RS	3.46 + 0.43 a	4.11 + 0.55 a	4.84 + 0.65 a	4.50 + 0.72 a
CFP	2.92 + 0.47 a	4.13 + 0.42 a	4.99 + 1.03 a	4.54 + 0.87 a
	(p = 0.455)	(p = 0.675)	(p = 0.955)	(p = 0.185)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 7. K uptake by shoots as influenced by treatments and sampling time in the WS 2003-04 (mean + standard deviation)

Treatment	K uptake by shoots (kg ha^{-1} $season^{-1}$)			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	70.68 + 7.46 a	88.48 + 11.18 a	98.58 + 14.17 a	139.34 + 20.70 a
I T	63.07 + 5.96 a	83.96 + 14.75 a	87.91 + 15.10 ab	110.25 + 15.54 ab
CFP + RS	60.67 + 9.96 a	79.02 + 16.44 a	80.18 + 11.92 b	104.95 + 19.98 ab
CFP	62.15 + 6.55 a	77.28 + 8.27 a	83.00 + 15.72 b	93.07 + 15.94 b
	(p = 0.426)	(p = 0.697)	(p = 0.079)	(p = 0.105)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 8. N uptake by roots as influenced by treatments and sampling time in the WS 2003-04 (mean ± standard deviation)

Treatment	N uptake by roots (kg ha^{-1} season^{-1})			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	11.17 ± 1.16 a	14.55 ± 2.29 a	11.04 ± 1.01 a	11.79 ± 3.36 a
I T	9.45 ± 0.64 ab	11.15 ± 0.28 b	9.82 ± 0.22 a	9.78 ± 1.85 a
CFP + RS	7.55 ± 0.44 b	7.63 ± 1.20 c	7.14 ± 1.71 b	10.17 ± 1.44 a
CFP	7.10 ± 1.55 b	7.48 ± 1.07 c	7.83 ± 0.31 b	9.32 ± 2.06 a
	(p = 0.031)	(p = 0.001)	(p = 0.006)	(p = 0.602)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 9. P uptake by roots as influenced by treatments and sampling time in the WS 2003-04 (mean ± standard deviation)

Treatment	P uptake by roots (kg ha^{-1} season^{-1})			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	1.60 ± 0.15 a	1.78 ± 0.21 a	1.67 ± 0.12 a	1.68 ± 0.11 a
I T	1.38 ± 0.10 a	1.40 ± 0.14 b	1.41 ± 0.15 a	1.46 ± 0.14 a
CFP + RS	0.92 ± 0.11 b	0.98 ± 0.15 c	0.87 ± 0.16 b	1.15 ± 0.15 b
CFP	0.95 ± 0.21 b	1.30 ± 0.15 b	0.91 ± 0.10 b	1.09 ± 0.18 b
	(p = 0.000)	(p = 0.002)	(p = 0.000)	(p = 0.004)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 10. K uptake by roots as influenced by treatments and sampling time in the WS 2003-04 (mean ± standard deviation)

Treatment	K uptake by roots (kg ha^{-1} season^{-1})			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	23.19 ± 1.06 a	29.55 ± 5.25 a	31.19 ± 5.44 a	42.70 ± 5.76 a
I T	23.41 ± 1.38 a	27.11 ± 2.97 a	27.06 ± 2.43a	34.35 ± 4.11 ab
CFP + RS	17.11 ± 3.17 b	17.68 ± 4.96 b	21.64 ± 4.24 a	27.74 ± 2.98 b
CFP	18.75 ± 2.29 ab	22.38 ± 2.59 ab	23.09 ± 4.15 a	30.51 ± 6.07 b
	(p = 0.012)	(p = 0.032)	(p = 0.497)	(p = 0.066)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 11. Shoots weight as influenced by treatments and sampling time in the WS 2003-04 (mean ± standard deviation)

Treatment	Weight of shoots (t ha^{-1})			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	1.89 ± 0.18 a	2.77 ± 0.19 a	3.95 ± 0.21 a	5.65 ± 0.23 a
I T	1.84 ± 0.20 a	2.70 ± 0.14 b	3.84 ± 0.20 a	5.26 ± 0.38 ab
CFP + RS	1.73 ± 0.13 a	2.52 ± 0.28 bc	3.39 ± 0.25 b	4.84 ± 0.44 bc
CFP	1.73 ± 0.14 a	2.51 ± 0.28 c	3.28 ± 0.24 b	4.61 ± 0.49 c
	(p = 0.520)	(p = 0.380)	(p = 0.002)	(p = 0.003)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 12. Weight of roots as influenced by treatments and sampling time in the WS 2003-04 (mean ± standard deviation)

Treatment	Weight of roots (t ha^{-1})			
	45 DAP	60 DAP	75 DAP	90 DAP
IT + RS	0.67 ± 0.09 a	1.03 ± 0.11 a	1.31 ± 0.11 a	1.94 ± 0.14 a
I T	0.65 ± 0.05 a	0.91 ± 0.08 b	1.28 ± 0.10 a	1.85 ± 0.08 a
CFP + RS	0.59 ± 0.03 a	0.87 ± 0.06 b	1.14 ± 0.06 b	1.72 ± 0.08 b
CFP	0.58 ± 0.04 a	0.89 ± 0.05 b	1.13 ± 0.06 b	1.63 ± 0.08 b
	(p = 0.164)	(p = 0.025)	(p = 0.017)	(p = 0.001)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 13. N uptake by shoots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	N uptake by shoots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	67.54 ± 6.88 a	94.06 ± 5.44 a	94.67 ± 3.77 a	83.18 ± 6.22 a
I T	55.48 ± 2.71 b	69.36 ± 1.85 b	70.85 ± 4.08 b	60.61 ± 3.14 b
CFP + RS	41.29 ± 2.97 c	53.40 ± 2.92 c	55.08 ± 3.96 c	53.91 ± 4.44 c
CFP	39.38 ± 2.98 c	48.27 ± 2.74 c	48.60 ± 3.11 c	48.92 ± 2.41 c
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 14. P uptake by shoots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	P uptake by shoots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	5.20 ± 1.08 a	5.90 ± 1.14 a	6.17 ± 0.78 a	6.99 ± 0.20 a
I T	3.88 ± 0.15 b	4.75 ± 0.36 ab	5.97 ± 0.25 ab	5.54 ± 0.52 b
CFP + RS	3.76 ± 0.19 b	4.68 ± 0.47 ab	5.74 ± 0.41 ab	4.95 ± 0.31 c
CFP	3.17 ± 0.26 b	4.38 ± 0.24 b	5.03 ± 0.25 b	4.44 ± 0.27 c
	(p = 0.014)	(p = 0.089)	(p = 0.080)	(p = 0.002)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 15. K uptake by shoots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	K uptake by shoots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	80.74 ± 1.73 a	105.45 ± 2.19 a	123.98 ± 9.42 a	157.10 ± 15.99 a
I T	69.25 ± 3.37 b	90.25 ± 4.94 b	113.42 ± 2.54 b	121.19 ± 3.02 b
CFP + RS	58.32 ± 4.50 c	84.25 ± 7.99 bc	104.57 ± 4.68 bc	105.30 ± 6.36 bc
CFP	53.46 ± 0.39 c	79.96 ± 2.40 c	101.88 ± 2.63 c	94.99 ± 2.79 c
	(p = 0.000)	(p = 0.001)	(p = 0.005)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 16. N uptake by roots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	N uptake by roots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	13.97 ± 1.57 a	17.56 ± 1.50 a	19.42 ± 1.05 a	19.28 ± 1.41 a
I T	10.56 ± 0.90 b	14.20 ± 0.87 b	16.46 ± 1.70 b	17.50 ± 1.14 a
CFP + RS	9.19 ± 0.85 c	11.27 ± 0.90 c	13.71 ± 1.81 c	12.53 ± 1.79 b
CFP	7.39 ± 0.26 d	10.21 ± 1.38 c	11.43 ± 1.42 d	10.79 ± 1.72 b
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 17. P uptake by roots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	P uptake by roots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	1.61 ± 0.13 a	1.98 ± 0.25 a	2.59 ± 0.46 a	2.48 ± 0.25 a
I T	1.31 ± 0.10 b	1.71 ± 0.26 ab	1.96 ± 0.20 b	1.83 ± 0.24 b
CFP + RS	1.05 ± 0.09 c	1.36 ± 0.16 bc	1.40 ± 0.16 c	1.53 ± 0.13 b
CFP	1.00 ± 0.13 c	1.29 ± 0.08 c	1.41 ± 0.07 c	1.44 ± 0.10 b
	(p = 0.001)	(p = 0.010)	(p = 0.001)	(p = 0.002)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 18. K uptake by roots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	K uptake by roots (kg ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	25.46 ± 1.31 a	35.50 ± 0.78 a	49.31 ± 1.45 a	54.17 ± 1.40 a
I T	22.49 ± 0.86 b	32.65 ± 1.28 b	41.89 ± 1.28 b	45.68 ± 1.43 b
CFP + RS	18.60 ± 0.64 c	25.23 ± 0.66 c	34.69 ± 2.50 c	37.95 ± 1.44 c
CFP	16.32 ± 0.88 d	23.69 ± 0.91 c	33.07 ± 1.64 c	35.62 ± 1.47 c
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p =0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 19. Weight of shoots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	Weight of shoots (t ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	2.08 ± 0.03 a	3.10 ± 0.16 a	4.51 ± 0.20 a	6.10 ± 0.13 a
I T	1.97 ± 0.04 b	2.85 ± 0.26 b	4.48 ± 0.20 ab	5.19 ± 0.14 b
CFP + RS	1.82 ± 0.05 c	2.81 ± 0.15 bc	4.42 ± 0.36 b	4.95 ± 0.30 c
CFP	1.76 ± 0.05 c	2.74 ± 0.20 c	4.32 ± 0.21 c	4.67 ± 0.16 d
	(p = 0.000)	(p = 0.000)	(p = 0.004)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 20. Weight of roots as influenced by treatments and sampling time in the DS 2004 (mean ± standard deviation)

Treatment	Weight of roots (t ha^{-1})			
	45 DAT	60 DAT	75 DAT	90 DAT
IT + RS	0.71 ± 0.12 a	1.12 ± 0.21 a	1.85 ± 0.20 a	2.40 ± 0.26 a
I T	0.65 ± 0.11 b	1.06 ± 0.18 b	1.73 ± 0.15 b	2.28 ± 0.25 b
CFP + RS	0.64 ± 0.10 c	1.00 ± 0.20 c	1.55 ± 0.16 c	2.09 ± 0.15 c
CFP	0.57 ± 0.10 d	0.94 ± 0.12 d	1.46 ± 0.16 d	1.96 ± 0.20 d
	(p = 0.000)	(p = 0.000)	(p = 0.000)	(p = 0.000)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 21. Seasonal variations of N, P, and K concentrations in shoots as influenced by treatments and sampling time (mean ± standard deviation)

Season	Nutrient concentrations in shoots (%)			
	45 DAT	60 DAT	75 DAT	90 DAT
N Concentrations:				
WS 2003-04	2.46 ± 0.50 a	2.10 ± 0.41 a	1.49 ± 0.21 a	1.05 ± 0.13 a
DS 2004	2.65 ± 0.46 a	2.30 ± 0.41 a	1.56 ± 0.35 a	1.16 ± 0.14 b
	(p = 0.349)	(p = 0.265)	(p = 0.620)	(p = 0.050)
P Concentrations:				
WS 2003-04	0.19 ± 0.04 a	0.17 ± 0.03 a	0.13 ± 0.02 a	0.09 ± 0.02 a
DS 2004	0.21 ± 0.03 a	0.17 ± 0.02 a	0.13 ± 0.01 a	0.10 ± 0.01 a
	(p = 0.363)	(p = 0.673)	(p = 0.251)	(p = 0.441)
K Concentrations:				
WS 2003-04	3.57 ± 0.42 a	3.11 ± 0.35 a	2.43 ± 0.25 a	2.19 ± 0.36 a
DS 2004	3.41 ± 0.36 a	3.12 ± 0.24 a	2.50 ± 0.21 a	2.26 ± 0.26 a
	(p = 0.315)	(p = 0.968)	(p = 0.439)	(p = 0.604)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 3. 22. Seasonal variations of N, P, and K concentrations in roots as influenced by treatments and sampling time (mean ± standard deviation)

Season	Nutrient concentrations in roots (%)			
	45 DAT	60 DAT	75 DAT	90 DAT
N Concentrations:				
WS 2003-04	1.41 ± 0.25 a	1.09 ± 0.18 a	1.49 ± 0.21 a	1.05 ± 0.13 a
DS 2004	2.65 ± 0.46 a	2.30 ± 0.41 a	1.56 ± 0.35 a	1.16 ± 0.14 b
	(p = 0.349)	(p = 0.265)	(p = 0.620)	(p = 0.050)
P Concentrations:				
WS 2003-04	0.19 ± 0.04 a	0.17 ± 0.03 a	0.13 ± 0.02 a	0.09 ± 0.02 a
DS 2004	0.21 ± 0.03 a	0.17 ± 0.02 a	0.13 ± 0.01 a	0.10 ± 0.01 a
	(p = 0.363)	(p = 0.673)	(p = 0.251)	(p = 0.441)
K Concentrations:				
WS 2003-04	3.57 ± 0.42 a	3.11 ± 0.35 a	2.43 ± 0.25 a	2.19 ± 0.36 a
DS 2004	3.41 ± 0.36 a	3.12 ± 0.24 a	2.50 ± 0.21 a	2.26 ± 0.26 a
	(p = 0.315)	(p = 0.968)	(p = 0.439)	(p = 0.604)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (= p-value ANOVA)

Appendix 5. 1. Estimated nutrient losses in sediment during harrowing in the WS 2003-04 and in the DS 2004

Treatment	Soil loss (kg ha^{-1})	Nutrient content in top soil			Estimated nutrient losses (kg ha^{-1})		
		N Organic (%)	P Total (mg/100g)	K Total (mg/100g)	N Organic	P Total	K Total
WS 2003-04							
IT + RS	239	0.13	140.0*	22.9**	0.31	0.33	0.05
IT	266	0.12	153.5	28.1	0.32	0.40	0.07
CFP + RS	338	0.09	121.2	18.0	0.30	0.41	0.06
CFP	480	0.10	145.4	22.6	0.48	0.70	0.11
DS 2004							
IT + RS	154	0.13	140.0*	22.9**	0.18	0.22	0.03
IT	203	0.12	153.5	28.1	0.24	0.31	0.06
CFP + RS	264	0.09	121.2	18.0	0.24	0.32	0.05
CFP	256	0.10	145.4	22.6	0.26	0.37	0.06

Note: * The value was estimated according to the average of IT, CFP+RS and CFP treatments
** The value was estimated according to the average of IT, CFP+RS and CFP treatments

Appendix 5. 2. Period of adding irrigation water, water input, incoming and outgoing nutrient during rice growing period, WS 2003-04

Stage	Duration (day)	Water input (l ha^{-1} day^{-1})		Incoming nutrient (kg ha^{-1} day^{-1})			Outgoing nutrient (kg ha^{-1} day^{-1})			Net Input (kg ha^{-1} day^{-1})		
		Inflowing	Outgoing	N	P	K	N	P	K	N	P	K
CFP:												
Puddling	1	569548 ± 201733	342357 ± 84 835	0.58	0.002	1.06	0.36	0.002	0.55	0.22	-	0.51
After puddling to planting	6	398271 ± 132088	322004 ± 91 340	0.70	0.010	0.71	0.51	0.003	0.44	0.20	0.003	0.27
Vegetative	18	455921 ± 142754	310127 ± 100190	1.25	0.015	0.90	0.72	0.007	0.60	0.55	0.008	0.38
Generative	10	465129 ± 145348	385494 ± 128270	0.95	0.007	0.84	0.72	0.004	0.60	0.23	0.003	0.24
CFP + RS:												
Puddling	1	678818 ± 152822	420585 ± 112023	1.20	0.020	1.57	0.86	0.040	0.93	0.33	-	0.64
After puddling to planting	6	612111 ± 89343	528379 ± 57448	1.08	0.010	1.10	0.94	0.005	0.65	0.15	0.005	0.45
Vegetative	18	613438 ± 228141	448822 ± 165071	1.64	0.016	1.27	1.11	0.009	0.81	0.53	0.007	0.46
Generative	10	609487 ± 106430	522491 ± 522491	1.25	0.009	1.10	1.02	0.005	0.91	0.23	0.004	0.18
IT:												
Puddling	1	486346 ± 79600	289996 ± 48860	0.52	0.002	0.87	0.34	0.003	0.46	0.18	-	0.41
After puddling to planting	6	306830 ± 49306	224459 ± 40009	0.54	0.010	0.55	0.36	0.005	0.32	0.18	0.005	0.23
Vegetative	18	264095 ± 67643	186923 ± 36438	0.70	0.008	0.55	0.47	0.004	0.32	0.23	0.005	0.22
Generative	10	322778 ± 81638	244076 ± 65372	0.66	0.005	0.58	0.48	0.004	0.41	0.18	0.001	0.15
IT + RS:												
Puddling	1	629262 ± 221570	454716 ± 133033	0.68	0.002	1.13	0.56	0.008	0.80	0.12	-	0.33
After puddling to planting	6	598471 ± 56134	502420 ± 61083	1.06	0.010	1.07	0.80	0.005	0.77	0.25	0.005	0.30
Vegetative	18	598762 ± 69794	366963 ± 118845	1.42	0.015	1.15	0.87	0.010	0.69	0.55	0.005	0.46
Generative	10	597593 ± 104516	506215 ± 116478	1.23	0.009	1.08	1.03	0.008	0.99	0.20	0.001	0.09

Appendix 5. 3. Period of adding irrigation water, water input, incoming and outgoing nutrient during rice growing period, DS 2004

Stage	Duration (day)	Water input (l ha^{-1} day^{-1})		Incoming nutrient (kg ha^{-1} day^{-1})			Outgoing nutrient (kg ha^{-1} day^{-1})			Net Input (kg ha^{-1} day^{-1})		
		Inflowing	Outgoing	N	P	K	N	P	K	N	P	K
CFP:												
Puddling	1	340706 ± 133438	198348 ± 98062	0.29	0.017	1.13	0.14	0.011	0.70	0.15	0.006	0.43
After puddling to planting	6	300519 ± 91655	212170 ± 80973	0.58	0.008	0.61	0.36	0.006	0.32	0.22	0.002	0.29
Vegetative	21	261021 ± 133878	171966 ± 116311	0.19	0.007	0.36	0.12	0.005	0.21	0.07	0.002	0.15
Generative	12	293351 ± 174483	218039 ± 151021	0.58	0.007	0.66	0.32	0.005	0.43	0.26	0.002	0.23
CFP + RS:												
Puddling	1	334976 ± 134436	175937 ± 51328	0.41	0.015	1.42	0.18	0.011	0.93	0.23	0.004	0.49
After puddling to planting	6	464137 ± 71023	361013 ± 30005	0.90	0.014	0.94	0.61	0.011	0.61	0.29	0.003	0.33
Vegetative	21	446904 ± 116866	341914 ± 74418	0.30	0.010	0.60	0.24	0.008	0.43	0.06	0.002	0.17
Generative	12	464137 ± 73002	348869 ± 71139	0.87	0.010	0.99	0.54	0.008	0.80	0.33	0.002	0.19
IT:												
Puddling	1	303153 ± 139279	138894 ± 15205	0.38	0.015	1.04	0.30	0.009	0.58	0.08	0.006	0.46
After puddling to planting	6	215990 ± 42201	120509 ± 12060	0.42	0.006	0.44	0.21	0.004	0.18	0.21	0.002	0.26
Vegetative	21	341941 ± 91605	195966 ± 73098	0.12	0.006	0.26	0.10	0.004	0.17	0.02	0.002	0.09
Generative	12	209318 ± 28478	130986 + 27119	0.42	0.005	0.47	0.25	0.004	0.26	0.17	0.001	0.21
IT + RS:												
Puddling	1	520122 ± 34138	215665 ± 63111	1.12	0.017	1.47	0.93	0.017	1.00	0.19	0.000	0.47
After puddling to planting	6	436422 ± 143287	317479 ± 140647	0.85	0.013	0.89	0.59	0.012	0.51	0.26	0.001	0.38
Vegetative	21	366017 ± 139524	270244 ± 116857	0.27	0.010	0.48	0.22	0.008	0.34	0.05	0.002	0.14
Generative	12	420748 ± 148490	328397 ± 148440	0.84	0.010	0.95	0.70	0.009	0.77	0.14	0.001	0.18

Appendix 6. 1. Rainfall data of the Semarang District, from 1978 to 2003

Development Plan	Year	Rainfall (mm)	Rain Events (days)
PELITA II	1978	2 340	145
PELITA III	1979	3 207	132
	1980	2 120	199
	1981	2 245	134
	1982	2 323	108
	1983	2 334	111
Mean		*2 446*	*137*
PELITA IV	1984	2 700	147
	1985	2 375	137
	1986	2 846	130
	1987	2 236	117
	1988	2 427	134
Mean		*2 517*	*133*
PELITA V	1989	2 546	144
	1990	1 873	107
	1991	1 873	93
	1992	2 270	156
	1993	2 176	125
Mean		*2 148*	*125*
Economic crisis	1994	1 938	111
	1995	2 672	132
	1996	2 130	120
	1997	1 924	97
	1998	3 196	157
Mean		*2 372*	*123*
The economic recovery era	1999	2 725	133
	2000	2 527	123
	2001	2 750	138
	2002	1 979	104
	2003	2 287	115
Mean		*2 454*	*123*

CURRICULUM VITAE

PERSONAL INFORMATION

Name	: Sukristiyonubowo
Place and Date of Birth	: Cilacap, Central Java, 10 December 1959
Religion	: Christian
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EDUCATION

2003 - 2007	Doctorate in Faculty of Bio Science Engineering, University of Ghent, Belgium
1995 – 1997	Master of Science in Faculty of Sciences, University of Ghent, Belgium
1982 – 1984	Engineering in Faculty of Agriculture, Satya Wacana Christian University, Salatiga, Indonesia
1978 – 1982	Bachelor of Science in Faculty of Agriculture, Satya Wacana Christian University, Salatiga, Indonesia
1975 – 1977	Senior High School in S M A N 1 Tegal, Indonesia
1972 – 1974	Junior High School in S M P N 2 Tegal, Indonesia
1966 – 1971	Preliminary School in S D Kristen Margoyudan, Solo, Indonesia

PUBLICATIONS

A1:

Sukristiyonubowo, Gabriels, D., and Verloo, M. Sediment movement behaviour in a terraced paddy field system. (submitted to Soil and Tillage Research)

Sukristiyonubowo, Du Laing, G., and Verloo, M. Nutrient balances under traditional irrigation in terraced paddy field systems. (submitted to Agricultural Systems)

Sukristiyonubowo, Du Laing, G., and Verloo, M. Nutrient balances of wetland rice farming systems for the Semarang District. (submitted to Agricultural Systems)

A2:

Santoso, D., and Sukristiyonubowo. 1996. Soil and crop management for sustainable slope land farming in Indonesia. FFTC. Extension Bulletin 425

A3:

Purnomo, J., Sukristiyonubowo, Wigena, P., and Santoso, D. 2000. Management of phosphorus and organic matter on acid soil in Jambi, Indonesia. Indonesian Soil and Climate Journal. No. 18, p. 64-72 (in Indonesian)

Sukristiyonubowo, Purnomo, J., Wigena, P., and Santoso, D. 2000. The effect of silvy pastoral systems on carrying capacity and soil properties of grassland. Indonesian Soil and Climate Journal. No 18. p. 54-63 (in Indonesian)

Sukristiyonubowo, Wigena, P., Mulyadi, and Kasno, A. 1993 Effect of organic matter, lime, and NPK fertilizer on soil properties and yield of peanut. Indonesian Soil and fertiliser Journal. Centre for Soil and Agroclimate Research. (in Indonesian)

C1 (International Proceedings, symposia, and workshops)

Agus, F., Vadari, T., Watung, R.L., Sukristiyonubowo, and Valentin, C. 2003. Effects of land use and management systems on water and sediment yields: Evaluation from several micro catchments in Southeast Asia. In From soil research to land and water management: Harmonising People and Nature. Proceedings of the IWMI-ADB Project Annual Meeting and 7th MSEC Assembly. Editors: Maglinao, A.R., Valentin, C., and de Vries, F.P. p: 135-149

Agus, F., and Sukristiyonubowo. 2002. Nutrient loss and on site cost of soil erosion under different land use systems in South East Asia. *In* Proceeding of Integrated catchment management for land and water conservation and sustainable agricultural production in Asia.

Agus, F., Sukristiyonubowo, Vadari, T., and Setiani, C. 2001. Catchment approach to managing soil erosion in Kaligarang Catchment of Java, Indonesia. Proceedings of the 5th Management of Soil Erosion Consortium (MSEC) Assembly. Thailand: IWMI. Southeast Asia Regional Office. 275p

Santoso, D., Sukristiyonubowo, Wigena, P., and Purnomo, J. 1999. Management of sloping lands for sustainable agriculture in Indonesia. The Management of Sloping Lands in Asia. Bangkok, Network Doc. No.24, p. 69-88

Santoso, D., Sukristiyonubowo, Wigena, P., and Purnomo, J. 1998. Management of sloping lands for sustainable agriculture in Indonesia. The Management of Sloping Lands in Asia. Bangkok, Network Doc. No.23, p. 43-58

Santoso, D., Sukristiyonubowo, Wigena, P., and Purnomo, J. 1997. Management of sloping lands for sustainable agriculture in Indonesia. The Management of Sloping Lands in Asia. Bangkok, Network Doc. No.22, p. 81-108

Santoso, D., Sukristiyonubowo, Wigena, P., and Purnomo, J. 1996. Management of sloping lands for sustainable agriculture in Indonesia. The Management of Sloping Lands in Asia. Bangkok, Network Doc. No.20, p. 87-108

Sukristiyonubowo, Agus, F., Gabriels, D., and Verloo, M. 2004. Sediment and nutrient balances under traditional irrigation at terraced paddy field systems. Paper presented at the second International Symposium on Land Use Change and Soil and Water processes in Tropical Mountain Environments held in Luang Prabang, Lao PDR

Sukristiyonubowo, Watung, R.L., Vadari, T., and Agus, F. 2003. Nutrient loss and on-site cost of soil erosion under different land use systems. Proceedings of the IWMI-ADB Project Annual Meeting and 7th MSEC Assembly. Editors: Maglinao, A.R, Valentin, C., and de Vries, F.P. p: 151-164

Sukristiyonubowo, Vadari, T., Watung, R.L., Sidik, H.T., and Agus, F. 2002. Impact assessment of MSEC Project in Indonesia. Paper presented at the training workshop on Impact Assessment organised by IWMI in Bangkok, Thailand.

National Proceedings:

Sukristiyonubowo, Purnomo, J., Wigena, P., and Santoso, D. 1999. Soil-crop management with silvy pastures system to improve pasture land productivity in Aceh. Proceeding of National seminar of land resources, climate, and fertilizer. p.1-18 (in Indonesian)

Sukristiyonubowo, Adiningsih, S., and Mukelar. 1988. The effect of nitrogen fertilizer and fungicides on rice blast in Kubang Ujo, Jambi. Proceeding of dry land farming system in Kubang Ujo, Jambi. (in Indonesian)

Sukristiyonubowo, Wigena, P., and Adiningsih, S. 1988. Economic analysis of lime application in Kubang Ujo, Jambi. Proceeding of dry land farming system in Kubang Ujo, Jambi. (in Indonesian)

Sukristiyonubowo, Mulyadi, Adiningsih, S., and Suwardjo. 1988 Economic analysis of poly culture system in Kubang Ujo, Jambi. Proceeding of dry land farming system in Kubang Ujo, Jambi. (in Indonesian)

Sukristiyonubowo, Wigena, P., and Wijaya Adhi, I. P. G. 1988. Evaluation of integrated farming system in Kubang Ujo, Jambi. Proceeding of dry land farming system in Kubang Ujo, Jambi. (in Indonesian)

Others:

Agus, F., Sukristiyonubowo, and Vadari, T. 2001. Managing Soil Erosion in Kaligarang Catchment of Java, Indonesia. Country Report of Management of Soil Erosion Consortium

Sukristiyonubowo, Vadari, T., and Hariyogo. 1993. The relation between level of farm management and food crop production. Survey Report. Centre for Soil and Agroclimate Research. (in Indonesian)

Sukristiyonubowo, Vadari T., and Hariyogo. 1993. Status of soil fertility of Covalima District, East Timor. Survey Report. Centre for Soil and Agroclimate Research. (in Indonesian)

PROFESSIONAL DEVELOPMENT (Attended Symposia, Conferences, and Workshops)

14 – 17 December 2004	The second International Symposium on Land Use Change and Soil and Water processes in Tropical Mountain Environments held in Luang Prabang, Lao PDR organised by the Ministry of Agriculture and Forestry, Lao PDR and sponsored by the National Agriculture and Forestry Research Institute (NAFRI), International Water Management Institute (IWMI) and Institut de Recherche pour le Développement (IRD)
2 – 7 December 2002	Annual review and meeting and the 7th MSEC assembly in Vientiane, LAO PDR
October 2002	The training workshop on Impact Assessment organised by IWMI in Bangkok, Thailand
10 – 15 December 2001	The 6th MSEC Assembly in Hanoi, Vietnam
April to May 2001	Training in English for Academic Preparation and Communication. CRIAS Language Centre, Bogor, Indonesia
21 – 23 November 2000	The International Workshop on improving soil fertility management in South East Asia
7 – 11 November 2000	The 5th MSEC Assembly in Semarang, Central Java, Indonesia
11 – 13 April 2000	Training on climatic data management and analyzing organised by CIRAD in Ungaran. Collaboration between CIRAD-France and CSARD, Bogor
November 1999	The 4th MSEC Assembly in Cagayan de Oro, Philippines

25 March – 10 April 1999	Training workshop on Catchment Research: Biophysical processes, Instrumentation, Data Collection, Analysis and Interpretation organized by Management Soil Erosion Consortium (MSEC)–IBSRAM (International Board for Soil Research and Management) Thailand
7 – 13 October 1998	Training on Participatory Approach, Monitoring and Analysis, organized by MSEC-IBSRAM, Thailand
5 – 6 October 1998	Training on Project Management organized by MSEC - IBSRAM, Thailand
September 1998	The annual meeting of sloping land management, organised by IBSRAM in Kunming, P R of China
08 – 28 September 1995	Training in English for Scientific: Purposes. Talent Centrum. University of Ghent, Belgium
January to Marc 1994	Training in English for Academic Purpose in Indonesia Australia Languages Foundation (IALF), Jakarta, Indonesia
Sept to December 1993	Basic English Training. University of Indonesia

ORGANISATION OF INTERNATIONAL CONFERENCES

7 – 11 November 2000	The leader of organising committee of the 5th MSEC Assembly in Semarang, Central Java, Indonesia

EMPLOYMENT EXPERIENCES

1985 – Present	Researcher at the Soil Research Institute Bogor recently dealing with nutrient management at watershed scale
1999 – 2001	Project Leader of Managing Soil Erosion Consortium Project. Collaboration between CSARD, Bogor and IWMI (International Water Management Institute) funded by ADB
2001	Trainer and conducting PRA (Participatory Rural Appraisal) on improvement of soil fertility of acid soil with rock

	phosphate in South Kalimantan. Collaboration between CSARD, Bogor and IMPHOS, Morocco
2000	Carrying out PRA for MSEC project
August – Sept 2000	Field trainer on data collection and analysis for the MSEC Projects in Nepal, Lao PDR, Vietnam, and Thailand
1997 – 1999	Research Coordinator of Management of Degraded Pasture Land in Aceh and Nusa Tenggara Barat
1998	Carrying out PRA for sloping land project
1993 – 1994	Site Coordinator of Rehabilitation of post coal mining land Project in Tanjung Enim, South Sumatera
1985 – 1990	Site Coordinator of Integrated farming system project in Kubang Ujo, Jambi

RESEARCH PROJECTS

1999 – 2003	Management of watershed for productive and sustainable natural resources in Indonesia funded by Asian Development Bank (ADB)
1997 – 1999	Management of degraded grassland in Nusa Tenggara Barat and Aceh Province
1997 – 1999	Asian Sloping Land Project in Kubang Ujo, Jambi funded by IBSRAM
1993 – 1994	Rehabilitation of post coal mining land, in Tanjung Enim, South Sumatera
1993	Survey for soil fertility in Covalima District East Timor
1990 – 1992	Efficiency of fertilizer usage at the different soils in Lampung, West Java, East Java, and Nusa Tenggara Barat Province for rice and soybean
1986 – 1990	Rehabilitation of *Imperata cylindrica* lands using rock

	phosphate, lime, and organic matter, in Kubang Ujo, Jambi
1985 – 1989	Hedge grow for polyculture and monoculture system in dry land agriculture Kubang Ujo, Jambi
1985 – 1989	Integrated farming system at dry land agriculture Kubang Ujo, Jambi.