Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2011.16.3.201

Seasonal Variation of Yields and Nutrient Uptakes of IR-64 Grown in Terraced Paddy Field System

Sukristiyonubowo[1] and Gijs Du Laing[2]

[1]Indonesian Soil Research Institute, Jl. Ir. Juanda 98 Bogor 16123, Indonesia.
[2]Department of Applied Analytical and Physical Chemistry, Laboratory of Analytical Chemistry and Applied Ecochemistry, Ghent University, Coupure Link 653, 9000 Ghent, Belgium.
Corresponding author: e-mail: sukristiyonubowo@yahoo.com, Tel: +62-81226277259

Received 30 July 2010 / accepted 18 July 2011

ABSTRACT

In the past, most rice study was carried out in irrigated lowland rice and less or no attention was paid to the terraced paddy field system. Study on seasonal rice biomass production and nutrient uptake variation of IR-64 variety cultivated in terraced paddy field system was carried out in Keji Village, Ungaran Sub district during the wet season 2003-04 and dry season 2004. The aim of the study was to evaluate the seasonal variation of rice biomass productions, nutrient concentrations and nutrient uptakes of IR-64. Data were taken from four treatments, namely conventional farmer practice, conventional farmer practices + rice straw, improved technology and improved technology + rice straw. 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, and potassium cloride ha^{-1} $season^{-1}$ were applied in the improved technology treatments. About 33% of rice straw produced from the previous season was recycled in the treatments of conventional farmer practices + rice straw and improved technology + rice straw. Each treatment was replicated three times and arranged in a Randomised Completely Block Design. Plants were sampled five times, at 45, 60, 75, 90 and 105 days after transplanting. The results indicated that overall production of the improved technology + rice straw treatment was significantly higher than the other treatments both in the wet season 2003-04 and the dry season 2004. Rice grains and rice residues in the dry season were higher than in the wet season, except for the rice straw. However, statistically, there were no significant variations of rice biomass production between the wet season 2003-04 and the dry season 2004. When the rice straw addition was considered, only rice grain production of the dry season was consistently greater than the rice grain production of the wet season. Concentrations of N, P, and K in shoots and roots significantly decreased during rice growth. In contrast to the concentrations, the nutrient uptake increased by the time of rice growth. The highest nutrient concentrations both in the wet and dry season were observed at 45 days after. Contrary to the nutrient concentrations, the highest N, P, and K uptakes were taken place at harvest. Seasonally, nutrient uptakes at harvest in the dry season were higher than in the wet season, but statistical evidences were not consistent. As 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 nutrients removal ranged between 114 and 119 kg N, 10 and 12 kg P, 133 and 148 kg K ha^{-1} $season^{-1}$.

Keywords: Nitrogen, phosphorous, potassium**,** seasonal nutrient uptake, terraced paddy field

INTRODUCTION

In the past most of the research for rice was conducted in semi or fully technical irrigated lowland rice, very seldom experiment was carried out in terraced paddy field system. Previous studies in terraced paddy field under traditional system show that the farmers in Keji Village only add nitrogen in the form of urea for about 50 kg ha^{-1} $season^{-1}$, but no phosphorus (P) and potassium (K). Rice straw is also removed from the field to feed their cattle: cows and buffaloes (Sukristiyonubowo *et al.* 2003). The similar cultural practices with imbalanced fertilisation were also observed in Thailand, Mexico and Malawi (Mosser *et al.* 2006; Hay *et al.* 2001; Harrington *et al.* 1991). Exploitation inherent soil fertility through improper management practices, therefore, is threatening the food security and position of the economically important agricultural sector in many developing countries including Indonesia (Sukristiyonubowo *et al.* 2004; Sukristiyonubowo *et al.* 2003; Stoorvogel *et al.* 1993; Harriton *et al.* 1991). Good agricultural practices through balanced fertilisation, in terms of rate and kind of fertilisers, including returning organics substances like rice straw to the field should be recommended.

The effects of fertilisers on crop production in terms of quantity and quality of yields have been studied and well documented. Many researchers reported that application of mineral fertilisers enhances rice yield and the responses of rice to fertilisers vary depending on varieties, soil-climate, and cultural practices. (Min *et al.* 2007; Cho *et al.* 2002 and 2000; Fageria and Baligar 2001; Soepartini 1995; Cooke 1970; Uexkull 1970). Specifically, Min *et al*. (2007) and Cho *et al.* (2002) reported that the production of protein, stimulation of root development, flowering and the prevention to disease are all dependent upon the presence of nitrogen, phosphorus, and potassium.

It is also well documented that addition of organic substances augment soil chemical and physical properties as well as rice growth and yield. Incorporation of organic materials including compost, organic manure and straw, in paddy soils improve soil fertility, root morphological characteristics, and yield (Xu *et al*. 2006; Fenning *et al*. 2005; Hasegawa *et al.* 2005; Yang *et al.* 2004; Senapati *et al.* 2004; Mandal *et al.* 2003; Eneji *et al.* 2001; Ray and Gupta 2001; Singh *et al.* 2001; Whitbread *et al.* 2000; Clark *et al.* 1998; Mohammad *et al.* 1992). Furthermore, Yang *et al.* (2004) observed that incorporation of organic manure in alternating wet and dry water regimes significantly increases N, P, and K uptakes by the rice plants and facilitates translocation of P to rice panicles and grains. Significant improvements in nutrient uptake, rice grains and rice straw yields were also observed in trials combining 12,500 kg 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). 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.

Many studies reported that the uptake of nutrients depends on variety, cultural practices, nutrients supply, and climate (Sukristiyonubowo and Tuherkih 2009; Yang *et al*. 2004; Sukristiyonubowo *et al.* 2003; Singh *et al.* 2001; Kemmler 1971; Sanchez and Calderon 1971; Uexkull 1970). In accordance with variety and climate, Uexkull (1970) observed that the total nutrients removals through rice grains and rice straw in the wet season are 77 kg N, 14 kg P, and 150 kg K ha^{-1} $season^{-1}$ and these are lower than in the dry season. According to Uexkull (1970), high yielding rice variety needs about 2.5 times more N and P and 4.5 times more K than the traditional varieties. Furthermore, 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. Hence, nutrients removed through harvest products of high yielding varieties are higher than improved local varieties. Depending on nutrient inputs and climate, 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). Therefore, it is interesting to study nutrient concentration in different planting season as well as the total nutrient uptake or removed through biomass product.

The objective of the study reported here was to evaluate the seasonal variation of rice biomass production, nutrient concentration and nutrient uptake of IR-64 variety cultivated in terraced paddy field under traditional irrigation systems.

MATERIALS AND METHODS

Field Experiments

Field experiments were carried out at Keji Village for the wet season 2003-04 (WS 2003-04) and the dry season 2004 (DS 2004). The study area is located at an elevation between 390 and 510 m above sea level. The soils were classified as Aquandic Epiaquepts medial isohyperthermic (Siswanto 2006). The high yielding rice variety IR-64 was selected and cultivated by the farmers.

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 Completely 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, triple super phosphate (TSP), and potassium chloride (KCl) were applied. These rates were introduced since the cropping season 2000-01 to improve their imbalanced fertilization. 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

Table 1. The treatments, dates of transplanting, the amounts of rice straw recycled, and fertilizer application rates.

Treatment	Replication	Date of transplanting		The amount of rice straw recycled (Mg ha^{-1})		Fertiliser Rates (kg ha^{-1} $season^{-1}$)		
		WS 2003-04	DS 2004	WS 2003-04	DS 2004	Urea	TSP	KCl
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
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
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	-	-

IT + RS = Improve Technology + Rice Straw, CFP + RS = Conventional Farmer Practies + Rice Straw, IT = Improve Technology, and CFP = Conventional Farmer Practies.

ploughing. The recycling of 33% of rice straw production is obtained from the results of previous study (Sukristiyonubowo *et al.* 2003) and accepted by farmers during the meeting. In this village, rice straw is given to feed their cattle. Twelve farmers were involved, corresponding to the four treatments and three replicates. Details about the treatments are given in Table 1.

Application of urea was split and conducted at two times, 21 and 35 DAT (days after transplanting). 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 January 2004 and harvest in April 2004 for the WS 2003-04, while for the 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 (Table 1).

Twenty-one-day old seedlings were transplanted at about 25 cm × 25 cm cropping distance with about three seedlings per hill. Rice biomass productions including grains, straw, and residues on a hectare basis were extrapolated from sampling areas of 1m × 1m. These sampling units were randomly selected at every terrace. Rice plants were cut about 10 to 15 cm above the ground surface, as commonly done by the farmers. The samples were manually separated into rice grains, rice straw, and rice residues. Rice residues included the roots and the part of the stem (stubble) left after cutting. 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 about 85^{o} 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.

Plants Sampling Analysis

Plants were sampled five times during the rice growing cycle at 45, 60, 75, 90, and 105 DAT or at harvest, demonstrating the vegetative, reproductive, ripening, and harvest phases of the rice growth cycle. According to Mikkelsen *et al.* (1995) and Anonymous (1977) 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. The duration of each growth stage is influenced by internal (genetics of variety) and external factors (plant nutrient supply, agronomic practices, and climatic conditions). Mikkelsen *et al.* (1995), Anonymous (1977) and Uexkull (1970) reported that assimilates produced during vegetative to flowering stages are trans-located to stem and leaves, while from flowering to ripening they are stored in grains.

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°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°C. The dried samples were ground and stored in cleaned 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 2009).

Data Analysis

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. The dry weight of rice grain, rice straw and rice residues by season were computed according to the yield of every treatment divided by four, respectively. All data were statistically examined by analysis of variance (ANOVA), using SPSS software. Means were compared using the Duncan's test (5%).

RESULTS AND DISCUSSION

Rice Biomass Production in the Wet Season 2003-04 and the Dry Season 2004

The average biomass production, including rice grains, rice straw, and rice residues, and their standard deviations for the WS 2003-04 and the DS 2004 are presented in Table 2 and 3, respectively. In the WS 2003-04, overall production of the IT + RS treatment was significantly higher than the other treatments ($p < 0.05$). The magnitudes of improvement were about 80%, 43%, and 52% over the 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 suggests that returning rice straw may improve the microbial activities, soil organic carbon, and soil physical properties, since the soil organic carbon in most rice producing area is low, ranging between 1 – 1.5 %.. Consequently, the soil fertility in term of biological, physical and chemical properties increase leading to better crop performance and rice yield. This result 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.

Significant enhancement of biomass production at IT+RS treatment also proved that to reach potential yield are not only macro nutrients needed, but micro nutrients contained in the straw as well. This finding also suggests that returning rice straw contribute Si needed by rice to overcome the levelling of. Therefore, it also can be said that combination between inorganic fertiliser and organic fertiliser is essential not only to improve soil properties, but to reach the optimal rice yield in term of agronomic and economical aspects as well. 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 rice biomass production. The standard deviations were small indicating the soil variability within treatment or farmers is small.

Table 2. Biomass production in the WS 2003-04 (mean ± standard deviation).

Treatment	Biomass production (Mg 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 significantly different according to Duncan's test. p denotes significance of the effect (p – value ANOVA).

Table 3. Biomass production in the DS 2004 (mean ± standard deviation).

Treatment	Biomass production (Mg 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 significantly different according to Duncan's test (5%). p denotes significance of the effect (p – value ANOVA).

The same as observed in the WS 2003-04, rice grain, rice straw, and rice residue production 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 3). The reasons given for the WS 2003-04 were also fit for the DS 2004. The data of rice biomass production in the wet and dry seasons also demonstrated that profitable and sustainable of rice farming in terraced paddy field system can only be achieved when the rice straw is returned combined with proper inorganic fertilizers.

Seasonal Biomass Production

Amounts of rice grain, rice straw, and rice residue produced in the wet and dry seasons have been compared in Table 5. Statistically, there were no significant variations of rice biomass production between the WS 2003-04 and the DS 2004 ($p > 0.05$ see Table 5). When the rice straw addition is considered, data indicated that only rice grain production of the dry season consistently was greater than the rice grain production of the wet season; however, the statistical differences were not really observed, only tended to increase (Table 5). This was most probably because of higher photosynthesis products during the dry period. Enough water and more available solar radiation during the dry period make better photosynthesis process resulting in more assimilate produced and it was trans-located to the grains. So far, significant seasonal variations were also observed in rice straw yield ($p < 0.05$).

The straw 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). 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 during harvest period may be the main reason, since the rice residue at harvest consists of roots and stubbles. 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 that in the harvest of WS 2003-04, there were more green leaves, unproductive tillers, and taller

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

Treatment	Biomass production (Mg ha^{-1} season^{-1})		
	Rice grain	Rice straw	Rice residue
+ RS (DS 2004)	5.01 ± 1.01 a	5.85 ± 0.90 b	5.93 ± 0.89 a
- RS (DS 2004)	4.08 ± 0.56 b	5.31 ± 0.63 b	5.42 ± 0.69 a
+ RS (WS 2003-04)	4.78 ± 1.16 ab	6.82 ± 1.05 a	5.76 ± 1.73 a
- RS (WS 2003-04)	3.67 ± 0.66 b	5.75 ± 0.72 b	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 significantly different according to Duncan's test (5%). p denotes significance of the effect (p – value ANOVA).

Table 5. Seasonal variations of rice grain yield, rice straw production, rice residue production, nutrient concentrations, and nutrient uptake at harvest (mean ± standard deviation).

Season	Yield ($Mg\ ha^{-1}$)	Nutrient concentration (%)			Uptake ($kg\ ha^{-1}\ season^{-1}$)		
		N	P	K	N	P	K
Rice grains:							
WS 2003-04	4.24 ± 1.07 a	1.26 ± 0.12 a	0.15 ± 0.03 a	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 ± 0.03 a	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 ± 0.01 a	2.05 ± 0.36 a	62.87 ± 18.60 a	5.08 ± 1.18 a	132.56 ± 38.73 a
DS 2004	5.58 ± 0.79 a	1.09 ± 0.14 b	0.08 ± 0.01 a	2.17 ± 0.30 b	61.21 ± 15.47a	4.62 ± 0.99 a	119.56 ± 28.21 a
	(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 ± 0.01 a	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 ± 0.01 a	1.89 ± 0.21 a	31.66 ± 8.90 a	4.14 ± 0.82 a	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 significantly different according to Duncan's test (5%). p denotes significance of the effect (= p-value ANOVA).

plants than in the DS 2004. Indeed, significant seasonal variations of plant heights were detected at 60 DAT, 90 DAT and at harvest (data not presented).

N, P, and K Concentrations and Uptakes during Rice Growth

Average and standard deviations of N, P and K concentrations in shoots and roots of the rice plants during growth for the WS 2003-04 and the DS 2004 are given in Table 6 and 7. In the WS 2003-04, the concentrations of N, P, and K in shoots and roots significantly decreased by the time of rice growth ($p < 0.05$). Decreasing nutrient concentrations may be related to the increasing of physiological activities to completely develop the vegetative and the generative components. So, translocation of photosynthesis products to the above and under ground part of rice plant is broken down to enhance the development of rice growth.

The highest concentrations of N, P, and K in all parts of the rice plants were observed at 45 DAT, representing end of the vegetative or the beginning of the reproductive phases. Similarly, Mikkelsen *et al.* (1995), Anonymous (1977) and Uexkull (1970) reported that assimilates produced during vegetative to flowering stages are trans-located to stem and leaves, while from flowering to ripening they are stored in grains. 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 standard deviations during rice growth illustrate variations due to the treatments (Table 6).

Like happening in the WS 2003-04, in the DS 2004 concentrations of N, P, and K in shoots and roots significantly decreased by the time of rice growth and development ($p < 0.05$). The highest concentrations of N, P, and K in all parts of the plants were observed at 45 DAT, representing end of the vegetative or the beginning of the reproductive phases. The concentrations of N, P, and K in shoots were 2.65 ± 0.46% N, 0.21 ± 0.03% P, and 3.41 ± 0.24% K and in roots 1.57 ± 0.29% N, 0.19 ± 0.03% P, and 3.17 ±

Table 6. N, P and K concentrations in shoots and roots during rice growth in the WS 2003-04 (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

Note: The mean values in the same column followed by the same letter are not significantly different according to Duncan's test (5%).

Table 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 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

Note: The mean values in the same column followed by the same letter are not significantly different according to Duncan's test (5%).

0.33% K. The standard deviations during rice growth illustrate variations due to the treatments (Table 7).

The data also indicated that during rice growth both in the WS and DS, 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 components, 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 (Mikkelsen *et al.* 1995; Anonymous 1977; Uexkull 1970). It is also noticed that between 45 and 90 DAT, N and P in the plant shoots decreased about 50%, showing that N and P demand during periods of panicle initiation to flowering was the highest. Therefore, it will be more useful when the N and P fertilizers are split in to two or three time's application.

Comparing Table 6 and 7, it seems that the N, P and K concentration in the shoot and root of the dry season 2004 was higher that for the wet season 2003-04. In the shoot, the differences varied from 0.09 to 0.19% N, 0.02% P and 0.07%, while in the root 0.05 – 0.16% N and 0.06 – 0.22% K depending upon the development of rice growth. Indeed, the main reason was related to abundance solar radiation, enough water and fewer disturbances during flowering and ripening resulting in more active photosynthesis activities. However, significant seasonal variations were not observed both in the shoot (Table 8) and in the root (Table 9).

Seasonal Variations of Nutrient Concentrations and Uptake at Harvest

At harvest, nutrients contents were separately estimated for rice residues (stubbles and roots), rice

Table 8. 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 significantly different according to Duncan's test (5%). p denotes significance of the effect (= p-value ANOVA).

straw, and rice grains (Tables 5, 8 and 9). 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 varied between 1.26 ± 0.12 and 1.30 ± 0.09% N and from 0.15 ± 0.03 to 0.16 ± 0.03% P, while the K concentration in straw was from 2.05 ± 0.36 to 2.17 ± 0.30% K (Table 5). Similar results were also reported in many studies (Sukristiyonubowo *et al.* 2004; 2003; Ghildyal 1971; Naphade and Ghildyal 1971; Sanchez and Calderon 1971). Furthermore, Ghildyal (1971) and Naphade and Ghildyal (1971) observed that concentrations of N and P in rice grains are higher than in rice straw.

Furthermore, seasonally the nutrient concentration in rice grain, rice straw, and rice residues in the dry season was higher than in the wet season, proving that physiological activities like respiration and assimilation in the dry period were more intense (Table 5) even during rice growth and development both in the above and under ground part of rice, however, statistical evidences were not observed (Table 8 and 9).

Contrary to the concentrations, the N, P, and K uptakes increased in accordance to the rice growth. This is due to a significant increase of rice plant height and completion of generative components during rice growth leading to increasing the weight of rice biomass. Nutrient uptakes by rice plants at harvest 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). Depending on the season, the nutrient uptakes were about 53-56 kg N, 6-7 kg P, and 13-15 kg K ha^{-1} $season^{-1}$; 61-63 kg N, 5 kg P, and 120-133 kg K ha^{-1} $season^{-1}$; and 29-32 kg N, 4 kg P, and 99-109 kg K ha^{-1} $season^{-1}$ for rice grains, rice straw, and rice residues, respectively.

Seasonal variations of nutrient at harvest showed that in grains, straw and residues the nutrient uptakes in the DS were higher than in the WS, but statistical evidences are not consistent ($p > 0.05$). Only K uptake in the WS in the rice straw was found to be higher (Table 5). In addition, the yield of rice straw was higher in the WS than in the DS due to the presence of unproductive tillers occurring during ripening. So far, considering the N and P uptake by rice grains, the data showed that N and P taken up by rice grains in the DS 2004 were significantly higher than in the WS 2003-04. This was due to significant higher rice grain yield and nutrients (N and P) concentration in the DS 2004 than in the WS 2003-04. Similarly, Uexkull (1970) reported that rice grains yield and nutrient uptakes in the DS are greater than in the WS.

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. Depending upon the planting season, the total removal ranged between 114 and 119 kg N, 10 and 12 kg P, 133 and 148 kg K ha^{-1} $season^{-1}$ (Table 5). So far, except for K, seasonally, the nutrient removal in the DS 2004 was bigger than the WS 2003-04. The differences were

Table 9. 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 significantly different according to Duncan's test (5%). p denotes significance of the effect (= p-value ANOVA).

about 4.51 kg N and 0.20 kg P ha^{-1}. The 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 WS 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.

CONCLUSIONS

Application of inorganic fertiliser with the rates of 100 kg ha^{-1} $season^{-1}$ each of urea, TSP, and KCl along with rice straw recycled of about 33% of the previous rice straw production (IT+RS treatment) significantly improved rice biomass production both in the wet season 2003-04 and the dry season 2004. Furthermore, there were no statistically significant seasonal variation of rice biomass production although the rice grain yield in the dry season 2004 was higher than in the wet season 2003-4. Concentrations of N, P, and K in shoots and roots significantly decreased during rice growth both in the wet season 2003-04 and the dry season 2004. The highest nutrient concentrations were observed 45 days after transplanting both in the wet and the dry seasons. Contrary to the concentrations, the N, P, and K uptake increased in accordance to the rice growth and the highest nutrient uptake was found at the harvest. Seasonal nutrient uptakes at harvest in the dry season were higher than in the wet season, but statistical evidences were not consistent. Depending on the inputs and season, total nutrient removal through rice grains and rice straw varied from 114 to 119 kg N, from 10 to 12 kg P, and from 133 to 148 kg K ha^{-1} $season^{-1}$. Therefore, it is recommended minimal fertilisers to be applied are about 250 - 260 kg urea, 50 – 60 kg TSP, and 250 – 300 kg KCl ha^{-1} $season^{-1}$ to replace the nutrient taken out from the field through harvest product.

REFERENCES

Alice J, RP Sujeetha and MS Venugopal. 2003. Effect of organic farming on management of rice brown plant hopper. *IRRN* 28 (2): 36-37.

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

Aulakh MS, TS Khera, JW Doran and KF Bronson. 2001. Managing crop residue with green, urea, and tillage in a rice-wheat rotation. *Soil Sci Soc Am J* 65: 820-827.

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

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

Cho JY, KW Han, JK Choi, YJ Kim and KS Yoon. 2002. N and P losses from paddy field plot in Central Korea. *Soil Sci Plant Nutr* 48: 301-306.

Cho JY, KW Han and JK Choi. 2000. Balance of nitrogen and phosphorus in a paddy field of central Korea. *Soil Sci Plant Nutr* 46: 343-354.

Clark MS, WR Horwath, C Shennan and KM Scow. 1998. Changes in soil chemical properties resulting from organic and low-input farming practices. *Agron J* 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.

Eneji AE, S Yamamoto and T Honna. 2001. Rice growth and uptake as affected by livestock manure in four Japanese soils. *J Plant Nutr* 123: 333-343.

Fageri NK and CV Balligar. 2001. Improving nutrient use efficiency of annual crops in Brazilian acid soils for sustainable crop production. *Commun Soil Sci Plant Anal* 32 (7 and 8): 1301-1319.

Fenning JO, T Adjie, Gyapong, E Yeboah, EO Ampontuah and G Wuansah. 2005. Soil Fertility status and potential organic inputs for improving smallholder crop production in the interior savannah zone of Ghana. *J Sustain Agric* 25 (4): 69- 92.

Ghildyal BP. 1971. Soil and water management for increased water and fertiliser use efficiency for rice production. In: JS Kanwar, NP Datta, SS Bains, DR Bhumbla and TD Biswas (eds), Proceedings of international symposium on soil fertility evaluation 1, pp. 499-509.

Harrington LS, S Whangthongtham, P Witowat, R Meesawat and S Suriyo. 1991. Beyond on-farm trials: The role of policy in explaining non-adoption of fertiliser to maize in Thailand. In Paper read at 11th annual AFSRE symposium, 5-10 October 1991. Michigan State University, pp: 1-34.

Hasegawa H, Y Furukawa and SD Kimura. 2005. On-farm assessment of organic amendments effects on nutrient status and nutrient use efficiency of organic rice fields in Northern Japan. *Agric Ecosyst Environ* 108: 350-362.

Hay RKM and RA Gilbert. 2001. Variation in the harvest index of tropical maize: Evaluation of recent evidence from Mexico to Malawi. *Ann Appl Biol* 138: 103-109.

Kaleeswari RK and S Subramanian. 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: JS Kanwar, NP Datta, SS Bains, DR Bhumbla and TD Biswas (eds), Proceedings of International Symposium on Soil Fertility Evaluation 1: 391-406.

Mandal UK, G Singh, US Victor and KL Sharma. 2003. Green Manuring: its effect on soil properties and crop growth under rice-wheat cropping system. *Europ J Agron* 19: 225-237.

Mikkelsen DS, GR Jayaweera and DE Rolston. 1995. Nitrogen fertilisation practices of lowland rice culture. p: 171-223.

Min YK, CS Myung and KK Min. 2007. Linking hydro-meteorological factors to the assessment of nutrient loading to stream from large plotted paddy rice fields. *Agric Water Manage* 87: 223-228.

Mohammad SZ, M Mohamad, A Muhammad and AG Maqsood. 1992. Integrated used of organic manure and inorganic fertilisers for cultivation of lowland rice in Pakistan. *Soil Sci Plant Nutr* 38: 331-338.

Mosser SB, B Fell, S Jampatong and D Stamp. 2006. Effect of pre anthesis drought, nitrogen fertiliser rate and variety on grain yield, yield component and harvest index of tropical maize. *Agric Water Manage* 81: 41-58.

Naphade JD and BP Ghildyal. 1971. Influences of puddling and water regimes on soil characteristics, ion uptake and rice growth. In: JS Kanwar, NP Datta, SS Bains, DR Bhumbla and TD Biswas (eds), Proceedings of international symposium on soil fertility evaluation 1, pp. 510-517.

Ray SS and RP Gupta. 2001. Effect of green manuring and tillage practices on physical properties of puddled loam soil under rice-wheat cropping system. *J Indian Soc Soil Sci* 49 (4): 670- 678.

Sanchez PA and M Calderon. 1971. Timing of nitrogen application for rice grown under intermittent flooding in the coast of Peru. In: JS Kanwar, NP Datta, SS Bains, DR Bhumbla and TD Biswas (eds), Proceedings of international symposium on soil fertility evaluation 1, pp. 595-602.

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

Singh B, RK Niranjan and RK Pathak. 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, VP Singh and KS Reddy. 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. *J Indian Soc Soil Sci* 49: 430-435.

Siswanto AB. 2006. Profile description of wetland rice in Babon Catchment. Field trip report. 3 p.

Soepartini M. 1995. Status kalium tanah sawah dan tanggap padi terhadap pemupukan KCl di Jawa Barat. *Pemb Penel Tanah* 13: 27-40.

Soil Research Institute. 2009. Procedure to measure soil chemical, plant, water and fertiliser. Soil Research Institute, Bogor. 234 p (in Indonesian)

Stoorvogel JJ, EMA Smaaling and BH Janssen. 1993. Calculating soil nutrient balances in Africa at different scales. I. Supra-national scale. *Fert Res* 35 (3): 227-236.

Sukristiyonubowo and E Tuherkih. 2009. Rice production in terraced paddy field systems. *J Pen Pert Tan Pangan* 28 (3): 139-147.

Sukristiyonubowo, F Agus, D Gabriels and M Verloo. 2004. Sediment and nutrient balances under traditional irrigation at terraced paddy field systems. Paper presented at the 2nd 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: AR Maglinao, C Valentin and FWT Penning de Vries (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.

Uexkull HR von. 1970. 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.

Whitbread AM, GJ Blair and RDB Lefroy. 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 Till Res* 54: 63-75.

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

Yang C, L Yang, Y Yang and O Zhu. 2004. Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. *Agric Water Manage* 70: 67-81.