International Journal of Modern Developments in Engineering and Science
Volume 3, Issue 1, January 2024
https://www.ijmdes.com | ISSN (Online): 2583-3138

Integrated Nutrient and Water Management for Improved Rice Production in Rainfed Sandy Soil of Central Vietnam

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***Abstract*: Rice is an important food crop in rainfed lowland area of Central Vietnam. However, there is still problem in nutrient and water management for rice in this area. This study was conducted to evaluated the integrated management of nutrient and water in rainfed lowland sandy soil of Thua Thien Hue province, Central Vietnam. Field experiments was tested in two seasons in 2022 which arranged in a split plot with 2 factors (water management and fertilizer combinations). Results indicated that application of site-specific nutrient management (SSNM) with water supplementary obtained the highest rice yield (4.11 – 4.62 t/ha), soil properties also improved after experiment. In order to maximize profit per unit of area for rice production to overcome the yield gap and soil fertility as well as water problems in the region, SSNM application is recommendation.**

***Keywords*: Nutrient, Paddy rice, Rainfed, Yield, Water.**

1. Introduction

Sandy soils make up 205,698 ha in the coastal zone of the North Central region of Vietnam. Thua Thien Hue province lying in the south of this region has predominantly sandy soils that cover about 46,760 ha of the 84,000 ha cultivated land area [1]. In Central Vietnam, people's livelihood is mainly dependent upon the sustainable production of lowland rainfed rice. Farmers are experiencing an increasing threat to sustainable rice productivity due to unreliable water availability and low soil fertility under rainfed conditions. Low and unstable rice production is leading to increasing poverty in communities.

Rainfed lowland areas of Central Vietnam are characterized by irregular flooding and drainage of the soils during the spring season (Jan-May), and by drying of soils after maximum tillering in the summer season (May- September). In addition, small to medium topographic differences may be causing variability in water availability, especially on the sandy soils. Therefore, the amount and timing of water availability in rainfed lowland rice ecosystems are considered the major constraints to rice productivity. Sandy soils of Thua Thien Hue have extremely low nutrient availability, particularly N, P, and K, low clay content (generally < 5%) and they have low pH when not flooded [1]. These sandy soils are prone to leach nutrients and drain quickly, which restricts N and P availability during crop growth. The unfavorable soil conditions are expected to cause a low yield and a significant impact on the livelihoods of people who depend on the rainfed lowland rice in Central Vietnam. Besides, there has been no data gathered describing the extent and severity of water availability variation and nutrient deficiencies/toxicities in lowland paddy fields under farmer's situations in Thua Thien Hue province of Central Vietnam. Previous studies have shown that imbalanced use of chemical fertilizers, especially those supplying nitrogen, phosphorous, and potassium resulted in the rapid loss of nitrogen from the rice fields, thereby decreasing the fertilizer use efficiency [2], [3]. Moreover, as soil organic matter content decreases the accumulation of mobile ions such as Al and Mn increases, and the ability of a soil to resist pH change declines [4]. There is still limited understanding of the water by nutrient interactions in acid sandy lowland rice soils in the rainfed ecosystem [5]. Detailed on-farm trials will be conducted to examine the effect of water and nutrient treatments and the effect of lime and farm yard manure on rice yields, water and nutrient use efficiency, and nitrogen input saving.

In this background, the objective of this study was to improve the sustainability of rainfed rice production through to examine the effect of water and nutrient treatments and the effect of lime and farm yard manure on rice yields, water and nutrient use efficiency, and nitrogen input saving.

2. Materials and Methods

A. Treatments and Crop Performance Parameters

Detailed on-farm trials were conducted in Quang Loi commune, Quang Dien district, Thua Thien Hue province, Central Vietnam and arranged in a split-plot design with two water management treatments (fully rainfed and supplementary irrigation at panicle initiation stage) in main plots and seven integrated nutrient and soil amendment treatments in sub-plots: control (P1); farmers' fertilizer practice of N120-$P_2O_5$40-K_2O30/ha (P2); balanced NPK fertilizer N100-$P_2O_5$60-K_2O60/ha /ha (P3); N100-$P_2O_5$60-K_2O60/ha + 500 kg lime/ha (P4); N50- $P_2O_5$40-K_2O30 + 5 t FYM/ha (P5); N50-$P_2O_5$40-

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Table 1
Soil properties before experiments

Season	pH_{KCl}	OC (%)	N_{tot} (%)	P_2O_{5tot} (%)	$P_2O_{5avail.}$ (%)	K_2O_{tot} (%)	CEC (cmolc/kg)	Sand (%)
Spring 2022	4.54	0.75	0.03	0.040	4.40	0.15	2.04	84.4
Summer 2022	4.50	0.80	0.04	0.035	6.50	0.21	2.40	84.0

Table 2
Characteristics of cattle manure applied in rice trial (elements in % dry matter)

Cattle manure characteristics	Water (%)	C/N	N (%)	P (%)	K (%)
Spring 2022	37.83	21.12	0.81	0.15	0.49
Summer 2022	40.21	20.15	0.80	0.20	0.46

K_2O30 + 500 kg lime + 5 t FYM/ha (P6) and; applying nutrients based on SSNM practice (P7), in which SSNM concept described by [6], [7] is implemented. In this treatment, N, P & K fertilizers were applied to the plot following the results done by [8] with 100N-40P_2O_5-60K_2O. In addition, N splitting and timing of split applications were finetuned using a SPAD chlorophyll meter. There were 3 replications. The experiments were conducted in the Spring season 2022 and Summer season 2022. For the supplementary irrigation treatment, water will be pumped to maintain standing water from the expected period of water deficit during maximum tillering to panicle initiation.

Nitrogen, phosphorous, and potassium were applied through urea (46% N), thermophosphate (16.5% P_2O_5) and muriate of potash (60% K_2O). Total FYM and P were applied as basal fertilizer combined with one-third of N and K just before sowing. The remaining two-thirds of N and K were applied at two stages: tillering and panicle initiation for rice crops.

A Chinese variety of rice frequently used in Central Vietnam, Khang Dan 18 *(Oryzae sativa L.)* which is a pure line variety, was grown by sowing directly in these trials.

At the maximum tillering stage, we collected leaf samples for analyzing N, P, and K contents. At the physiological maturity stage (when the grain of the lower portion of secondary and tertiary panicles reached the hard dough stage and began to lose their green color), we collected yield component samples from two 0.25 m^2 quadrats in the sampling zone surrounding the grain yield harvest area. The variables recorded at harvestable maturity included: the number of all panicles in the 0.5 m^2 area, total spikelets per panicle, filled spikelets per panicle, and 1,000 filled grains weights. Plot grain yield was measured from a 4 m^2 harvested area, centered within the treatment plot to be sampled. Harvest index define as a ratio between economical yield and biological yield [9].

B. Analyses of Soils and Plant, Farm Yard Manure

Composite soil samples were collected (0-20 cm depth) at two different times, before and after the experimentation. Soil chemical properties analyses included pH_{KCl}, EC, organic C, total N, total and available P_2O_5, total K_2O, CEC (cation exchange capacity), and soil texture. The analyses were performed using the methods according to classical laboratory procedures that are described in the extended soil analyses book of [10]. The following characteristics are measured: pH of soil-1M KCl suspensions (1:5 ratio), electrical conductivity (EC) and pH_{H2O} of soil-water suspension (1:5 ratio), organic carbon (C, Walkley and Black method), total nitrogen (N, Kjeldahl method), total phosphorus (P_{tot}, extraction with aqua regia), available phosphorus (P_{av}, Bray II method), and cation exchange capacity (CEC, extraction of exchangeable cations by 1M NH_4OAc, pH 7, desorption of NH_4^+ by 1M KCl). Soil properties before experiments were as shown in Table 1.

Samples of farm yard manures were collected before applying them in field trials. Samples of plants and farm yard manure were dried at 70ºC for the determination of N content and 105°C for 6 hours for total C, P, and K concentrations. The following characteristics were measured: total nitrogen (Kjeldahl method), total phosphorus, and total potassium (HNO_3: $HClO_4$ digestion); approximate organic carbon was estimated by loss to ignition at 550°C: carbon was considered to represent 55% of weight loss, according to [11]. All the analyses were carried out at the Soil Science Department of the University of Agriculture and Forestry, Hue University. The analyzed characteristics of the organic amendment are presented in Table 2.

In general, the quality of cattle manure used in the trials was reasonably good in terms of C/N value and N content. The C/N value of the organic amendment was found to be low to moderate, as a ratio of around 20 is considered optimal for adequate mineralization and nutrient availability.

C. Data Analysis

The results from field experiments were analysed by using statistic program including Statistix Version 10 (America). Descriptive statistics, analysis of variance (General AOV/AOVC), comparisons of means using least significant difference (LSD), and correlation analysis were used for the analysis of information about crop yield parameters and soil properties in field experiments.

3. Results and Discussion

A. Rice Yield

Data from Table 3 indicated that the number of panicles per unit area and 1000-grain weight at the treatments with the SSNM appeared to be significantly superior to the treatments without inorganic fertilizer or manure across the fully rainfed and supplementary irrigation. This implies that the enhanced supply of nutrients along with organic amendments contributed to increasing plant stand and individual grain weight. However, the treatments appeared mostly at par for the number of total and filled spikelets per panicle. This is probably due to the compensating effect of an increased number of panicles per unit area in the treatments with higher nutrient supply [12].

The yield components and final grain yield seemed to be largely influenced by the FYM rates and N-P-K fertilization. Our results corroborated the earlier finding that panicle density is the most important component of yield in direct water-seeded

Table 3
Yield components and yield of rice in spring and summer season 2022

Water management	Fertilizer	No. of panicle/m²		No. of fill spikelets/panicle		Theory yield (t/ha)		Actual yield (t/ha)		Harvest index (%)	
		Spring 2022	Summer 2022	Spring 2022	Summer 2022	Spring 2022	Summer 2022	Spring 2022	Summer 2022	Spring 2022	Summer 2022
Fully rainfed	P1	260.7c	244.9b	75.4bc	62.6d	4.25d	2.96e	2.55d	2.22d	38	36
	P2	347.0ab	274.6ab	77.9bc	72.0cd	6.38bcd	3.78d	3.59c	2.91c	43	39
	P3	321.6b	302.8a	95.4b	90.6ab	6.72bc	5.32b	4.28ab	3.39abc	44	39
	P4	319.2b	304.4ab	85.9abc	85.6ab	5.99bcd	5.19bc	4.34ab	3.47ab	46	41
	P5	375.1a	304.0a	84.4abc	83.5ab	6.81bc	5.18bc	3.98b	3.24bc	46	42
	P6	321.2b	297.6ab	71.6c	81.3bc	5.12 cd	4.74c	4.07b	3.49ab	47	45
	P7	362.3a	309.9a	95.7a	94.1a	7.59a	6.09a	4.52a	3.82a	53	50
Supplementary irrigation	P1	291.9b	246.7c	84.1b	56.5d	5.92a	2.75e	2.66d	2.37d	39	37
	P2	304.9ab	279.3bc	99.0ab	69.1c	6.61a	3.89d	3.81c	3.03c	46	42
	P3	310.7ab	325.0a	97.1ab	82.1b	6.96ab	5.76c	4.32ab	3.63ab	47	44
	P4	290.7b	292.3ab	101.3ab	89.5ab	6.68a	5.59c	4.41ab	3.87ab	51	49
	P5	346.8a	296.6ab	99.9ab	88.2ab	7.66b	5.68c	4.06b	3.78ab	47	46
	P6	327.0ab	279.8bc	109.6a	96.6a	7.49b	6.08b	4.17ab	3.81ab	48	47
	P7	316.9ab	308.3ab	106.5a	94.3a	7.63b	6.57a	4.62a	4.11a	54	52

Means followed by the same letter(s) within the columns do not differ significantly at P < 0.05

Table 4
Effect of water and nutrient management on leaf N, P, K content

Water management	Fertilizer	Spring 2022			Summer 2022		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Fully rainfed	P1	2.25	0.22	1.40	2.43	0.29	1.44
	P2	2.24	0.28	1.45	2.41	0.31	1.44
	P3	2.54	0.35	1.42	2.42	0.41	1.45
	P4	2.58	0.45	1.45	2.48	0.34	1.46
	P5	2.50	0.42	1.50	2.36	0.33	1.56
	P6	2.46	0.39	1.55	2.39	0.37	1.50
	P7	2.45	0.40	1.56	2.52	0.36	1.60
Supplementary irrigation	P1	2.35	0.32	1.55	2.40	0.31	1.54
	P2	2.45	0.35	1.55	2.50	0.31	1.50
	P3	2.50	0.42	1.60	2.44	0.39	1.64
	P4	2.51	0.40	1.65	2.41	0.35	1.62
	P5	2.50	0.45	1.56	2.43	0.44	1.54
	P6	2.55	0.40	1.60	2.49	0.44	1.66
	P7	2.64	0.45	1.62	2.55	0.43	1.58

rice [13], [7]. As shown in Table 3, the actual grain yield was always smaller than the theoretical grain yield estimated from yield components. The theoretical grain yield of rice ranged from 2.96 - 4.25 t/ha in the spring and summer seasons with control treatment having the lowest grain yield. This is because the yield component analysis does not take proper account of missing hills or those damaged by insects and diseases. Furthermore, post-harvest losses in rice often surpass 20% [14].

The actual grain yield with rainfed ranged from 3.59 - 4.52 t/ha and supplementary irrigation ranged from 3.81 - 4.62 t/ha in the spring season. The actual grain yield in the summer season is lower than in the spring season with all fertilizer combinations. The actual grain yield in treatments with irrigation was higher than in fully rainfed treatments. This is consistent with the study of [15] which reports SSNM only increases yield by 0.19 ton per hectare and is not statistically significant.

The SSNM approach encourages farmers to apply phosphorus and potassium within 14 days after transplanting and apply potassium at panicle initiation stage of the crop growth. Since potassium plays an important role in increasing the size and weight of the grains, it follows that yield increases [16].

Harvest index (HI) in the spring season ranged from 38 – 54% and the summer season ranged from 36 – 52%. The highest HI was found at SSNM from 53 – 54% in the spring season and from 50 – 52% in the summer season. The significance of water interval on reproductive parameters may be due to significant effect of water management on the number of tillers, this result confirmed with [17] who applied that water regime management significantly affected number of tillers and the interaction between water regime management and varieties was also significant. Among straw and grain yield the significant differences may be due to the small total dry matter which related to the relatively shallow root system and stomata closure and reduced photosynthesis in response to surface soil drying which agreed with [18].

B. Interaction Between Water and Nutrients on Rice Yield

There was a relationship between water and nutrient management on rice yield in spring and summer seasons. High correlations were found (R^2 from 0.76 to 0.87 in two seasons). In the spring season, the effect of water on rice yield with supplementary irrigation was not different with fully rainfed (R^2 = 0,76 and 0,78, respectively), because there is high rainfall amount in this season. In contrast, it was found a higher correlation between water and nutrient management in rice yield with supplementary irrigation than fully rainfed in the summer season (R^2 = 0.87). It is widely known that positive interactions of nutrient and water improve rice growth and final yield by coordinating source-sink relationships [19].

Table 5
Effect of water and nutrient management on average soil properties after experiment in both seasons

Water management	Fertilizer	pH_{KCl}	pH_{H2O}	OC (%)	N (%)	P_2O_5 (%)	P_2O_5 (mg/100g)	K_2O (%)	CEC (cmolc/kg)
	P1	4.48	5.32	0.81	0.042	0.043	6.50	0.20	2.42
	P2	4.50	5.29	1.12	0.040	0.045	6.54	0.22	2.44
	P3	4.62	5.46	1.34	0.041	0.047	6.15	0.24	2.50
Fully rainfed	P4	4.65	5.50	1.29	0.044	0.045	7.09	0.23	2.46
	P5	4.59	5.57	1.38	0.045	0.048	8.45	0.19	2.53
	P6	4.69	5.64	1.39	0.042	0.051	8.80	0.24	2.61
	P7	4.68	5.65	1.42	0.046	0.050	10.10	0.20	2.60
	P1	4.53	5.40	0.83	0.040	0.044	6.40	0.19	2.40
	P2	4.55	5.36	0.95	0.042	0.048	6.65	0.21	2.51
	P3	4.64	5.49	1.36	0.042	0.046	6.17	0.25	2.55
Supplementary irrigation	P4	4.72	5.53	1.58	0.044	0.041	5.95	0.24	2.62
	P5	4.60	5.61	1.79	0.046	0.045	7.89	0.26	2.72
	P6	5.12	5.87	1.50	0.040	0.049	9.56	0.25	2.70
	P7	5.10	5.95	1.68	0.046	0.052	11.21	0.27	2.84

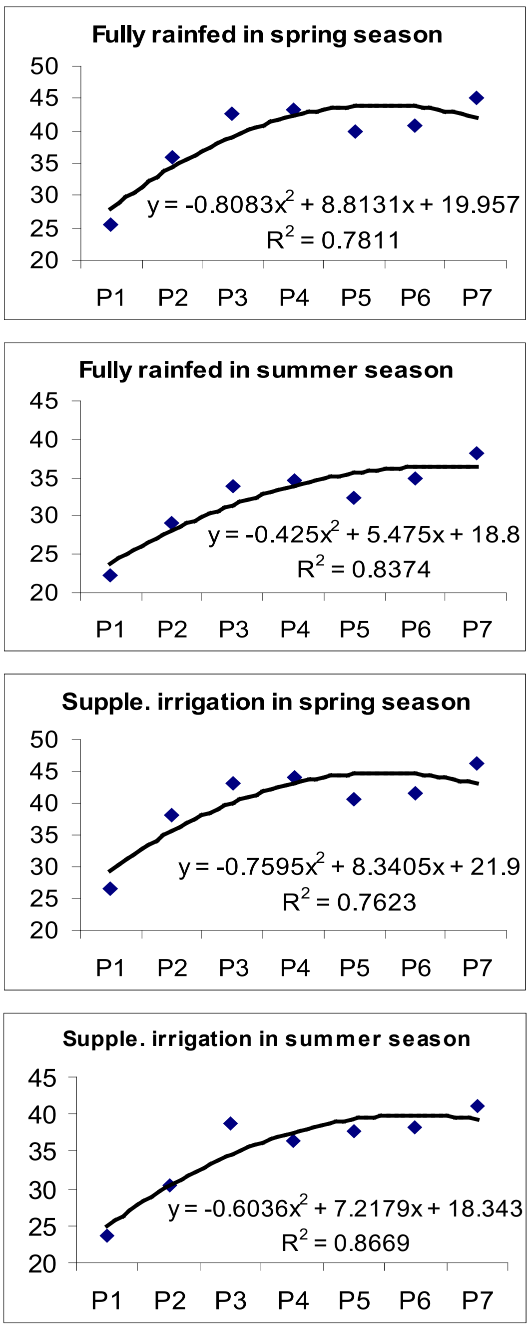

Fig. 1. Interaction between water and nutrient management on rice yield

C. Leaf N, P, K Content

Nutrient concentration was determined over two seasons. The means of nutrient concentrations in rice leaves is presented in Table 4.

For rice, leaf %N at the fully rainfed conditions and supplementary irrigation ranged from 2.24 to 2.58%, 2.35 to 2.64% in the spring season, respectively, and from 2.39 to 2.52%, 2.39 to 2.45% in the summer season. Leaf %N contents in SSNM treatment with supplementary irrigation were observed higher than in fully rainfed conditions. [20] suggested a critical leaf blade %N of 2.5 at tillering (45 DAT), suggesting that N deficiency may have occurred in P2, P3, and control treatments.

There were effects of irrigation and fertilizer treatment on leaf %P for rice across seasons. Analyses of individual treatments revealed that the range in rice leaf %P was from 0.22 to 0.45%. The critical limits for rice straw %P at maturity were 0.08 to 0.10% [21]. However, [22] observed that rice responded to P application when P concentration in leaf blade at tillering was 0.37%, and P% in sprinkler-irrigated treatments in rice was around 0.18% showing deficiency symptoms. These findings suggest that P deficiency undoubtedly occurred in different treatments at different crop seasons.

The mean %K in rice leaf was from 1.40 to 1.66% compared with reported critical values for %K in rice grain of 0.4% [23].

D. Soil Properties After Field Trials

Data in Table 5 indicated that treatments receiving fertilizer had higher chemical properties than the no-fertilizer check in both seasons. Changes in the pH_{KCl} values depended on water and fertilizer management. An increase in fertilizer with liming application increased pH_{KCl} in both fully rainfed and supplementary irrigation management. The average maximum pH_{KCl} was 5.12. Organic C was also affected by fertilizer application. The highest organic C was 1.97% at SSNM treatment. N content was 0.046%. Similarly phosphorous, potassium, and CEC. CEC value was 2.84 cmolc/kg. It has been reported that the application of organic matter, such as animal manure, can increase N, P availability in highly weathered soils [24], [25]. With SSNM, fertilizer application is timed to match supply and peak demand periods for each nutrient for a particular crop, increasing nutrient uptake and nutrient use efficiency and soil properties [15].

4. Conclusion

This study assessed the efficiency of water and nutrient management on sustainable rice yield in rainfed lowland soil of Thua Thien Hue province, Central Vietnam. Water and nutrient management are likely to be the most important step towards improving food crop productivity in the study region. Despite some differences in the efficiency of the nutrients examined, we observed that fertilizer combination as well as water management had positive impacts on rice yield and improvement of soil properties. The highly pronounced response of crops to water and nutrients signifies that both of them are two of the major limiting factors in the prevailing cropping systems. The highest rice yields were obtained in treatments with an application of SSNM in experiment fields. It was similar to the harvest index. It was shown that soil fertility was improved with water and nutrient management for rice. There were some positive changes in pH_{KCL}, OC, total N, P and K, and CEC in rice. SSNM practice had improved all soil properties better than others. The best levels of fertilizer application for rice were 5 t ha^{-1} of FYM combined with 100 kg N, 60 kg P_2O_5, 60 kg K_2O, and 500 kg lime ha^{-1} and supplementary irrigation. The study findings hold promise to be recommended to farmers to maximize profit per unit of area for rice production to overcome the yield gap and soil fertility as well as water problems in the region.

Acknowledgements

This work was partially supported by Hue University under the Core Research Program, Grant No. NCM.DHH.2020.07.

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