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On-farm assessment of site-specific nutrient management for rainfed lowland rice in the Philippines

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ABSTRACT

Rice yield in the drought-prone rainfed lowlands is constrained by low availability of nutrients and water. Fertilizer applications currently conducted by farmers may not match the crop demands nor be resource-use efficient. The objective of this study was to characterize the farmers' practices of nutrient management (FP) in rainfed lowland environments, and compare it with the site-specific nutrient management guideline by using decision-support software (*Rice Crop Manager*; RCM) in terms of rice yield and production cost. On-farm trials were conducted in northern Philippines in the wet seasons of 2011–2014. Average application rate of N, P and K in RCM was 82, 10 and 21 kg ha^{-1}, respectively, while the application rate was 93, 11 and 18 kg ha^{-1} in FP (n = 93). Grain yield in FP, which ranged from 1.82 to 6.49 t ha^{-1}, was significantly enhanced by RCM by 6% on average (4.48 vs. 4.22 t ha^{-1}). The yield difference was mainly associated with the different N application regimes in RCM and FP. Average number of N applications was 1.94 in FP with 52% of total N applied during the first 15 days after transplanting while there were 2.63 applications in RCM with 29% applied during the first 15 days after transplanting and 44% at panicle initiation, respectively. Total cost for fertilizer was comparable or lower in RCM than FP, and hence the net income was increased by 154 US$ ha^{-1}. The results of this study showed that site-specific nutrient management improved productivity and profitability in rainfed lowlands of the Philippines.

1. Introduction

Of the 161 million ha of rice (*Oryza sativa* L.) area in the world, about 31% are rainfed lowlands where rice is grown with non-continuous flooding of variable depth and duration (GRiSP, 2013). The rainfed lowland ecosystem in Asia covers about 45 million ha (Haefele et al., 2014). In this ecosystem, the drought-prone lowlands with shallow water depth are equally distributed between South and Southeast Asia (15.3 and 16.1 million ha, respectively). Rainfed lowland rice is grown mostly in the rainy season, with > 80% of the annual rainfall deposited within a few months. As a consequence of the low and unstable system productivity, poverty is widespread and often severe in the communities largely dependent on rainfed rice farming.

The Philippines has 4.7 million ha of rice area, composed of irrigated (3.2 million ha) and rainfed (1.5 million ha) with an average yield of 4.30 t ha^{-1} and 2.98 t ha^{-1}, respectively (PSA-BAS, 2016). Due to erratic rainfall patterns, the main abiotic stress affecting productivity in rainfed lowlands is drought (Wade et al., 1999; Haefele et al., 2006; Fukai and Ouk, 2012), while submergence frequently happens after typhoons in the low-lying areas (Marler, 2014). To date, a series of varieties adapted to water stresses have been released in all the countries in South and Southeast Asia (Kumar et al., 2014; Mackill et al., 2012), giving us an opportunity to improve natural resource and crop management in rainfed lowlands (Haefele et al., 2016).

For rainfed lowland rice, low soil fertility is another major yield constraint. Rainfed lowlands have often poorer soil fertility than irrigated environments (Haefele et al., 2014). Nutrient management in rainfed lowland rice is a challenging task due to unpredictable water conditions in the field (Wade et al., 1999). Farmers often apply fertilizer inefficiently, with regards to the amount and type of fertilizer at a certain rice growth stage, causing low recovery efficiency of fertilizer. Thus an appropriate nutrient management strategy could help to maximize the return from farmers' investments in fertilizer. Availability of ponded water is considered beneficial for the application of fertilizers, and regular drought occurrence in rainfed lowlands leads to low agronomic efficiency of nutrient (i.e., low rice yield per nutrient input)

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(Haefele et al., 2010; Linquist and Sengxua, 2001). Upon the disappearance of standing water, nutrient fixation in the soil is considered to be another factor lowering nutrient-use efficiency (Kato et al., 2016; Kato and Katsura, 2014). In addition, rice doesn't respond to N topdressing under drought stress, but N topdressing is important for growth recovery upon rewatering or rainfall (Prasertsak and Fukai, 1997). This was validated by multi-location trials of nutrient management in rainfed lowland rice in Bangladesh, Indonesia, India, Thailand and Philippines (Wade et al., 1999). Nevertheless, positive yield response to balanced fertilizer application compared with no nutrient input can be expected even under drought in on-farm trials (Haefele et al., 2013).

It is widely recognized that existing fertilizer recommendations for most rainfed environments are still blanket (i.e., one recommendation applied to large regions), mostly ignoring the high spatial and temporal variability of water availability and topographic influences (Haefele et al., 2016). Therefore, a single recommendation for highly variable field conditions in the rice ecosystem can result in low agronomic efficiency (Dobermann and White, 1999). Although the soil test-based nutrient management, i.e., calculation of necessary amount of fertilizer of each rice field based on the soil chemical properties, was considered in the past, Dobermann et al. (2003) showed a poor relationship between soil nutrient status determined by basic soil analysis and rice yield in nutrient omission plots, which serves as a field measure of indigenous nutrient supply. On the other hand, leaf color chart (an indicator for leaf N status)-based N management greatly contributed to the improved fertilizer N-use efficiency (Alam et al., 2006), but it is not applicable to basal fertilizer and other nutrients such as P and K (Buresh et al., 2010; Dobermann et al., 2002b). Site-specific nutrient management (SSNM) was developed as an integrated nutrient management strategy, taking into account the quantitative relationship of nutrient supply and crop demand for each field which varies tremendously in space and time in most rice systems (Dobermann et al., 2002a, 2003; Witt et al., 1999). Consequently, the concept of "feed the crop as needed" has been shown to increase the economic viability of rice farming for farmers (Peng et al., 2010). A number of studies have shown that SSNM could optimize nutrient management for a given soil fertility in irrigated ecosystems (Buresh et al., 2005; Wang et al., 2007; Pampolino et al., 2007; He et al., 2008; Stalin et al., 2008). In the Philippines, a dissemination program of SSNM for irrigated rice through a decision-support software (*Nutrient Manager for Rice*, upgraded to *Rice Crop Manager*, hereafter RCM) was conceptualized and started in 2008 (Buresh and Witt, 2008). RCM takes a heuristic approach which does not require rigorous soil analysis to make a decision on nutrient management, because the majority of smallholder rice farmers in the tropics lack access to soil testing services. However, since not only soil fertility but also water condition vary greatly among fields, our current understanding on SSNM may not be enough to improve rice yield and economic viability (i.e., net benefit) in rainfed lowlands. Therefore, a careful analysis of SSNM use in on-farm trials is needed for further enhancing rainfed lowland rice yield.

Our overall aim is to develop integrated crop and natural resource management for the stress-prone rainfed lowlands in the Philippines. The specific objective of this study was to assess the current farmers' practices of nutrient management (FP) in rainfed lowland rice, and to evaluate rice yield and economic viability of SSNM in on-farm trials by evaluating the decision support software (RCM) in comparison to FP.

2. Materials and methods

We selected 16 municipalities from 9 provinces in northern Philippines (northern and central Luzon island; Pangasinan, La Union, Ilocos Sur, Ilocos Norte, Isabela, Tarlac, Nueva Ecija, Bulacan, and Zambales) for on-farm trials during the wet seasons of 2011–2014 with 93 farmers in total (Table 1 and Fig. 1). These provinces have more than 10,000 ha of rainfed rice area or over 25% of total rice area is rainfed (Philippine Rice Research Institute, 2008). The whole region is located in the warm humid tropics with a rainy season from June to November. Intermittent drought often occurs at any time of the crop growth in the wet season, while flooding is rarely a problem in the target region. Long-term mean wet season (June-November) rainfall in the region ranges from 1600 to 2800 mm and the average annual temperature is around 24–27° C (The World Bank: Climate Change Knowledge Portal, 2016). At each village, collaborating farmers were selected based on their interest in using their own fields.

Table 1
Number of on-farm trials for the validation of site-specific nutrient management in drought-prone rainfed lowlands of the Philippines.

Year	Province (number of farmers' fields in parenthesis)	Field trial number (n)
2011	Pangasinan (10), Tarlac (9)	19
2012	Nueva Ecija (8), Tarlac (9)	17
2013	Ilocos Norte/Sur (5), La Union (2), Pangasinan (9), Isabela (3), Zambales (9), Nueva Ecija (2), Bulacan (4)	34
2014	La Union (4), Pangasinan (4), Zambales (11), Bulacan (4)	23
Total		93

2.1. Experimental layout

Two nutrient management treatments were compared in each farmer's field; FP and RCM (http://webapps.irri.org/ph/rcm/). The plot size of each treatment was 500 m^2. Rice was grown under rainfed lowland conditions. The recommended amount of fertilizer in RCM was calculated by the software for each field, using information on the history of the field collected through one-to-one interviews with the farmers. In FP, the nutrient management was according to the participating farmers' own decisions. In each year, new sets of farmers were chosen in different districts. Other than fertilizer applications, the agronomic practices followed the farmers' practices in both treatments. Application of fertilizers and field monitoring were done by researchers in coordination with the farmers. Varieties used were chosen by farmers for their field. Popular varieties planted by farmers were mostly irrigated varieties such as NSIC Rc222, NSIC Rc160, NSIC Rc216, PSB Rc10 and PSB Rc18, with growth durations ranging from 106 to 123 days. When the soil became saturated after receiving ample rainfall, the fields were puddled for rice planting, mostly by using two-wheel tractors. Common practice for crop establishment in the region was transplanting using 25–30 day-old seedlings, while some farmers practiced wet direct seeding at the seeding rate of 120–200 kg ha^{-1}. A combination of hand weeding and use of herbicides and insecticides to control weeds and insects was common practice among farmers.

2.2. The concept of SSNM and the algorithm of RCM

The principles for determining field-specific fertilizer N, P and K requirements in SSNM enable the determination of crop requirements for fertilizer N using a yield gain approach, and for fertilizer P and K using a field-level nutrient balance approach (Dobermann et al., 2002b). Fertilizer N required by a cereal crop to achieve an attainable target yield is determined from the anticipated yield gain to application of fertilizer N and a target efficiency of N fertilizer use to attain the target yield. On the other hand, the crop requirement for fertilizer P or K to achieve a target yield is estimated from the deficit in the nutrient balance (Buresh et al., 2010).

Based on the above principles of SSNM, RCM determines the optimal rate of fertilizer for rice, using the yield level obtained without fertilizer application and the target yield. Twenty-three questions are asked to farmers to generate recommendation per field by the software, such as size of the landholding, political unit (region, province, district