DECOMPOSING RICE YIELD GAPS IN SOUTHEAST ASIA

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INTRODUCTION

The global population is increasing with a projection of 9 billion people by 2050 (ALEXANDRATOS & BRUINSMA, 2012). Tied to population growth is the food demand, especially for less developed countries in Asia, Africa and Latin America where the projections for food insecurity are worrisome (GODFRAY et al., 2010; ALEXANDRATOS & BRUINSMA, 2012). With rice (*Oryza sativa* L.) as the main staple food for more than half of the world's population (PANDEY et al., 2010), and the need to supply the future global rice demand, studies are necessary to identify how food production can be increased sustainably. To supply the future rice demand, food production can be increased by expanding the farming area, or by sustainably increasing the yield of the current farming area. However, is well known that agriculture faces enormous challenges due to declining farmland, water, resources and rural labor (ROSEGRANT & CAI, 2002; BOUMAN et al., 2007; LAMPAYAN et al., 2015), so productivity raise must also ensure the resource use efficiency and reduction of environmental footprint.

One of the strategies to expand the food production and meet the future food demand, is by closing the existing yield gap (FOLEY et al., 2011). Yield gap studies play a key role in food security studies, as they can estimate the difference between the actual farmers yield (Ya), and the potential yield (Yp) of crops (VAN ITTERSUM & RABBINAGE, 1997; EVANS & FISCHER, 1999); identify major factors limiting yield; and provide inputs that can drive research, development and interventions (VAN ITTERSUM et al., 2013).

Southeast Asia (SE Asia) is one the major rice production regions in the world, responsible for 28% of the total rice production, with an average yield of 4.3 t ha^{-1} (FAO, 2019). Previous studies estimated the rice yield potential and yield gaps across countries in SE Asia (AGUSTIANI et al., 2018; LABORTE et al., 2012; STUART et al., 2016), but there's still a gap of information about the importance of the major direct factors affecting yield gaps, which can be estimated by decomposing the yield gap. Regarding the importance of explaining the rice yield gap in Southeast Asia, the aim of this study is to provide a comparison of yield gaps and their determinants across rice bowls in SE Asia, identifying how much of the yield gap can be explained directly by the environmental conditions, genetics and manageable factors.

MATERIAL AND METHODS

The study area consists of four intensive lowland irrigated rice areas in Southeast Asia:

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Yogyakarta (Indonesia), Bago (Myanmar), Nakhon Sawan (Thailand) and Can Tho (Vietnam), as these countries represent c. 84% of SE Asia rice production (FAOSTAT, 2019). At each location, survey respondents were randomly selected from a list of rice farmers in each of four geographical units (i.e. village or commune), except for Thailand where a complete enumeration of farmers from each village community rice centers was conducted. Farmers were surveyed using a structured questionnaire to collect data on crop management practices (i.e. variety, crop establishment method, planting date, variety) and rice production output (t ha^{-1}). From the survey data, the Actual farmer's yield (Ya) was extracted, and it represents the mean grain yield.

The crop model ORYZA v3 (LI et al., 2017) was used to estimate Yp for each farmer in this study. The model simulated the Yp in 'exploration' mode, assuming no water and nitrogen limitation (i.e. water and nitrogen balance = off). To decompose the yield gaps, three variations of Yp were estimated for each field: modeled yield potential for optimum sowing date (Yp_a); Modeled yield potential for highest yielding variety (Yp_b); Modeled yield potential at field level (Yp_c).

To quantify and explain rice yield gaps in Southeast Asia, we decomposed the yield gap into three categories: The Yield gap (Yg) is the total yield gap and is defined as the difference between Yp_a and Ya. The Environmental yield gap (Yg_e) is the difference between Yp_a and Yp_b. This yield gap captures the effect of the environmental conditions; The Genetic yield gap (Yg_g) is defined as the difference between Yp_b and Yp_c. This yield gap captures the effect of the rice variety on Yp; The Management yield gap (Yg_m) is defined as the difference between Yp_c and Ya and quantifies the remaining yield gap that is not explained by the sowing date or rice variety.

RESULTS AND DISCUSSION

The yield potential across the rice bowls in study ranged from 8.6 t ha^{-1} to 10.4 t ha^{-1} for the wet season, and from 9.2 t ha^{-1} to 11.8 t ha^{-1} for the dry season (Table 1). The higher yield potential for the dry season can be explained by the higher availability of solar radiation during the growing season, as to estimate the Yp, water is not considered a limiting factor on this study. Table 1 show the results of the Yg decomposition, which is detailed below.

Table 1 – Decomposition of rice yield gaps in Southeast Asia. Yp_a: modeled yield potential for optimum sowing date (t ha^{-1}); Yp_b: modeled yield potential for highest yielding variety (t ha^{-1}); Yp_c: modeled yield potential at field level (t ha^{-1}); Ya: actual farm yield (t ha^{-1}); Yg: total yield gap (t ha^{-1}); Yg_e: environmental yield gap (% of Yg); Yg_g: genetic yield gap (% of Yg); Yg_m: management yield gap (% of Yg).

Country	Season	Yp_a	Yp_b	Yp_c	Ya	Yg	%Yg_e	%Yg_g	%Yg_m
Myanmar	Dry Season	10.8	8.8	8	2.7	8.1	24.3%	9.6%	66.2%
	Wet Season	9.8	8.6	8.2	2.5	7.2	16.0%	5.6%	78.4%
Vietnam	Dry Season	11.8	11.6	11.4	7.9	3.9	5.0%	4.7%	90.6%
	Wet Season	10.1	8.7	7.3	4.9	5.2	27.0%	28.7%	45.0%
Thailand	Dry Season	9.2	7.7	7.7	4.6	4.6	32.4%	0.0%	68.0%
	Wet Season	8.6	7.6	7.6	4.8	3.8	26.0%	0.0%	74.0%
Indonesia	Dry Season	10.4	7.6	7.1	4.9	5.5	52.4%	8.6%	44.8%
	Wet Season	10.4	9.2	8.7	4.8	5.6	21.8%	8.6%	71.2%

Myanmar is the country with the largest yield gap (8.1 t ha^{-1} and 7.2 t ha^{-1}, for dry and wet seasons, respectively). Myanmar is a low intensively managed system, driven mainly by the management practices adopted by the farmers, e.g. low fertilizer rate, low seed quality and poor weed and water management (NAING et al., 2008), which reduces the actual yield, being the Yg_m the major Yg cause in Myanmar. The use of low yielding varieties by the farmers are not a major constraint, as the Yg_g represents 5.6-9.6% of the total yield gap.

Vietnam is the rice bowl with the higher Ya, reaching 67% of the Yp in the dry season, close to the exploitable yield (80% of Yp) that has been proposed and used as the economic optimum level of production (LOBELL et al., 2009). Considering that 90.6% of the Yg is caused by management factors in dry season, a fine tune in management practices can be proposed in Vietnam, but the main focus in Vietnam should regard the reduction of production costs and environmental impact, as the Ya is near the optimum yield. The use of high yielding varieties on wet season can contribute to reduce Yg, as this season have the largest Yg_g among the sites/seasons in study.

In Thailand the study was not able to capture the genetic role on Yg, as for the country there was only one variety calibrated in the ORYZA model. Considering that c. 30% of the Yg is caused by environmental conditions, one of the strategies for Thailand farmers increase their yields is the adjustment of the sowing date, as fields sowed near the optimum window reduces the risk of extreme conditions during the critical phases of the crop. The authors acknowledge that the optimum sowing date was not established considering water limitations, which can be limiting factor for rainfed cropping systems.

The Yg_e in the dry season of Indonesia is the largest relative Yg_e across the sites in study, regarding that sowing date is a major limiting factor for Indonesia. The dry season in Indonesia have a large sowing window, mainly because the country has three growing seasons/year, and some farmers might have provided unprecise information, which extended the sowing window of this study. For the wet season, the main limiting factors are related to the management practices adopted by the farmers. Besides the yield increase, Indonesian farmers can reduce costs and environmental impact caused by misuse of nitrogen fertilizer, as one of the farming characteristics of Indonesia is the use of high N rates, above the crop requirement.

CONCLUSION

There is a wide yield gap across the farming systems in Southeast Asia, ranging from 8.6 t ha^{-1} to 10.4 t ha^{-1} for the wet season, and from 9.2 t ha^{-1} to 11.8 t ha^{-1} for the dry season. The decomposition of yield gaps using the modelling approach, imply that each rice bowl has their particularities regarding the major limitations of yield. The adjustment of the sowing date to provide better environmental conditions to the crop, is a practice that can be used by farmers to reduce the environmental yield gap, without increase costs or input use. The genetic yield gap represents the smallest portion of Yg, as the majority of the farmers are already using high yielding varieties. Best management practices can be proposed to farmers to reduce the management yield gap and contribute to the global food security and reduction of environmental impact.

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