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Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management

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ABSTRACT

Rising incomes and changing dietary requirements are swiftly transforming maize (*Zea mays L*) in Southeast Asia from a food staple into an important industrial commodity. Increased maize production is required to meet rising demands, but additional production should come from the sustainable intensification of existing farmlands to minimize the undesirable effects of agriculture on the environment. We hypothesize that maize yields, profit, and N use efficiencies can be significantly increased through site-specific nutrient management (SSNM), thereby reducing yield gaps in the region. Through a combined approach of simulation modeling and on-farm research in at least 65 sites in 13 major maize-producing domains across Indonesia, Vietnam and the Philippines from 2004 to 2008, we were able to (a) quantify maize yield gaps and yield responses to fertilizer application, (b) evaluate the agronomic and economic performance of SSNM, and (c) evaluate the incremental profitability of SSNM in various production and grain and fertilizer price scenarios. The average exploitable yield gap between the attainable yield and current farmers' yield in Southeast Asia was about 0.9 t ha^{-1}. Yield responses to fertilizer application across the region followed the order N > > P > K. Yield response to N was higher in irrigated sites than in rainfed sites (6 t ha^{-1} versus 2 t ha^{-1}), while P and K fertilizer responses were similar across production systems (<2 t ha^{-1}). Yield with SSNM was 1.0 t ha^{-1} (+13%) higher than the current farmers' fertilizer practice (FFP) measured in the same cropping seasons. Yield increases were associated with a 10% decrease in the average N rate, but with increased application of K at sites where the previous K rates were low. Average N use efficiency increased by 42%, mainly by adjusting the rates and timing of N application to the stages of crop development. Across all sites and seasons, profitability increased by US$167 ha^{-1} per crop, which was equivalent to15% of the total average net return. Opportunities for achieving higher income over the FFP (≥US$100 ha^{-1} season) were greatest in highly favorable rainfed environments; less favorable rainfed areas were vulnerable to unfavorable market prices. We conclude that SSNM has the potential to close existing yield gaps in the maize production systems of Southeast Asia by improving yield, nutrient use efficiency, and profitability.

1. Introduction

Maize in Southeast Asia is swiftly being transformed from a food staple into an important industrial commodity. Rising incomes and the consequent growth in meat and poultry consumption have resulted in a rapid increase in demand for maize as feed for the livestock industry. It is projected that by 2020, maize requirements in East and Southeast Asia may rise to 291 million tons (IFPRI, 2001); current maize production total 250 million tons (FAOSTAT, 2013).

Additional maize production should largely come from the sustainable intensification of existing farmlands to minimize negative impacts on the environment (Pretty, 2008; Tilman et al., 2011). Much attention has been given recently to intensification prospects from closing yield gaps (Lobell et al., 2009; Licker et al., 2010; Grassini and Cassman, 2012). The term 'yield gap' (Y_g) commonly refers to the difference between the potential yield (Y_p, in irrigated systems) or water-limited yield (Y_w, in rainfed conditions) and the actual yield (Y_a) achieved in farmers' fields (Lobell et al., 2009). The

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Y_p is the yield of a crop cultivar grown in environments to which it is adapted, without limitations from water, weeds, nutrients, pests, or diseases (Van Ittersum and Rabbinge, 1997). In rainfed systems, water-limited yield (Y_w) – defined similarly as Y_p, but crop growth is limited by water supply – is the more relevant benchmark. Y_p and Y_w are commonly estimated using crop simulation models.

Closing this yield gap, however, is neither possible nor cost-effective for farmers as yield response to applied inputs follows the law of diminishing returns (Koning et al., 2008; Lobell et al., 2009). Management objectives should, therefore, aim for closing gaps at a lower yield level of about 75–85% of Y_p or Y_w, otherwise called the exploitable yield gap (Van Ittersum et al., 2013). Fischer et al. (2009) and Fischer and Edmeades (2010) defined the exploitable yield gap as the difference between the economically attainable yield (Y_{att}) and Y_a. Hall et al. (2013) used different methods to estimate Y_{att}. In this paper, we estimate Y_{att} as the yield achieved in farmers' fields with current best crop management practices and where nutrients are not limiting. This is not the same as Y_w in rainfed systems, although it may approximate the latter in some sites if the current management practice is optimal.

Mueller et al. (2012), in their global-scale assessment of yield gaps, found considerable yield-gain opportunities from improving water and nutrient management. Site-specific nutrient management (SSNM) is defined as the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their variation in time and space. SSNM has shown the potential to close existing yield gaps in the intensive rice cropping systems of Asia (Dobermann et al., 2002) and irrigated wheat in northwest India (Khurana et al., 2008). The SSNM approach was originally based on a modification of the QUEFTS model (Janssen et al., 1990; Smaling and Janssen, 1993) that required information on the yield potential and yield goal, estimates of the indigenous nutrient supply, recovery efficiencies of applied fertilizer, plant nutrient accumulation and its relationship to grain yield (Dobermann and Witt, 2004). The approach has since been systematically transformed into a simplified framework that estimates fertilizer requirements based on an established attainable yield target and the anticipated crop response to fertilizer application using the omission plot technique (Dobermann et al., 2003; Pampolino et al., 2007; Buresh et al., 2010).

As farmers strive to close yield gaps in their fields, they are faced with many uncertainties and risks that will likely affect their decision to adopt a new promising technology (Feder and Umali, 1993; Marra et al., 2003). These uncertainties are typically related to climatic variation affecting crop production or to market fluctuations affecting the profitability of the innovation. As on-farm research usually does not capture adequately the full extent of climatic variability in a location due to the limited time that experiments could be continued in the field, crop simulation models, when driven by long-term weather data, are excellent tools for assessing weather-induced risks to crop production (Angulo et al., 2012; Van Ittersum et al., 2013). Monte Carlo simulation is another useful tool in quantitative risk analysis and decision-making. It works by modeling possible outcomes using probability distributions for any input factor that has inherent uncertainty. Results show not only the outcome, but also the likelihood of that outcome occurring. Scenario analysis allows the evaluation of the effect of different combinations of values for different inputs (e.g., yield, grain and fertilizer prices) on the outcome (e.g., profit).

In this paper, we applied a combined simulation and on-farm research approach to: (1) quantify yield gaps and yield responses to fertilizer application in the major maize production systems of Indonesia, the Philippines, and Vietnam, (2) evaluate the agronomic and economic performance of SSNM adapted for maize in closing the existing yield gaps, (3) evaluate the incremental profitability of SSNM in various production, grain and fertilizer price scenarios.

2. Materials and methods

2.1. On-farm research approach

On-farm trials to develop and evaluate SSNM for hybrid maize were conducted for three years at major centers of maize production in Indonesia (2004–2007), the Philippines, and Vietnam (2005–2008) covering a wide range of agroecological zones in favorable rainfed and irrigated maize environments (Fig. 1, Table 1). Each site was selected to represent a large area with similar soils and cropping systems. In each domain, on-farm experiments were conducted in at least five farmer's fields. In general, farmers were

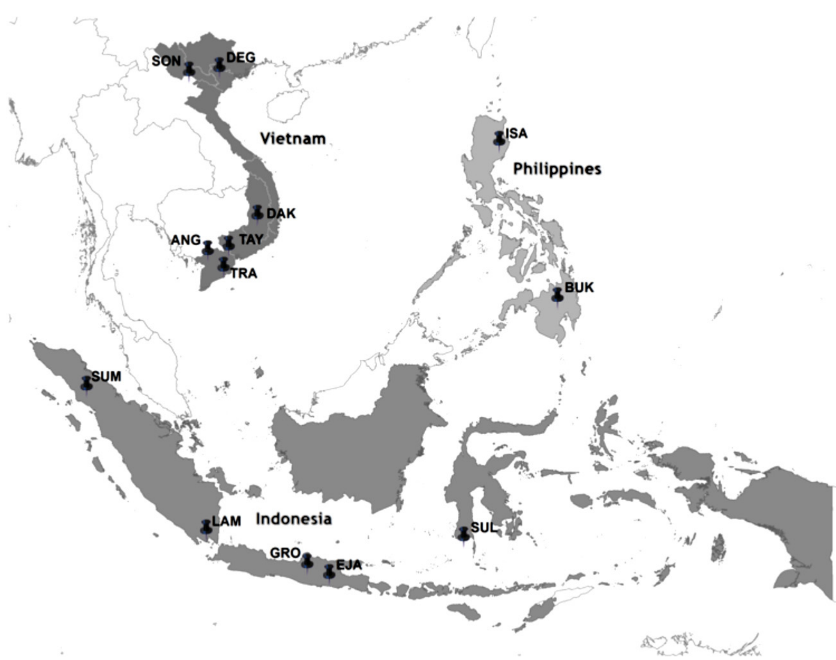

Fig. 1. Location of on-farm trial sites in Indonesia, Vietnam and the Philippines.