#7581 NUTRIENT MANAGEMENT TAILORED TO SMALLHOLDER AGRICULTURE ENHANCES PRODUCTIVITY AND SUSTAINABILITY

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ABSTRACT

Plant nutrition plays a central role in the global challenge to produce sufficient and nutritious food, lessen rural poverty, and reduce the environmental footprint of crop production. Efficient fertilizer use requires tailored solutions that are scientifically sound, practical and scalable especially for smallholder farmers, such as the crop-led site-specific nutrient management (SSNM) approach developed in the 1990s for cereal production systems in Asia to address variability among farms. Originating from a simple model to calculate crop nutrient requirements, this unique approach has evolved over 25 years, covering a growing number of crops and countries in Asia and Africa with development of digital tools and dissemination approaches. We performed a meta-analysis using 61 published papers across 11 countries to compare SSNM with the farmer fertilizer practice (FFP), for rice, wheat and maize. Overall, relative to the FFP, grain yield was 0.7 Mg ha^{-1} (12%) greater with SSNM, and this was achieved using about 20 kg N ha^{-1} less nitrogen (N) fertilizer; associated with greater agronomic N use efficiency under SSNM than the FFP (17 vs 12 kg grain kg^{-1} N applied). This was likely because SSNM had more splits of N fertilizer than FFP, which was applied in better congruence with key periods of crop growth and N demand, thereby reducing N pollution to the environment and sustaining soil health. Moreover, the benefits with SSNM were achieved through balanced nutrition, with application of the same amount of phosphorus (P) but higher potassium (K) rates than FFP. In countries where grain yield with the FFP was high, a substantial reduction in N application rate with SSNM resulted in greater improvement of N use efficiency and reduced N loss and this was especially the case for China across the three crops. In contrast, larger yield gains were observed for farmers who typically attain low yields than farmers that already have high yields. Such cases were mainly observed in Africa and South Asia. We know no other agronomic intervention that has increased crop yield, profitability, and N use efficiency across three cereal crops and geographies. This approach represents a win-win situation from which millions of smallholder farmers could benefit.

INTRODUCTION

Nutrient management is an important component for sustainable crop production to meet the challenges of rising food demand driven by population growth, while protecting the environment. Production of cereal crops increased significantly in the developing world since the 1960's, largely due to increased use of fertilizer and agrochemicals, coupled with adoption of improved, high yielding varieties, and increased access to irrigation (Pingali, 2012). However, the orientation of producing more food has been associated with overuse of fertilizers, although fertilizer use has been widely variable across regions and crops (FAO, 2006; Lu and Tian, 2017). More than 50% of the global nitrogen (N) is used in Asia while less than 5% is used in Africa (Heffer et al., 2017). While low fertilizer us in Africa has been associated with low crop productivity, in Asia fertilizers have been overused, with losses to the environment; both cases affect sustainability of cropping systems. Scientifically sound, tailored nutrient management solutions that are scalable are needed especially in smallholder farming systems.

The site specific nutrient management (SSNM) approach, developed in the 1990's to calculate field specific requirements for fertilizer N, P and K for cereal crops (Dobermann et al., 2004) can potentially contribute to the attainment of sustainable cropping systems. This approach was initially conceptualized for rice cropping systems in Asia, based on principles from the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model (Janssen et al., 1990) to estimate fertilizer nutrient requirements as the difference between the total amount of nutrient required by the crop to achieve a specific target yield and the indigenous supply of the nutrient (Witt and Dobermann, 2004). SSNM was shown to improve crop yields, nutrient use efficiency and profit versus the farmer fertilizer practice (FFP), which is often based on blanket recommendations (Dobermann et al., 2002; Pampolino et al., 2007; Peng et al., 2010; Wang et al., 2001), sometimes while reducing fertilizer application (Peng et al., 2010). The timing of fertilizer application is adjusted to meet peak crop demand to enhance nutrient use efficiency.

This unique approach has evolved over 25 years, covering a growing number of crops (Khurana et al., 2008; Witt et al., 2006) and extended to other geographies in Asia and Africa (Saito et al., 2015). The advancements in information and communication technology, the SSNM approach have led to the development of digital tools (Buresh et al., 2019; Pampolino et al., 2012; Saito et al., 2015) for wider dissemination of SSNM recommendations to smallholder farmers. In this study we conducted a meta-analysis using 61 published papers to provide a comprehensive and systematic evaluation of the performance of SSNM in terms of grain yield, N use efficiency and profit compared to the FFP for three cereal crops; maize, rice and wheat.

MATERIALS AND METHODS

We conducted a meta-analysis using data collected from 61 published studies conducted in 11 countries in Asia and Africa. A literature search was conducted on major search engines using search terms: site-specific nutrient management (SSNM), SSNM rice, SSNM maize, SSNM wheat, SSNM cereals, SSNM vs farmers' fertilizer practice (FFP). We focused on rice, wheat and maize, which account for an estimated 43% of the world's food calorie supply and consume about half of the world's NPK fertilizers annually. To be included in this meta-analysis, studies should have reported grain yield under SSNM and FFP, and other agronomic management practices were similar between SSNM and FFP. Of the reviewed studies, 65, 21, and 14% were on rice, wheat and maize, respectively; all conducted in Asia, except three papers on rice in Africa.

Means for grain yield, agronomic N use efficiency (AEN) under SSNM and FFP were retrieved from each study. Site characteristics including location, study duration, soil properties, climatic conditions were recorded. Management practices were also recorded. We calculated partial factor productivity of N (PFP N), another index for N use efficiency, based on grain yield and total N fertilizer applied, using the following equation:

$$\text{PFP N} = GY_N \text{ (kg ha}^{-1}\text{)/ N rate (kg N ha}^{-1}\text{)}$$

Where GY_N is the grain yield in a treatment with N application and GY_0 is the grain yield in a treatment without N application.

We also calculated economic performance of SSNM compared to FFP: total fertilizer cost (TFC), gross return, and gross return above fertilizer cost (GRF) using the following equations:

$$\text{TFC (US\\$ ha}^{-1}) = (pN \times N_{rate}) + (pP \times P_{rate}) + (pK \times K_{rate})$$

$$\text{Gross return (US\\$ ha}^{-1}) = FGP \times GY$$

$$\text{GRF (US\\$ ha}^{-1}) = \text{Gross return} - TFC$$

Where pN, pP, pK = prices of N, P and K fertilizers, respectively (US \$ kg^{-1}); N_{rate}, P_{rate}, K_{rate} = amount of N, P and K applied (kg ha^{-1}); FGP = farmgate price of paddy rice, maize or wheat (US\$ kg^{-1}); GY = grain yield of paddy rice, maize and wheat (kg ha^{-1})

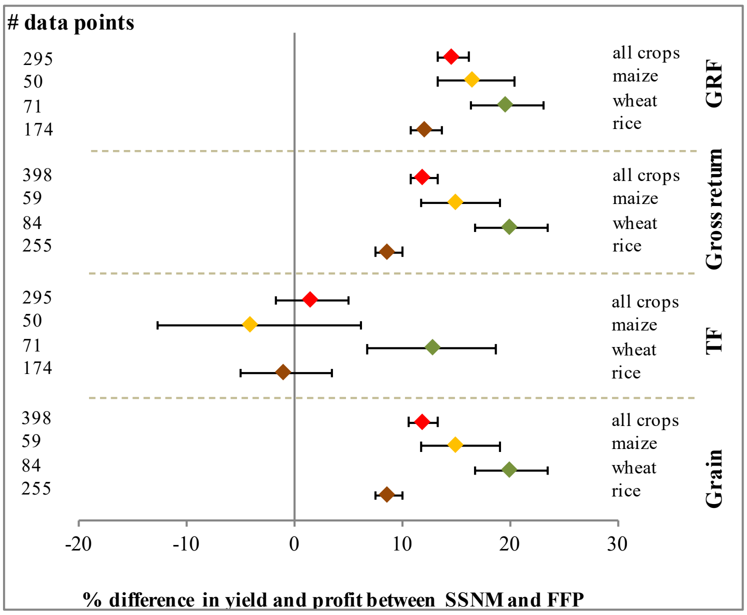
We estimated fertilizer prices from the 10-year average across countries listed in the database (indexmundi, 2020) and reported as per unit of nutrient; US\$ 0.642 kg^{-1} N, US\$ 2.151 kg^{-1} P, and US\$ 0.633 kg^{-1} K. We used grain prices of US\$ 0.25 kg^{-1} paddy rice, US\$ 0.15 kg^{-1} maize and US\$ 0.20 kg^{-1} wheat based on the trend of the market prices over the last 25 years.

Grain yield, N fertilizer rates, number of N splits, AEN, PFPN and economic parameters were analyzed using MetaWin 2.1 software (Rosenburg et al., 2000).

RESULTS AND DISCUSSION

Overall, relative to the FFP, SSNM increased grain yield, gross return on fertilizer, agronomic efficiency of N (i.e., additional grain yield per kg of fertilizer N applied), by 12, 15, and 46% respectively (Fig. 1). While mean grain yield increases were 0.7 Mg ha^{-1} (12%) across the three crops, greater increases were for wheat (20%), followed by maize (15%), with lowest for rice (9%). Gross return was 12% greater, while gross return above fertilizer cost was 15% higher under SSNM than FFP. This resulted in an average profit of USD 140 ha^{-1} greater under SSNM than FFP. Importantly, grain yield and N use efficiencies were greater with SSNM, but with 20 kg N ha^{-1} (11%) lower N fertilizer rates than FFP. This was because of more N splits under SSNM (3.1) compared to 2.6 times under FFP, and N fertilizer was applied in better congruence with key periods of crop growth and N demand (Cassman et al., 2002), thereby reducing N pollution to the environment and sustaining soil health. This resulted in greater N use efficiency with SSNM than FFP where AEN was 17 kg grain kg^{-1} N applied for SSNM compared to 12 kg grain kg^{-1} N applied for FFP. Similarly, PFP N was 54 and 43 kg grain kg^{-1} N applied for SSNM and FFP, respectively. Moreover, the benefits with SSNM compared to FFP were achieved through balanced nutrition, with application of the same amount of P but higher K rates than FFP. Larger yield gains were observed for farmers who typically attain low yields than farmers that already have high yields. Such cases were mainly observed in Africa and South Asia (data not shown). In contrast, where grain yield in FFP was high, a substantial reduction in N application rate in SSNM resulted in greater improvement of N use efficiency and reduced N loss. This was especially the case for China.

a)



b)

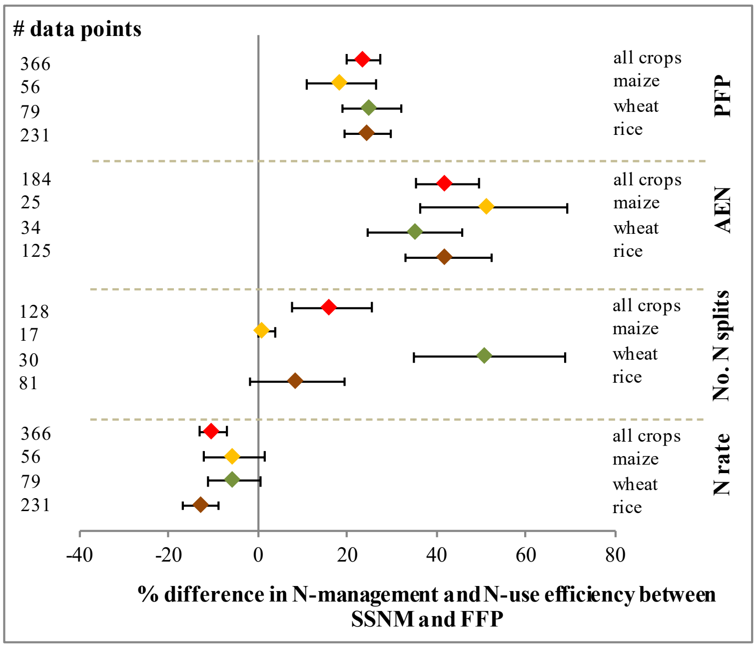


Figure 1. a) Grain yield, total fertilizer cost (TFC), gross return and gross return above fertilizer cost (GRF), and b) N use efficiency (agronomic N use efficiency; AEN, partial factor of productivity; PFP N) responses to site-specific nutrient management (SSNM) compared to the farmer fertilizer practice (FFP) for rice, wheat and maize. Responses are expressed as mean response percentage with 95% confidence intervals represented by error bars. Numbers of effect size comparisons are given as # of data points.

We know no other agronomic intervention that has achieved increase in crop yield, profitability, and N use efficiency across three cereal crops and geographies. SSNM represents a win-win situation from which millions of smallholder farmers could benefit and is an essential component of agronomic solutions for improving crop production. Several digital decision support tools and platforms were recently developed in collaboration with national agricultural extension agencies and other partners to scale out SSNM adoption. Examples include Nutrient Expert (Pampolino et al., 2012; Xu et al., 2017), Rice Crop Manager (Buresh et al., 2019; Sharma et al., 2019), and RiceAdvice (Saito et al., 2015). Evaluation of these tools with smallholder farmers has shown improved yields, profitability and N use efficiency under irrigated and rainfed conditions that are comparable to our meta-analysis, indicating a very robust performance in widely varying environments. Reaching millions of farmers can be achieved through integration of policy incentives, financial and input supply services, and improved knowledge exchange among extension, public and private partners.

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