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Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint

Tek B. Sapkota[a,*], Kaushik Majumdar[b], M.L. Jat[a], A. Kumar[a], Dalip K. Bishnoi[a,c], A.J. McDonald[d], Mirasol Pampolino[e]

[a] International Maize and Wheat Improvement Center, DPS Margh, NASC Complex, New Delhi 110012, India
[b] International Plant Nutrition Institute (IPNI), 354, Sector-21, HUDA, Gurgaon 122016, Haryana, India
[c] Chaudhary Charan Singh Haryana Agricultural University, Hisar 125 004, India
[d] International Maize and Wheat Improvement Center, South Asia Regional Office, Kathmandu, Nepal
[e] International Plant Nutrition Institute, c/o Crop and Environmental Sciences Division, International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila 1301, Philippines

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ABSTRACT

In the high-yielding wheat production systems in Northwest (NW) Indo-Gangetic Plains of India, intensive tillage operations and blanket fertilizer recommendations have led to high production costs, decreased nutrient use efficiency, lower profits and significant environmental externalities. No-tillage (NT) has been increasingly adopted in this region to reduce costs and increase input use efficiency. But, optimal nutrient management practices for NT based wheat production are still poorly understood. Opportunities exist to further enhance the yield, profitability, and resource use efficiency of NT wheat through site-specific nutrient management (SSNM).

On-farm trials were conducted in seven districts of Haryana, India for two consecutive years (2010–11 and 2011–12) to evaluate three different approaches to SSNM based on recommendations from the *Nutrient Expert*® (NE) decision support system in NT and conventional tillage (CT) based wheat production systems. Performance of NE based recommendations was evaluated against current state recommendations and farmers' practices for nutrient management. Three SSNM treatments based on NE based recommendation were (1) 'NE80:20' with 80% N applied at planting and 20% at second irrigation (2) 'NE33:33:33' with N split as 33% basal, 33% at Crown Root Initiation (CRI) and 33% at second irrigation; and (3) 'NE80:GS' with N split as 80% basal and further application of N based on optical sensor (Green Seeker™)-guided recommendations. Yield, nutrient use efficiency and economic profitability were determined following standard agronomic and economic measurements and calculations. Cool Farm Tool (CFT), an empirical model to estimate greenhouse gases (GHGs) from agriculture production, was used to estimate GHG emissions under different treatments.

Wheat grain and biomass yield were higher under NT in 2010–11 but no difference was observed in 2011–12. The three NE-based nutrient management strategies increased yield, nutrient use efficiency as well as net return as compared to state recommendation and farmers' fertilization practice. Global warming potential (GWP) of wheat production was also lower with NT system as compared to CT system and NE-based nutrient managements as compared to farmers' fertilization practice. State recommended nutrient management had similar GWP as NE-based nutrient managements except NE80:GS in which GWP was the lowest. Results suggest that no-tillage system along with site-specific approaches for nutrient management can increase yield, nutrient use efficiency and profitability while decreasing GHG from wheat production in NW India.

1. Introduction

Wheat (*Triticum aestivum* L) is the most important cereal crop and stands next to rice in India. The area under wheat in India is over 29 million hectares (M ha) which is about 24% of the total area under food grains (Majumdar et al., 2013). It is the staple food and

* Corresponding author. Tel.: +91 8377004282.
E-mail addresses: t.sapkota@cgiar.org, teksapkota@yahoo.com (T.B. Sapkota).

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meets about 61% of the protein requirement of India. Therefore, assured supply of wheat is essential for food security of the country. Current production is sufficient to meet the wheat demand of India, but the country has to increase wheat production from 93 Mt per annum at present to 105 Mt per annum by 2025 to meet the increasing demand (Prasad, 2011). As no additional land is available for wheat area expansion, this increase in wheat production has to come through increased yield per unit of production area. However, the production data for wheat in India shows no significant increase in productivity over last ten years (2000–2010) (Fertilizer Statistics, 2010–11). Various factors may be responsible for stagnating wheat yields in NW India such as late planting, inappropriate crop establishment, inadequate and imbalance nutrient management, and degrading soil health. Growing labour and water shortages, increasing cost of fuel, changing climatic conditions are likely to further affect the productivity of wheat adversely (Gathala et al., 2011; Saharawat et al., 2010).

Traditionally, wheat is grown in the winter season following rice. Farmers typically perform multiple tillage operations after rice harvest to prepare field for wheat planting. The intensive tillage contributes to an increased cost of cultivation leading to decreased profitability (Chhokar et al., 2007; Ladha et al., 2009). Increased use of machinery and fuel for repeated tillage operations also emits large amount of greenhouse gases (GHGs) into the atmosphere. The use of blanket nutrient management recommendations in India has led to low nutrient use efficiencies, lowered profits and increased environmental problems (Pampolino et al., 2012a). Nutrient recommendations in India are based upon crop response data averaged over large geographic areas and do not take into account the spatial variability in indigenous nutrient supplying capacity of soils (Majumdar et al., 2013). Blanket fertilizer application, therefore, results into under-fertilization in some cases and over-fertilization in other. Surveys in the Indo-Gangetic Plains (IGP) revealed that farmers often apply greater than recommended rates of fertilizer N and P, but ignore the sufficient application of potassium and other secondary and micro-nutrients (Singh et al., 2005). Such unbalanced and inadequate use of nutrients can decrease the nutrient use efficiency and profitability and may increase environmental risks associated with loss of unutilized nutrient through emission or leaching. This further increases the agriculture's share to total GHGs emissions. Therefore, traditional practices of wheat production need refinement to produce more food with less production costs and minimal emissions of GHGs through efficient use of land, labour, nutrient, water and other agro-chemicals.

Recently, conservation agriculture (CA), defined as minimal soil disturbance and permanent organic soil cover combined with efficient and economically viable rotations, has emerged as an important cropping system management strategy to address many of the pressing challenges confronting intensified wheat systems in NW India. NT has been widely adopted by farmers in wheat production, particularly in NW India, primarily to facilitate early planting of wheat in areas where rice is harvested late, to lower production cost and increase yield so as to increase profitability (Chhokar et al., 2007; Jat et al., 2009a,b; Saharawat et al., 2010). With the development of planting equipment that can handle loose straw left in field after combine harvesting of rice and drill seed and fertilizer directly through the residues at appropriate depth (e.g. Turbo happy seeder), farmers are also retaining previous crop residue and moving towards full conservation agriculture based wheat system (Sidhu et al., 2007; Sharma et al., 2012). However, optimal nutrient management practices for wheat under NT with varied levels of surface residues are poorly understood. An opportunity exists to further enhance the yield, profitability, and nutrient use efficiency of these systems through SSNM. SSNM captures the spatial and temporal variability in soil fertility in smallholder production system and provides an approach to "feeding" crops with all the required nutrients based on crop's needs and thus improves the crop yield (Das et al., 2009; Tiwari et al., 2006) and nutrient use efficiency (IPNI, 2013).

On-farm participatory research was conducted in NW Indo-Gangetic Plain (IGP) of India to evaluate SSNM under two contrasting tillage systems (NT and CT). We hypothesized that optimized nutrient management through site-specific approaches would increase yield, improve nutrient use efficiency, enhance the profitability and reduce environmental footprint of wheat production in NW India.

2. Materials and methods

2.1. Study site

The study was conducted in seven districts (Karnal, Kurukshetra, Kaithal, Ambala, Sonepat, Panipat and Yamunanager) of Haryana, India (29°07′15′ N to 30°08′15 N, 75°02′20′ E to 77°04′10′ E). Fig. 1. shows the locations of study area in the IGP of NW India.

2.2. Site characteristics

The climate of the study area is semi-arid with mean annual rainfall varying from 650 mm to 970 mm, about 80% of which is received between June to September. The study area experiences temperature extremes across the year with daily minimum temperature of 0–4 °C in January, daily maximum temperature of 41–44 °C in June, and relative humidity of 50–90% throughout the year. Wheat is grown during the cold and dry winter season from November to April (Timsina and Connor, 2001) wherein wheat crop suffers due to terminal heat in many instances. The study area consists predominantly of alluvial and calcareous soil with low organic carbon and weakly structured, sandy loam to clay loam type of soil (Harrington et al., 1993). Basic soil properties of the study sites are presented in Table 1.

Treatments and experimental details

Fifteen on-farm experiments were conducted in seven districts of Haryana, India in 2010–11 and 2011–12. Each farmer had a complete set of five nutrient management treatments randomized separately under two tillage methods i.e. CT and NT. The five nutrient management treatments included in this study were: (1) NE80:20-Nutrient Expert® (NE) nutrient decision support tool (described below in section 2.4) based recommendation with N rate split as 80% basal and 20% at second irrigation (40–45 days after sowing, DAS); (2) NE33:33:33-NE based recommendation with N rate split as 33% basal, 33% at CRI stage (20–25 DAS) and 33% at second irrigation (40–45 DAS); (3) NE80:GS-NE based recommendation with N rate split as 80% basal and further application of N based on optical sensor (GreenSeeker™) (Bijay-Singh et al., 2011)-guided prescriptions; (4) SR50:50-application based on generalized state recommendation with N rate split as 50% basal and 50% at CRI stage; and (5) FFP-farmers fertilization practice. The plot size ranged from 1000 to 1500 m^2. The trials were mainly managed by farmers with technical advice of researchers but researchers were responsible to collect relevant data from the experimental plots.

2.3. Nutrient Expert®

A recently developed decision support systems (DSS), ***Nutrient Expert***® for wheat, synthesized the on-farm research data into a simple delivery system that enables wheat farmers to rapidly implement SSNM for their individual fields. The Nutrient Expert (NE) DSS for wheat developed and validated by International Plant Nutrition Institute (IPNI) and International Maize and Wheat Improvement Centre (CIMMYT), is an easy-to-use,