SITE SPECIFIC NUTRIENT MANAGEMENT IN MAIZE: A REVIEW

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ABSTRACT

Maize, being a highly nutrient responsive crop, indiscriminate and sole reliance on one or two chemical fertilizers resulted into imbalanced and inadequate nutrient supply to the crop coupled with depletion of soil. However, site specific nutrient management (SSNM) is turning to be a proven technology for higher and efficient nutrient use efficiency by virtue of right time in situ supply of balanced nutrients to the crop. In this light of background, a review of research work done in India and abroad is presented hereunder with the emphasis on impact of SSNM on growth parameters, yield attributes, yield, nutrient uptake and status in soil and economics of maize crop. It is obvious from the reviews that adoption of SSNM in integration of organic sources improves yield performance of maize besides improvement in nutrient uptake and soil nutrient status.

KEY WORDS: Farmers' Fertilizer Practice (FFP), Maize, Site specific nutrient management (SSNM)

INTRODUCTION

Maize (*Zea mays* L.), often referred to as "Backbone of America", "Miracle Crop", "King of Grain Crops" and "Queen of Cereals", is one of the most important cereal crops of worldwide economic importance, together with rice and wheat, provides approximately 30 per cent of the food calories to more than 4.5 billion people in 94 developing countries and the demand for maize in these countries is expected to double by 2050. In India, maize is considered as the third most important food crop among the cereals and contributes to nearly 9 per cent of the national food basket. In India, though maize is traditionally grown during the *kharif* season, presently cultivation of *rabi* maize has opened up a viable alternative where irrigation facilities are available owing to its high productivity potential (Ferguson *et al.*,2002). Application of adequate quantities of nutrients is a key aspect in increasing maize productivity and production, however, balanced supply of nutrients based on the plant demand needs to be focused on knowledge intensive technologies and adoption of the same on individual farms or fields (Dobermann *et al.*, 2003). Inappropriate method of fertilizer application, physic-chemical properties of soil, inadequate supply or even unavailability of fertilizer at the time of requirement, adulteration and high cost are some of the major issues related with dwindled fertilizer use efficiency (FUE) and resulted into meagre crop-fertilizer response (CFR). Large scale applications of nitrogen (N) fertilizer have also shown deleterious effects on ground water quality, especially its nitrate content, which is harmful to soil and human health. Furthermore, gaseous losses of nitrogen as NH; and NO; resulting from nitrogen fertilization had adverse effects on the environment (Ferguson *et al.*, 2002). In this context, Site-Specific Nutrient Management (SSNM) approach is one of such options which focus on balanced and crop need based nutrient application (Johnston *et al.,* 2009). An effective nutrient management involves development of site specific nutrient recommendations including balanced NPK doses, timely application of fertilizer using appropriate methods, development and production of slow-release nitrogen fertilizers and indigenous nitrification inhibitors and developing and practicing an integrated plant nutrient supply system (Prasad, 2009). Therefore, site-specific nutrient management (SSNM) seems to be the possible means of taping the unexploited potential of the crop.

Site specific nutrient management

The SSNM concept was first developed for irrigated rice in Asia (Dobermann *el al.,* 2002; Witt *el al.,* 2007 and IRRI, 2007), but the principles are generic and applicable to the other crops. It aims at improving crop performance and environmental quality by matching resource application and agronomic practices with soil and crop requirements as they vary in space and time (Pierce and Nowak, 1999). The plant's need for fertilizer nitrogen, phosphorus or potassium is determined from the gap between the crop demand for sufficient nutrient to achieve a yield target and the supply of the nutrient from indigenous sources, including soil, crop residues, manures and irrigation water (Sharma, 2011).

Agricultural production being an interactive effect of soil-water-fertilizer-climate continuum, a wise scientific management of this complex system is crucial for enhancing crop productivity on a sustained basis without any detrimental effect to the environmental ecology. Among the various inputs, the mineral nutrition of plants is considered as the key input in making maximum contribution to the crop productivity (Streeter and Barter, 1985). About 55 per cent of increase in food grain production during the last two decades has come through increased fertilizer use. However, the total annual removal of plant nutrient by the crops and cropping systems being much higher than the amount added through the fertilizers, has resulted in a negative nutrient balance (Yadav *et al.*,1998). This gap between nutrient removal and their replenishment, imbalanced use of NPK fertilizers and emerging deficiency of secondary as well as micronutrients have led to a decline in crop productivity as well as deleterious effect on soil productivity and health (Swamp, 2002). The law of maximum plant yield (Wallace, 2000) stated that limiting factors interact in a sequentially additive manner so that when they are corrected progressively, more response is obtained from the use of each input. Nitrogen fertilizer requirements depend on many factors, including yield goal, inorganic soil nitrogen, potential nitrogen mineralization and soil type (Schlegel and Havlin, 1995). Climate, soil and management factors cause crop response to nitrogen and the optimal nitrogen rate to vary, both spatially within and between fields and from year to year (Mamo *et al.*, 2003; Scharf *et al.*, 2005 and Schmidt *et al.,* 2007). The SSNM strategy for nitrogen includes the determination of the total fertilizer nitrogen requirement of a maize crop for a given yield target and the distribution of nitrogen applications into 2-3 splits to coincide with plant demand at critical growth stages. The SSNM approach advocates the sufficient use of fertilizer phosphorus and potassium to overcome deficiencies, while simultaneously accounting to some extent for the nutrient removal with harvested products. Thus, site specific management of soil fertility inputs is an attractive and intuitive approach for increasing fertilizer use efficiency (Ferguson *et al.,* 2002) to promote better plant growth to achieve higher yield (Raun *et al.,* 2002) by narrowing down the gap between average grain production and potential production (Lan *et al*. 2008).

Murni *et al.* (2010) reported that a substantial yield gap of about 1 to 2 Mg/ha exists between farmers' actual yield and what is attainable with optimal crop and nutrient management and SSNM provides substantial opportunities for farmers to increase productivity and profitability of maize through improved nitrogen use efficiency with more appropriate fertilizer nitrogen rates and better timing of nitrogen application practiced in the SSNM treatments. Compared with traditional local management practices, SSNM demonstrated 7, 30 and 12 per cent increase in yield, REN and net returns, respectively (Pathak and Ladha, 2011).

Effect on growth parameters of maize

The plant height is an important growth character directly linked with the productive potential of crop. An optimum plant height is claimed to be positively correlated with the productivity of crop (Saeed *et al.,* 2001). Plant height is an important crop growth as well as yield component and it has a direct proportionality to 100 grain mass (Saidaiah *et al.,* 2008). Plant height is positively correlated with grain yield, the higher the plant height, better the crop yield (Tenaw, 2000).

Kumar *et al.* (2002b) reported significantly higher plant height with combined application of 100% RDF (120-60 N-P kg/ha) + 10 t/ha FYM. However, Pathak *et al.* (2002) observed maximum plant height, leaf area index, dry matter accumulation, net assimilation rate and crop growth rate by applying 75% N-P-K through fertilizer + 25% N through FYM (100% RDF 100-50-25 kg N-P-K/ha). Similar trend for plant height, dry matter accumulation and leaf area index in maize was reported by Louraduraj (2006) with combined application of 100% RDF (135-62.5-50 kg N-P-K/ha) with 5.0 t/ha vermicompost. Khadtare *et al*. (2006) recorded significant values in respect of cob girth, cob length and green cob weight in treatment RDF (150-50-00 kg N-P-K /ha) followed by 75 % RDN + 25 % N through vermicompost (VC) prepared from *Parthenium hysterophorous* L. And 75 % RDN + 25 % N through VC prepared from *Amaranthus spinosus* L.. Shinde *et al.* (2011) found significantly higher plant height and dry matter accumulation with application of 75% N-P-K through fertilizer + 25% N through FYM (100% RDF 120-60-60 kg N-P-K/ha) as compared to 50% RDF (60-30-30 kg N-P-K/ha), while at MPUAT, Udaipur, Tetarwal *et al.* (2011) recorded significantly higher plant height and dry matter accumulation at harvest with application of 100% RDF (40-15 kg N-P/ha) + 10 t/ha FYM. Verma *et al.* (2012) noted significantly higher plant height, leaf area index and number of days to maturity and silking with 100 kg N/ha along with 7.5 t FYM/ha. The results are in close proximity to those reported by Jadhav *et al.* (2012), Shilpashree *et al.* (2012), Joshi *et al.* (2013), Kannan *et al.* (2013), Shinde *et al.* (2014) and Maske *et al*. (2015). An application of 25% RDF (30-15-15 kg N-P-K/ha) + biofertilizers (*Azotobacter* + PSB) + green manuring with sunnhemp + compost resulted in significantly taller plants and maximum total plant dry matter accumulation (Kalhapure *et al.*, 2013), whereas significantly the highest plant height and number of leaves per plant was observed under application of 75 % N from urea + 25 % N from poultry manure which was at par with 100 % N from urea (Iqbal *et al.*, 2014).

Mashego (2013) reported that site-specific nitrogen management (SSNM) and conventional approaches recorded the plant height of 1.06 and 1.07 m, respectively, were significantly higher than control (0.89 m). According to Ogbomo and Ogbomo (2009), maize plants were the tallest (168.35 cm) that received 600 kg NPK/ha than that of its lower rate. Adekayode and Ogunkoya (2010) also reported that the highest plant height (197.6 cm) was observed in plot with 300 kg NPK/ha and the lowest (167.9 cm) in plot without fertilizer. Higher fertilizer levels (NPK 15:15:15) increased the plant height of maize (Obidiebube *et al.*, 2012). This result agreed with earlier study, which stated that maize production can be increased with higher levels of fertilizer application especially NPK (FAO, 2004). Asghar *et al.* (2010) also found that plant height increased linearly with NPK application. Among different treatments, application of 250-110-85 kg NPK/ha gave the maximum plant height (198.55 cm) against the minimum (143.60 cm) recorded in control. Similar results were reported by Maqsood *et al.* (2001), Ayub et *al.* (2002), Sharar *et al.* (2003) and Ekwere *et al.* (2013). Also, the maximum plant height (216.5 cm) was observed with full dose of nitrogen (250 kg/ha), while the minimum plant height (184.5 cm) was recorded with no fertilizer (Rehman *et al.*, 2010). Increase plant height with increasing in nitrogen rate was also observed by Khan *et al.* (1999), Maqsood *et al.* (2000) and Mashego (2013).

Effect on yield attributes of maize

Significantly higher yield attributes *viz*., cobs/plot (136), cob length (19.l cm), cob girth (14.2 cm), grain rows/cob (13.29), grains/row (31.87), cob yield (5.50 t/ha), shelling per cent (85.22) and harvest index (38.l2) and grain yield (4.62 t/ha) were recorded by SSNM over absolute control and 50% RDF, however, it remained at par with 100% RDF (Kumar *et al.*, 2014). Singh *et al.* (2012) found that yield attributes increased with increasing nitrogen up to 150 kg/ha, while Vishram *et al.*(2006) recorded enhancement in yield attributes such as cob length, cob girth, grain weight per cob, shelling percent, test weight as well as grain and stover yield with 180 kg nitrogen/ha applied through chemical fertilizers. The increase in cob length of maize was associated with fertilizer application as the maximum ear length (17.37 cm) was obtained with full dose of nitrogen (250 kg/ha), while maize without fertilizer produced the minimum cob length (l0.39 cm) (Rehman e*t al.*, 20 l 0). The results are in confirmatory with Santalla *et al.* (1994), Adekayode and Ogunkoya (2010) and Obidiebube *et al.* (2012). Sahu (2006) reported maximum number of cobs in treatment receiving inorganic fertilizers (150-60-60 kg N-P-K/ha) along with FYM @ 1.1 t/ha + poultry manure @ 1.1 t/ha + vermicompost @ 1.1 t/ha to *rabi* maize, nevertheless, combined application of 50 or 75% RDF with FYM @ 12 t/ha or vermicompost @ 2.7 t/ha significantly increased the cobs per plant, cob length, cob girth and test weight of maize compared with the application of either only inorganic fertilizer or organic sources (Nanjappa *et al.*,2001). Similarly, significantly higher grains per cob and test weight were recorded with application of 100% RDF (120-60 N-P kg/ha) + 10 t/ha FYM by Kumar *et al.* (2002a). On the other hand, Pathak*et al.* (2002) revealed maximum cobs per plant, cob length, cob girth and test weight of maize with 75% N through RDF (100% RDF 100-50-25 kg N-P-K/ha) + 25% N through FYM.

Muthukumar *et al.* (2005) reported that application of nitrogen in split doses had significant influence on the yield parameters *viz.*, cob length, cob girth and cob weight. Similarly, Kalpana and Krishnarajan (2002) reported that application of 150 kg K/ha in three split doses resulted in the highest cobs per plant (3.63), cob length (18.33 cm), cob width (3.16 cm), whereas Asghar *et al.* (20l0) found that the number of cobs per plant was not significantly affected by different NPK rates. Among the NPK levels, treatment with (250-110-85) NPK recorded maximum number of cobs per plant (1.51). Non-significant effects of fertilizer application on cobs per plant had also been reported by Maqsood *et al.* (2001) and Sharar *et al.* (2003). However, these results are contradictory to findings of Khan *et al.* (1999), as they found significant effect of NP applications on number of cobs per plant.

The number of grain rows per cob under site-specific management approach was statistically at par with that of conventional management approach (Mashego, 2013). Similarly, the maximum number of grain rows per cob (15.30) was produced with NPK application at the rate of 250-110-85kg/ha, which was higher than other rates of fertilizer (Asghar *et al.*, 2010). These results are in agreement with those of Ali *et al.* (2002) and Younas *et al.* (2002), who reported that number of grain rows per cob was increased with the increase in application of fertilizers.

Khuong and Tan (2006) reported that SSNM treatment produced 471 kernels /ear in dry season and 416 kernels /ear in wet season at Veitnam. The maximum number of grains (692.0) per ear was recorded with application of full dose of nitrogen (250 kg/ha), while the minimum number of grains (386.0) per ear was observed with no fertilizer (Rehman *et al.*, 2010). These results are in contrary with the findings of Raja and Reddy (1990), who reported that nitrogen fertilizer did not affect the number of grains per cob. The maximum ear weight (256.9 g), number of grains per ear (570) and grain yield (1661.7 kg/ha) were recorded significantly higher with 300 kg/ha nitrogen application (Adekayode and Ogunkoya, 2010). Similarly, application of 250-110-85 kg NPK/ha gave more grain weight/cob (104.99 g) followed by 175-80-60 kg NPK/ha (101.53g), and 100-50-35 kg NPK/ha (95.63g) and control (90.00g) (Asghar *et al.*, 2010). The results are supported by Hussain *et al.* (1999), who reported that grain weight per cob increased with increasing levels of NPK fertilizers.

The l00 grain mass is positively correlated with grain yield (Alvi *et al.*, 2003; Bocanski *et al.*, 2009). Site-specific nitrogen management recorded significantly higher 100 grain mass than the control and conventional management approach (Mashego, 2013). Application of NPK (15:15:15) to maize plants produced significantly higher 100 seed weight than the untreated plants as the highest 100 seed weight (11.62 g) was observed with 400 kg/ha nitrogen fertilizer (Ogborno and Ogbomo, 2009). This result agreed with earlier study which stated that maize production could be increased with higher levels of fertilizer application especially NPK (Jennifer, 1996; Kang, 2004).

Effect on yield

The fertilizer requirement for a field or location is estimated from the expected yield response to each fertilizer nutrient, which is the difference between the attainable yield and the nutrient-limited yield. Nutrient-limited yields are determined from nutrient omission trials in farmers' fields, while attainable yield is the yield using best management practices without nutrient limitation. The amount of nutrients taken up by a crop is directly related to its yield. The attainable yield indicates the total nutrient requirement and the nutrient-limited yield is the yield supported only by the indigenous supply of the concerned nutrient without any external application (Dobermann *et al.*, 2003).

Jat *et al.* (2013) observed significantly higher yield of maize under site specific nutrient management (SSNM) as compared to state recommendations at most of the locations (Delhi, Bajaura, Udhampur, Dhoti, Ludhiana, Pantnagar, Banswara and Ranchi). Similarly, Meena *et al.*, (2014) reported that SSNM improved productivity and micronutrients realization on maize crop in Udaipur which led to 962.40, 50.52 and 55.02, and also 17.95, 17.35 and 17.59 per cent higher grain, stover and biological yields over control and state recommendation of nutrients, respectively. Sreelatha *et al.* (2012) also observed the highest yield of rice and maize as well as system productivity with SSNM. Ferguson *et al.* (2002) reported that application of nutrient as per SSNM (200:120:100 N:P:K) resulted in higher maize yield (9.85 t/ha grain yield in dry season and 8.58 t/ha grain yield during the wet season, which was superior over farmer fertilizer practice (FFP) treatment (180:91:71 N:P: K). It was further reported that yield reduction of 10 to 15 per cent was observed in plots without phosphorus or potassium, while 80 per cent yield reduction in plot without nitrogen. Significant effect of SSNM on maize grain yield was also observed in trials conducted at Kanpur (Kumar *et al.*, 2006). Murni *et al.* (2010) observed that SSNM generated a yield gain of 1.5 Mg/ha (19%) over current farmer fertilizer practice (FFP) with improved timing of nitrogen application. They further reported that grain yield in omission plots was in the order of PK (5.9 Mg/ha) < NP (7.8 Mg/ha) < NK (7.9 Mg/ha), which showed that nitrogen was the most limiting nutrient affecting maize yield, whereas phosphorus and potassium supply were equally limiting factors. Biradar *et al.*, (2012) also reported that SSNM led to yield enhancement (7.02 t/ha) of 17.4 per cent and 28.6 per cent over recommended dose of fertilizers (RDF) and farmers fertilizer practice (5.44 t/ha), respectively. Increase in yield by 8 to 19 per cent with SSNM was also reported by Meena *et al*. (2014).

Pasuquin *et al.* (2010) conducted an experiment at 19 locations of Indonesia, Philippines, and Vietnam with hybrid maize and reported that SSNM improved yield by about 0.9 to 1.3 Mg/ha and 53 per cent increase in agronomic efficiency of nitrogen fertilizer as compared to the farmers' fertilizer practice (FFP). Similarly, Witt *et al.* (2010) also conducted an experiment at 19 locations with hybrid maize in Indonesia, Philippines and Vietnam and reported that SSNM improved yield by 0.8 to 1.2 Mg/ha compared with the farmers' fertilizer practice (FFP), but the full yield advantage of 1.5 to 1.7 Mg/ha with SSNM could often only be achieved once other constraints to yield improvement were addressed. Based on two-year study, Lan *et al.* (2008) found that SSNM approach had 11 and 33 per cent more maize yield than conventional management approach, while the amount of fertilizer was reduced by 32 and 29 per cent, which indicated that variable rate application or site-specific application approach is more feasible for maize cultivation to produce optimum yields with minimum fertilizers.

Optimum maize yield using lower nitrogen rate can be achieved through site-specific nitrogen management than the conventional nitrogen management approach (Paz *et al.*, 1997). Site-specific nitrogen management resulted in the highest grain yield of 5.2 t/ha than conventional nitrogen management approach (4.0 t/ha) and control (3.2 t/ha). Which, besides improvement in 1.2 t/ha in required 63 per cent lesser nitrogen than conventional nitrogen management approach (Mashego, 2013). The grain yields were significantly affected by NPK fertilizer application as the lowest grain yield (3.52 t/ha) obtained from plants without fertilizer treatment, while the highest grain yield (7.95 t/ha) was obtained at 400 kg/ha fertilizer (NPK-15:15:15) (Ogbomo and Ogbomo, 2009). Akmal *et al.* (2010) also reported that application of 150 kg/ha nitrogen application yielded the highest grain yield (4827 kg/ha) followed by 120 kg nitrogen application (3962 kg/ha). These findings are in lined with the view of Adediran and Banjoko (2003).

Madhavi *et al.* (1995) stated that the grain and stover yield of maize were significantly increased by increasing level of NPK fertilizer from 0 to 100 per cent of the recommended NPK fertilizer (120:60:60 NPK kg/ha), while Bundi and Andraski (2001) pointed out that application of fertilizer even at a higher rate (150:26:32 NPK kg/ha) significantly increased the grain and stover yield. Ashoka *et al.,* (2008) observed that the application of RDF (150:75:40 kg $N:P_20_5:K_20$/ha) + 25 kg $ZnS0_4$/ha + 10 kg $FeS0_4$/ha recorded significantly higher yield and green fodder yield. The maximum grain yield (6.717 t/ha) was obtained in plot with full dose of nitrogen, while the minimum (2.697 t/ha) was observed in plot without fertilizer (Rehman *et al.,* 20l0). Experiments carried out at different locations revealed that maximum grain and straw yield of maize were found higher with application of 100% RDF (135-62.5-50 kg N-P-K/ha) along with vermicompost @ 5 t/ha (Louraduraj , 2006); 75 % RDN + 25 % N through VC prepared from *Parthenium hysterophorous* L. and 75 % RDN + 25 % N through VC prepared from *Amaranthus spinosus* L. (Khadtare *et al.*,2006); 75% RDF (100% RDF 120-60-60 kg N-P-K/ha) + 5 t/ha biocompost (Tripathi *et al.,* 2007); 120 kg N/ha + 1.5 t VC/ha (Meena *et al.,* 2007); FYM @ 10t/ha or vermicompost @ 2.5 t/ha with 100% RDF (150-75-37.5 kg N-P-K/ha) (Channabasavanna *et al.*, 2008); 100% RDF (40-15 kg N-P/ha) + 10 t/ha FYM (Tetarwal *et al.*, 2011);100 kg nitrogen/ha along with 7.5 t FYM/ha (Verma *et al*., 2012); and 100% RDF (120-60-30 kg N-P-K/ha) + FYM @ 10 t/ha (Joshi *et al.*, 2013). Similar trend was reported by Shinde *et al.* (2014), Pandey and Avasthi (2014) and Maske *et al*. (2015). The improvement in grain yield was probably due to more number of rows per ear, number of grains per row and l000 grain weight, etc. The results are in line with the findings of Jayakumar *et al.* (2008).

Significantly higher shelling percentage was recorded by CMH 08-292 and the lowest yield attributes and grain yield were recorded by HQPM-1(Kumar *et al.*, 2014). Giunta *et al.* (2009) and Kolo *et al.* (2012) confirmed the similar findings in maize.

Nutrient uptake and nutrient status of soil

Pawar and Patil (2007) suggested that application of vermicompost @ 5 t/ha along with 100% RDF (120-60-40 kg NPK/ha) recorded maximum uptake of NPK and Ca, Mg, S, Zn, Mn, Cu and Fe over other treatments. The available amount of N, P, K and S in soil after harvest of maize crop was 249.42, 41.47, 460.22 and 17.61 kg/ha in the same treatment, respectively. Kumar *et al.* (2002a) observed significant improvement in NPK uptake by hybrid maize as well as available NP and organic carbon in soil with application of 100% RDF (120-60-40 kg N-P-K/ha) + 10 t/ha FYM. Likewise, significant improvement in available N, P and K status of the soil was observed by Jamwal (2006) with application of 50 % RDF (60-40-20 NPK kg/ha) along with 50% FYM. Meena *et al.* (2007) also reiterated improved nutrient content and uptake compared with120 kg N/ha + 1.5 t vermicompost/ha. Though Tripathi *et al.*

(2007) recorded higher available organic carbon and N in soil after crop harvest with 75% N and P through fertilizer (100% RDF 120-60-60 kg N-P-K/ha) + 5 t/ha bio-compost. Singh and Nepalia (2009) reported similar outcomes with 100% RDF (90-40 kg N-P/ha) +5 t/ha vermicompost. On the other hand, 100% RDF (40-15-00 kg N-P-K/ha) + 10 t/ha FYM registered maximum NPK uptake by maize and available N and P status to the tune of 1.28 and 14.89 per cent, respectively over initial status of soil fertility (Tetarwal *et al.,* 2011). The results are in close proximity to that of reported by Singh *et al.* (2012). Significantly higher values of organic carbon, available N, P_2O_5 and K_2O content in soil were recorded with application of 25% RDF (30-15-15 kg N-P-K/ha) + biofertilizers (*Azotobacter* + PSB) + green manuring with sunnhemp + compost (Kalhapure *et al.*2013), whereas Pandey and Avasthi (2014) found highest total porosity, CEC, organic carbon, available N, P_2O_5 and Zn in soil with the application of RDF (120-60-40 kg N-P-K/ha) + FYM 10 t/ha.

The site-specific nitrogen management approach required lesser amount nitrogen fertilizer than the conventional nitrogen management approach by 63, 63, 69 and 43 per cent at different sites *viz*., Towoomba, Leeukraal, Radium and Ga-Marishane areas, respectively (Mashego, 2013). Pasuquin *et al.* (2010) observed that average agronomic efficiency of nitrogen (AEN) under SSNM was raised up to 25.1 kg grain kg / N. An increase of 53% compared to the farmers' fertilizer practice (FFP) might be due to better timing and splitting of fertilizer K applications during the season. They further reported that nitrogen content and uptake in grain and straw was significantly higher with SSNM over absolute control and remained at par with 100% RDF. Almost similar findings were also obtained by Gilkes and Prakongkep (2010) who showed that adoption of SSNM in maize increased the agronomic efficiency of N fertilizer by 53 per cent as compared to the FFP. Amongst genotypes, significantly higher nitrogen content and uptake by grain and straw was obtained by CMH 08-292, however, it remained at par with PMH-1 (Kumar *et al.,* 2014).

Economics

SSNM is a set of nutrient management principles which when combined with efficient crop management practices will help farmers to attain high yield and profitability. The field evaluation trial conducted all around the country also showed that the location-specific nutrient recommendations increased yield and economic benefits of wheat farmers as compared to the existing practices. Pampolino *et al.* (2012) found that adoption of Nutrient Expert for Hybrid Maize (NEHM) increased profits of farmers in Indonesia and Philippine by 270 and 379 US$/ha, respectively over farmer's fertilizer practice (FFP). Meena *et al*. (2014) reported that adoption of SSNM on maize crop led to 65.17 per cent higher returns over control. Site specific nutrient management improved income by 455 to 520 Yuan Chinese currency (RMB)/ha. Attanandana et *al*. (2006) reported that the investment was higher with lower yield for the farmers who did not use site-specific nutrient management technique. The site specific nutrient application (SSNM) led to additional net income of 2219 ₹/ha over RDF and 4057 ₹/ha over FFP (Biradar *et al.,* 2012). Added net benefits of 140 US$ /ha/crop in Indonesia, 103 US$ /ha/crop in Philippine and 218 US$/ha/crop in Vietnam were also obtained under site specific nutrient application (SSNM) as compared to the farmers' practice in hybrid maize (Pasuquin *et al.,* 2010).

Based on 120 on-farm experiments with hybrid maize during 2004-2008 in lndonesia, Philippines and Vietnam, Gilkes and Prakongkep (2010) reported that adoption of SSNM added net benefit of 184 US$/ha/crop, which was attributed to increased yield rather than reduced costs of inputs. The application of 120:90:0 N:P:K kg/ha turned out to be the cheapest alternative in terms of total costs, while in terms of net benefits, 120:90:90 N:P:K kg/ha was marginally higher than that of 120:90:0 NPK kg/ha (Chaudhary *et al.*, 2002). Ashoka *et al.* (2008) reported that the significantly higher gross returns of 96,838 ₹/ha, net return of 76,889 ₹/ha and B:C ratio of 3.85 was noticed in RDF + 25 kg $ZnS0_4$. Ferguson *et al.* (2002) obtained a profit of 833,000 VND (Vietnamese dong)/ha in dry season and 786,000 VND/ha during the wet season at Vietnam with higher NPK rate of SSNM. Koch *et al.* (2004) found that variable-rate nitrogen application was more economically feasible than conventional uniform nitrogen application. Johnston *et al.* (2009) found that SSNM approach implemented by the IPNI that improved field specific recommendation to a farmer, in a cost effective and timely fashion.

Shanwad *et al.* (2010) fetched significantly higher gross returns (69,059 ₹/ha) and net returns (51,659 ₹/ha) with 100% RDF (100-50-25 kg N-P-K/ha) + 7.5 t/ha FYM over only chemical fertilizer treatment (100-50-25 kg N-P-K/ha). However, Tetarwal *et al.* (2011) obtained maximum net returns (13741 ₹/ha) and benefit: cost ratio (0.93) with 100% RDF (40-15-00 kg N-PK/ha) + 10 t/ha FYM over control in *kharif* maize. Kalhapure *et al.* (2013) concluded that application of 25% RDF (30-15-15 kg N-P-K/ha) + biofertilizers (*Azotobacter* + PSB) + green manuring with sunnhemp + compost recorded significantly the highest gross return ($95.9x10^3$ ₹/ha), net return (54.2×10^3 ₹/ha) and B: C ratio (1.30), which were 212.38, 537.6 and 242.1 per cent more than that of control treatment, respectively.

CONCLUSION

In the light of above discussion, it can be concluded that for highly nutrient demanding crop like maize, balanced and real time management as well as integration of nutrients through site specific nutrient management resulted into higher return in yield and income besides improved nutrient use efficiency, curtailing chemical load in the soil without compromising on yield front.

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