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Research Articles

Nutrient Expert assisted site-specific-nutrient-management: An alternative precision fertilization technology for maize-wheat cropping system in South-Asian Indo-Gangetic Plains

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ABSTRACT

Site-specific-nutrient-management (SSNM)-nutrient expert (NE) is the recently developed precision nutrient management technology guided by decision-support system software for improving crop yields, environmental-quality and overall agricultural sustainability specifically in South-Asian Indo-Gangetic Plains Region (IGPR). SSNM-NE in maize-wheat cropping system (MWCS) assumes a great-significance to restore soil-fertility and enhance farm nutrient-use efficiency with minimal deleterious effects on environment. Therefore, an attempt was made to develop and standardize SSNM-NE technology in MWCS. Results indicated that system-productivity in terms of wheat-equivalent yield (WEY) with SSNM-NE + FYM @ 5 tonnes/ha (9.60 Mg/ha) and with 125% recommended NPK (RDF) (9.33 Mg/ha) was ~38.8; 12.3% and 36.8; 9.8% higher over control and 100%RDF (2 years' av.), respectively. Among nutrient-management schedules, SSNM-NE + FYM registered highest available N, K and soil organic carbon (SOC) in 0-15 cm soil-depth which was closely followed by 125%RDF and SSNM treatments while plots under 125%RDF registered significantly highest available P over other treatments. SSNM-NE alongwith FYM led to highest soil microbial biomass carbon (SMBC) and dehydrogenase-activity which was 9.25 and 11.6% higher over 125%RDF. However, non-significant variation was observed in bulk density at both soil-depths (0–15; 15–30 cm). SSNM-NE + FYM experienced highest root-length density and root-surface area (RSA) in both crops followed by 125%RDF. SSNM-NE + FYM and SSNM-NE treatments exhibited significantly higher agronomic–efficiency of applied-N and P over rest of the treatments in both crops. Overall, SSNM-NE in combination with FYM led to significant improvement in soil physico-chemical and microbial properties as well as nutrient use-efficiencies; which assume paramount importance for long-term soil productivity that may translate into sustained MWCS productivity in South-Asian IGPR. Besides, this SSNM-NE decision support system software is easy to handle and operationalizable by the field extension functionaries, progressive farmers and through custom hiring services to illiterate and resource poor farming clientele at village level in developing world.

Key words: Agronomic efficiency, Decision support system software, Maize-wheat cropping system, Nutrient-expert, Site specific nutrient management, System productivity

Under emerging challenges of natural resource-base degradation, declining crop productivity, and ecological problems with the existing rice-wheat system, the maize-based cropping systems are emerging as an alternative option for diversification of rice-wheat and rice-rice production systems in south- Asian Indo-Gangetic Plains Region (IGPR) in general and India in particular. With the development of high yielding varieties and hybrids in maize which are competitive to rice with respect to farm–profitability and resource–use–efficiency under diverse climatic conditions; the maize–wheat cropping system is gaining importance as a predominant maize based system (1.8 m ha) in India alone being 3rd major rotation which contributes ~3% in national food basket (Jat *et al.* 2013). Saharawat *et al*. (2010) reported that simulated, attainable and actual maize yields in maize growing agro–ecologies in South-Asia revealed wide management yield gaps ranging from 36–77%. These yield gaps are due to poor yielding genotypes and crop establishment techniques as well as imbalanced nutrient applications as 15–45% maize area remains unfertilized (Jat *et al*. 2011). By introduction of single cross hybrids in maize, productivity increased up to 7.0 t/ha and total nutrient removal has also increased to 420 kg/ha (Jat *et al*. 2013).

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Adopting best fertilization management practices by following the SSNM-NE concept have shown improvement in yields and it is based on estimations of crop need-based nutrient-supplying capacity as per target yield. This considers indigenous nutrient supply of soil and productivity targets capable to sustained yields and assured restoration of soil fertility. International Plant Nutrition Institute (IPNI) in collaboration with CIMMYT has recently developed a Nutrient Expert (NE), a nutrient decision support system, based on SSNM principles. NE provides fertilizer recommendations by considering yield responses and targeted agronomic efficiencies alongwith contribution of nutrients from indigenous sources. This system follows systematic approach of capturing site-specific information that is important for developing a location-specific–recommendation. NE has been successfully used to provide fertilizer recommendations in major maize growing agro–ecologies of country and also increased yield and farm-profitability over existing fertilizer recommendations. A study showed that the average use of N, P_2O_5, and K_2O by farmers is 193, 89, and 114 kg/ha, but, fertilizer application based on NE reduces N, P_2O_5, and K_2O use by 32, 50, 66 kg/ha and indicating 17, 56, and 58% reductions in fertilizer use over farmers' practice (Satyanarayana *et al*. 2013, Jat *et al*. 2013). It also helps in providing information about prevailing climatic conditions affecting nutrient management under specific–location and right rate of nutrients to meet attainable yield goals. Considering above facts, an attempt has been made in this study to develop SSNM-NE practice besides re–orienting nutrient management practices for enhancing productivity and farm–profitability as well as nutrient use-efficiencies in MWCS in South-- Asian Indo-Gangetic Plains Region (IGPR).

MATERIALS AND METHODS

Current field–experimentation was carried–out during *kharif* (July–October)–*rabi* (November–April) seasons of the years 2012–13 and 2013–14 at experimental–farm of Indian Agricultural Research Institute (IARI), New Delhi, India (28º40' N latitude and 77º12' E longitude, 229 m above mean sea level). The climate of above experimental–farm is semi–arid with average annual rainfall of 650 mm, 80% of which is received through south–west monsoon during July to September, and the rest is received during the western disturbances from December to February. The hottest months are May–June with mean daily maximum temperature varying from 40 to 46 ºC, whereas December–January are the coldest months with mean daily minimum temperature ranging from 5 to 8 ºC.

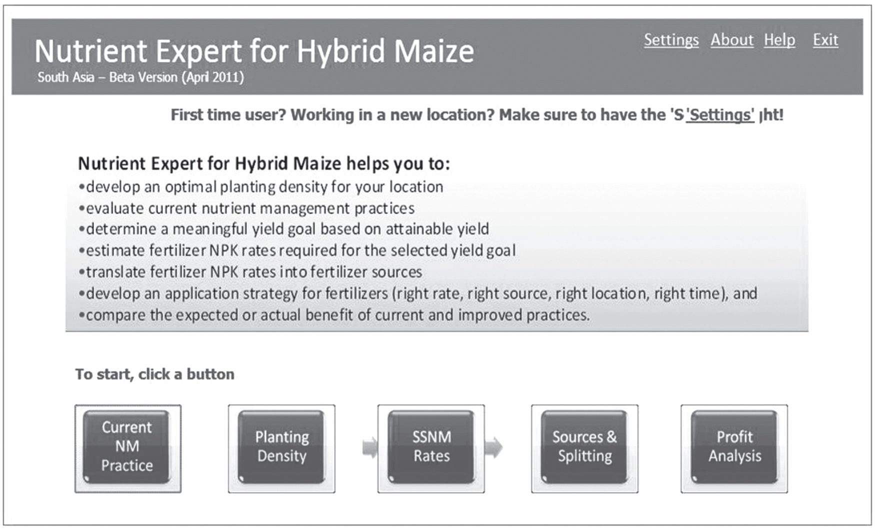
The initiation of present experimentation under maize–wheat cropping system (MWCS) in this experimental–field has been started in 2011–12 as uniformity trial and this study includes pooled data of 2012–13 and 2013–14. In this study, five treatments comprising, viz. (i) absolute control (no fertilizers), (ii) 100% recommended dose of fertilizers (RDF), (iii) site–specific nutrient management based on nutrient expert (SSNM-NE), (iv) SSNM-NE + FYM @ 5 tonne/ha, (v) 125% RDF (Table 1). The experiment was laid–out in randomized block design and replicated six times. All agronomic cultivation practices were followed as per the IARI recommendations. Nitrogen (N) as prilled urea (46% N), phosphorous (P) as single super phosphate (16% P_2O_5) and potassium (K) as muriate of potash (60% K_2O); were applied as per treatments (Table 1). In maize, sowing was done at 75 × 20 cm in the first fortnight of July and harvested in October while wheat was sown in November and harvested in April. Well decomposed FYM was applied in respective treatment before sowing of maize and wheat crops which contained 0.55% N, 0.28% P_2O_5, and 0.51% K_2O. The soil of the experimental field belongs to the major group of Indo–Gangetic alluvium and the soil (0–15 cm layer; taken initially) was sandy–loam in texture having pH 7.5 (1:2.5 soil and water ratio) with Walkley–Black C (oxidizable–SOC) 0.39%, alkaline $KMnO_4$ oxidizable–N 155.3 kg/ha, 0.5 M $NaHCO_3$ extractable–P 10.3 kg/ha, and 1 N NH_4OAc extractable–K 211.7 kg/ha (Prasad *et al*. 2006).

Table 1 Treatment details for maize and wheat crops

Treatment	For maize (N: P_2O_5: K_2O)	For wheat (N: P_2O_5: K_2O)
100% RDF	[150:60:50 kg/ha]	[120:60:40 kg/ha]
SSNM–NE	[140:40:46 kg/ha]	[125:47:59 kg/ha]
SSNM–NE +FYM	[167.5:54:71.5 kg/ha]	[152.5:61:84.5 kg/ha]
125% RDF	[187:75:62.5 kg/ha]	[150:75:50 kg/ha]

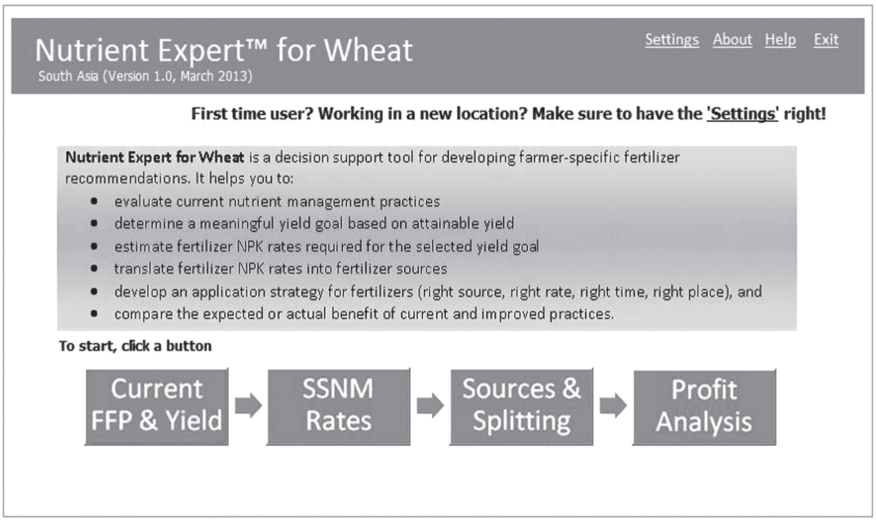
In developing world, most of the nutrient management practices are based on general blanket recommendations or the site–specific nutrient management approach for different field crops keeping in view their genetic potential and the specific crop management practices in a given agro-ecological situation. But, it is observed that even after considering above factors, the efficiency of applied nutrients is quite low and the *in-situ* losses are relatively higher resulting in low productivity than expected levels. In this direction, SSNM–nutrient expert assisted decision-support system software is a recent development which takes care of the efficient nutrient management in the field crops. The SSNM-NE is the appropriate answer to above resource drifts which are putting the crop productivity and environmental quality at the stake. This SSNM-NE software tool is developed by International Plant Nutrition Institute (IPNI) in collaboration with International Maize and Wheat Improvement Centre (CIMMYT) (Satyanarayana *et al.* 2013).

SSNM-NE was officially launched for public domain in South-Asia in general and India in particular in the year 2013 jointly by IPNI and CIMMYT (*http://www.ipni.net*). Basically, Nutrient Expert is a decision support tools for maize and wheat crops which is based on SSNM principles and is an easy-to-use, highly interactive, and computer-based decision support system that rapidly provides nutrient recommendations for an individual farmer field both in the presence or absence of soil-testing data, and thus develops fertilizer recommendations for a specific plot or growing environment. SSNM-NE takes into account the most important factors affecting nutrient management recommendations which are rather not foreseen critically in other approaches. Moreover, other conventional SSNM approaches like soil-test crop response (STCR) require more analytical data like soil test values etc. for final fertilizer requirement of a specific crop for desired yield levels (Paul *et al.* 2011); thus, makes these conventional approaches away from the reach of resource-poor farmers'. While, SSNM-NE is quite easy to handle and does not require much detailed data; rather requiring very limited information unlike other sophisticated nutrient decision support software as well as other conventional approaches. SSNM-NE allows users to draw required information from their own experiences, farmers' knowledge of the specific location and farmers' prevalent farm practices. With NE, parameters can be estimated using proxy information, which allows farm advisors to develop fertilizer guidelines for a location without data from field trials (Satyanarayana *et al.* 2013). In order to estimate the required nutrient doses under SSNM-NE for a specific location or the farm, it requires following information (Majumdar *et al.* 2013):



(*Source:* http://software.ipni.net/package/770C5AEE1A369CD 785257C430053D4CC)

Fig 1 *Nutrient–Expert* decision support system software for hybrid maize



(*Source:* http://software.ipni.net/package/D56F6FAFBB9C 613B85257C430053009B)

Fig 2 *Nutrient–Expert* decision support system software for wheat crop

(i) Farmers' fertilization practices viz. amount of fertilizers (inorganic/organic), scheduling of fertilizer application for getting a targeted yield.
(ii) Estimate of the attainable yield at the proposed field, if available or growing environment situations (irrigated/rainfed/flooding/drought, presence of soil constraints other than NPK like soil salinity/alkalinity/acidity).
(iii) Yield responses of particular crop/genotype to fertilizer N, P and K (if available) or soil fertility parameters (soil texture and colour, use of organic manures) and preceding crop history (yield, fertilizer inputs, crop residue management) to be used by the SSNM-NE software in order to estimate yield responses.
(iv) Crop residue management and use of organic inputs.
(v) Price of maize/wheat grain produce as well as cost of seeds and fertilizers.

The on-farm trial data are used to develop algorithm for calculating nutrient requirements in NE using SSNM guidelines. In this approach, the fertilizer NPK requirements are given based on the relationships between nutrients uptake at harvest and grain yield, i.e. internal nutrient efficiency and is predicted using the QUEFTS (quantitative evaluation of the fertility of tropical soils) model (Satyanarayana *et al.* 2013). These software are MS access friendly which has five tabs in case of hybrid maize (Fig 1) and four tabs in wheat (Fig 2) and are free of cost available at *http://software.ipni.net/article/nutrient-expert*. In addition to the fertilizer doses this software also gives recommendations for stage specific fertilizer scheduling for top dressing specifically for critical growth stages. It also appropriates the planting density in case of maize for desired yield levels. These prescriptions can be downloaded in pdf file format for target field/farmer and can be provided to end user as print agro-advisory.

Harvesting of maize and wheat crops was undertaken as soon as the cobs/grains matured with hand picking/sickles after leaving border area of each plot. The moisture content in grains of all the crops at harvest was around 18–22%. The harvested produce was sun–dried for 3–4 days to bring down the moisture content around 13–16%. After that, the maize and wheat produce was threshed and grains were then cleaned by tractor drawn winnower and yield was thoroughly recorded and expressed in tonnes/ha. The system–productivity was compared by computing wheat–equivalent yield (WEY) in different treatments by using the following formula:

$$\text{WEY} = \frac{\text{Yield of maize crop (t/ha)} \times \text{Economic value of maize crop (INR/t)}}{\text{Price of wheat (INR/t)}}$$

The system productivity of maize–wheat system was calculated by adding the WEY of maize to wheat yield.

Soil samples were taken randomly from each plot after end of each cropping season. Ten soil cores (5 cm diameter, 0–15 cm depth) were taken from each plot. The soil samples were put in polyethylene bags and not allowed to dry and transported to the laboratory where visible plant material was removed manually. The samples were then stored overnight at 5ºC in the dark, and prior to biological analyses they were equilibrated to 22–25ºC. Soil dehydrogenase activity (as a measure of microbial activity) was measured by the procedure given by Casida *et al.* (1964). Soil microbial biomass–C (SMB–C) was determined by fumigation extraction method (Vance *et al.* 1987). Three replicate (25 g) soil samples from each treatment were weighed into 100 ml capacity beakers and fumigated with ethanol–free chloroform for 24 h at 25ºC. After fumigant removal, the soils were extracted with 100 ml 0.5 M K_2SO_4 for 30 minutes. Three replicates each of un–fumigated soil were extracted similarly at the time fumigation commenced. The organic–C in the soil–extract was measured by dichromate oxidation. The SMB-C was calculated as follows:

$$\text{MBC} = 2.64\ \text{EC};$$

where, EC = [Organic–C extracted from fumigated soil] – [Organic–C extracted from unfumigated soil]

Root samples were taken at tasseling stage in maize and grain–filling stage in wheat. A root–auger of 8 cm diameter was used to take root samples up to 15 cm depth of soil profile for both crops. The core of the auger was placed so as to keep the base of the stem at the centre. The root samples were soaked overnight in water containing sodium hexa–meta–phosphate and floating roots were decanted into another container. The procedure was repeated three to four times for complete separation of roots from soils. Then, the roots were air-dried so as to make the root samples ready for scanning. Measurements of root morphological characteristics were based on Regent's non-statistical method (Guay and Arseneault 1996). Bulk density of surface (0–15 cm) and sub-surface (15–30 cm) soil was determined by the core sampler method from three randomly chosen spots from each plot. The estimated values of nutrient–use efficiencies of applied NPK were computed using the following expressions:

Agronomic N efficiency (AEN) = $(GY_{NPK} - GY_{N0})/FN$;

Agronomic P efficiency (AEP) = $(GY_{NPK} - GY_{P0})/FP$;

Agronomic K efficiency (AEK) = $(GY_{NPK} - GY_{K0})/FK$.

Where, GY_{NPK} refer to the grain yield in NPK fertilized plots; $GY_{N0,\ P0,\ K0}$ refers to the grain yield in NPK omitted plots; FN, FP, FK refers to the rate of NPK fertilizer application.

Data obtained from maize and wheat for consecutive two years were statistically analysed, using the F-test as per the procedure given by Gomez and Gomez (1984). CD values at *P*=0.05 were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Yield and system productivity

Existing fertilizer recommendations are madeup of pre–determined rates of major nutrients which are constant over time; however, crop needs differ due to season, management and climate. SSNM-NE being a nutrient decision support system provides effective fertilizer recommendations by considering yield responses, targeted agronomic efficiencies alongwith contribution of nutrients from indigenous sources as well as systematic approach of capturing site–specific information. That's why, the yields of maize and wheat under conventional nutrient management option are comparatively less and variable over SSNM-NE in the current study. Further, the SSNM-NE coupled with FYM led to highest yields in both the crops (Fig 3). SSNM-NE + FYM realized highest system productivity which was higher by 10.5% and 14% over SSNM-NE and 100% RDF. SSNM-NE remained at par with 100% RDF w.r.t. system productivity. The higher yields in SSNM-NE may be ascribed to efficient adjustments in applying nutrients to accommodate field specific needs of the crops for supplementing plant nutrients. Application of 125% RDF gave maximum yield after SSNM-NE + FYM. The maize and wheat yield trends

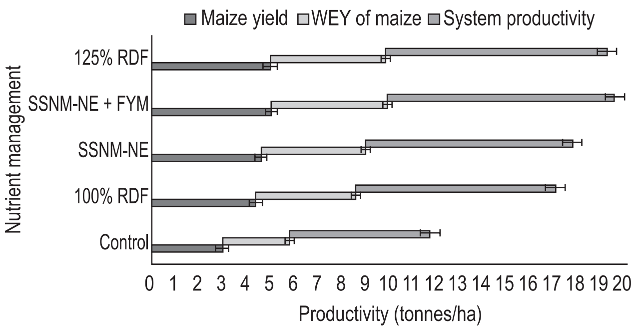


Fig 3 Influence of *Nutrient–Expert* assisted nutrient management on crop yields and system productivity of maize–wheat cropping system (2 years' av.). Bars show CD values at P=0.05 to determine the significance differences among treatment means

followed the same pattern as that of system productivity. Higher yields in SSNM-NE + FYM ascribed to better yield attributes due to balanced supply of nutrients through inorganic fertilizers alongwith FYM. The 125% RDF recorded higher yield than 100% RDF, SSNM-NE and control, but remained inferior to SSNM-NE + FYM, exhibiting inadequate nutrients supplying capacity even by higher dose of fertilizers. Yield enhancement with SSNM-NE based fertilizer application could be attributed to an adequate nutrient supply based on precision SSNM principles. It also helps in promoting balanced use of major nutrients, thereby, improving yields (Jat *et al*. 2013). Overall, SSNM–NE based NPK application alongwith FYM @ 5 tonnes/ha realized higher system productivity under maize–wheat cropping system.

Soil biological parameters and bulk density

Various treatments significantly influenced the soil microbial biomass–C (SMB–C) and dehydrogenase activity (DHA). Although, highest SMB–C was recorded with SSNM–NE + FYM, but, it was statistically at par with SSNM–NE. The increases in SMB–C under SSNM–NE + FYM was to the tune of 4.1, 8.1, 9.3 and 13% over SSNM-NE, 100% RDF, 125% RDF and control, respectively (Fig 4). Application of well decomposed FYM resulted in increased carbon–mineralization due to available carbon for microbial respiration and attributed for plant nutrient supplies vis-a-vis significantly higher soil microorganism populations. Thus, it also has a clear impact on soil microbial biomass and dehydrogenase activity. As FYM enhanced growth and activity of soil microorganism which in turn improved the soil fertility under MWCS. Nutrient management significantly influenced the dehydrogenase activity in maize–wheat cropping system. SSNM-NE + FYM recorded significantly higher soil dehydrogenase activity followed by SSNM-NE and 100% RDF, respectively. The magnitude of increase in dehydrogenase activity (µg TPF/g soil/day) with SSNM-NE + FYM was of the order of 5.8, 10.9, 11.6 and 19.6 over SSNM-NE, 100% RDF, 125% RDF and control, respectively. The positive effect of organic sources on dehydrogenase activity was more pronounced due to combined application of FYM + NPK fertilizers, which attributed to increased mineralization of nutrients by FYM decomposition. Organic sources supply readily mineralizable-C and -N and improve soil organic matter content, which lead to higher SMB-C (Pooniya *et al.* 2012).

FYM application along with inorganic fertilizers resulted in reduction of bulk density in both 0–15 and 15–30 cm layers (Fig 5). Application of FYM improved the total soil pore space, thereby, decreased bulk density. The density was lower in 0–15 cm than 15–30 cm soil layer, indicating a tendency of sub–surface soil compaction. The extent of reduction in bulk density in FYM supplied plots over control was 0.06 and 0.03 Mg/m^3 in both 0–15 and 15–30 cm layers after two cropping cycles. The improvement in soil physical conditions as a result of higher organic matter addition through FYM is associated with lowering of soil bulk density, however, the non–significant variation was observed among treatments w.r.t. bulk density at both soil depths (0–15 and 15–30 cm) in this study. Bulk density was found to be lower in organic nutrition treatments compared to fertilizer application. Sub–surface layer resulted in higher bulk density due to less soil matrix disturbance, which resulted in less porosity compared to surface layer. Similarly, FYM + SSNM-NE decreases bulk density due to improved soil aggregation and soil organic matter that helps in improving soil porosity. A very strong negative correlation (ranging from 0.76 to 0.98) was observed between bulk density and organic carbon in the current study.

Agronomic efficiencies

A yield enhancement over control is explained by the agronomic efficiency (AE) of any nutrient applied which is best measure for estimation of efficiency of that applied nutrient. Various fertilization treatments had a significant effect on agronomic–efficiencies of applied N, P and K both in maize and wheat except efficiency of applied N to wheat. The maximum AE of N in maize and wheat.viz. 12.3 and 11.2 kg grain/kg N was obtained with SSNM-NE + FYM closely followed by SSNM-NE. The lowest AE of applied N was recorded with 100% RDF plots and it remained at par with 125% RDF. In context to AE of applied P in maize and

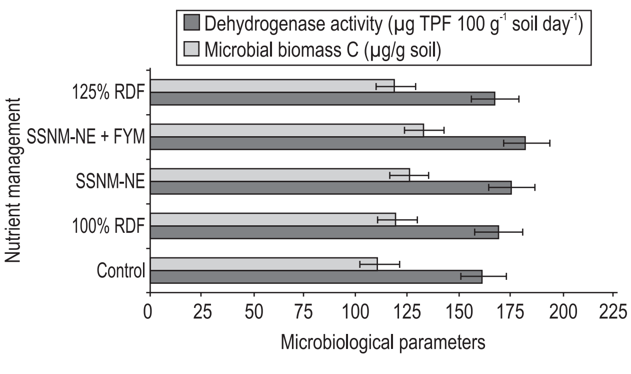


Fig 4 Changes in soil biological properties under maize–wheat cropping system as influenced by *Nutrient–Expert* assisted nutrient management (2 years' av.). Bars show CD values at P=0.05 to determine the significance differences among treatment means

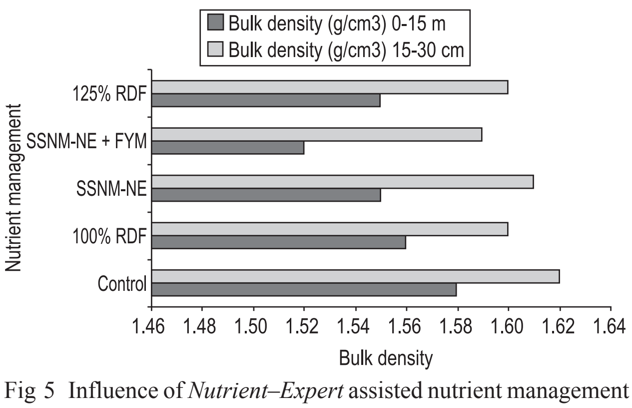


Fig 5 Influence of *Nutrient–Expert* assisted nutrient management on soil bulk density under maize– wheat cropping system (2 years' av.)

Table 2 Influence of *Nutrient Expert* assisted nutrient management on root parameters in plough layer (0–15 cm) (2 years' av.)

Treatment	Maize		Wheat	
	Root length density (cm/cm^3)	Root surface area density (cm^2/cm^3)	Root length density (cm/cm^3)	Root surface area density (cm^2/cm^3)
Control	1.40	1.19	1.49	0.277
100% RDF	1.86	1.31	1.79	0.407
SSNM–NE	1.88	1.30	1.82	0.413
SSNM–NE + FYM	2.15	1.44	1.99	0.470
125% RDF	2.02	1.39	1.93	0.440
SEm±	0.037	0.021	0.025	0.013
CD (P=0.05)	0.121	0.070	0.082	0.042

wheat, the highest AE, viz. 40.4 and 27.9 kg grain/kg of P applied was recorded with SSNM-NE, and SSNM-NE + FYM; and it was superior to that obtained in 100% and 125% RDF. The SSNM-NE registered highest AE of applied K (35.2 kg grain/kg K) followed by 125% RDF (31 kg grain/kg K) in maize. In wheat, 100 and 125% RDF treatments were superior w.r.t. AE of applied K. Results showed that balanced nutrition as per SSNM-NE resulted in significantly higher N and P efficiencies because of higher yield produced by SSNM-NE. The higher amount of nutrient application led to lowering of AE of applied N compared to K and P.

Root length density and root surface area

The influence of nutrient management practices on root parameters of maize and wheat, viz. root length density (RLD) and root surface area density (RSAD) was found significant (Table 2). The maximum values of RLD (2.15 cm/cm^3) and RSAD (1.44 cm^2/cm^3) in maize were recorded under SSNM–NE + FYM and it remained at par with 125% RDF; while minimum values (1.40; 1.19 cm^2/cm^3) were observed under control plots. Whereas in wheat, the maximum RLD (1.99 cm/cm^3) and RSAD values (0.47 cm^2/cm^3) were registered under SSNM–NE which was closely followed by 125% RDF and SSNM–NE treatments. While minimum values (1.49; 0.28 cm^2/cm^3) were recorded under control. In general, these root parameters increased with higher nutrient levels, which might have helped in preceding crop roots' decomposition. In 125% RDF, the P supply was even more than SSNM–NE + FYM treatment (Table 1), inspite of that RLD and RSAD both in maize and wheat was more in FYM incorporated SSNM–NE + FYM treatment which might be attributed to improved soil physico-chemical environment resulting in better root growth influencing above root parameters in both the crops (Choudhary and Suri 2009).

Table 3 Influence of *Nutrient Expert* assisted nutrient management on soil organic carbon (SOC) and available NPK nutrient status in plough layer (0–15 cm) after two cropping cycles

Treatment	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Soil organic carbon (%)
Control	152.8	10.5	212.4	0.39
100% RDF	166.3	12.4	221.7	0.41
SSNM–NE	166.4	11.8	220.5	0.42
SSNM–NE + FYM	173.9	12.3	227.9	0.44
125% RDF	169.8	13.6	224.6	0.42
SEm±	2.29	0.418	2.31	0.006
CD (P=0.05)	7.60	1.384	7.67	0.022

Soil chemical properties

In current study, the sources of plant nutrients had significant changes in soil chemical properties such as available N, P, K and soil organic carbon (SOC) content in soil after completion of two cropping cycles (Table 3). The highest available N, K and SOC content were recorded with SSNM–NE + FYM, although, this remained statistically at par with SSNM–NE and 125% RDF w.r.t. available K and SOC. The FYM application helped in improving available N, K and SOC over 100% RDF and control. It might be attributed to biological immobilization and continuous mineralization of FYM on surface soil layer. 125% RDF exhibited highest available–P being statistically at par with SSNM-NE + FYM. The FYM application increased available K content in soil due to direct K supply and carry–over effects by slow mineralization of organic components, and quick releases of K^+ ion from inorganic soil components (Choudhary and Suri 2009; 2014). Beneficial effect of organic amendments on available K are explained in the light of the facts that besides acting as a source of K, it also releases organic–colloids having higher cation exchange capacity attracting K from applied-K and non–labile pool into available pool which ultimately favours available-K status in soil (Choudhary and Suri 2009). SOC was found to be higher under SSNM-NE + FYM owing to more carbon additions. Thus, FYM application led to highest residual SOC and available–N. Likewise, soil–N also increased significantly after incorporating organics into soils due to direct and buffering effect; besides enhancing available P and K status due to release of organic acids as well as better soil–microbial–biomass–carbon and dehydrogenase–activity (Fig 4).

The SSNM-NE is the recently developed precision nutrient management technology which assumes great significance in improving crop yields, restoring soil–fertility and enhancing nutrient use efficiencies with minimal deleterious effects on environment. In current study, it was concluded that this software based nutrient management strategy out-yielded over the recommended blanket nutrient prescription (100% RDF). For added advantages in terms of sustainable crop and soil productivity, the SSNM–NE + FYM @ 5 tonne/ha led to significantly highest MWCS system productivity, soil fertility, soil–microbial–biomass–carbon and dehydrogenase activity. SSNM–NE + FYM also experienced highest root length density and root surfacearea in both the crops. SSNM–NE + FYM and SSNM–NE treatments also exhibited significantly higher agronomic–efficiency of applied–N and P. Overall, SSNM–NE in combination with FYM led to significant improvement in soil physicochemical and microbial properties as well as nutrient–use efficiencies; which assume paramount importance in long–term soil productivity and sustainability of MWCS productivity in South-Asian IGPR. Inspite of that, SSNM-NE decision support system software is easy to handle and operationalizable by the field extension functionaries, progressive farmers and through custom hiring services to illiterate and resource poor farming clientele at village level in developing world.

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REFERENCES

Casida L E Jr, Klein D A and Santoro T. 1964. Soil dehydrogenase activity. *Soil Science* **93**: 371–6.

Choudhary A K and Suri V K. 2009. Effect of organic manures and inorganic fertilizers on productivity, nutrient uptake and soil fertility in wheat–paddy crop sequence in western Himalayas. *Current Advances in Agricultural Sciences* **1** (2): 65–9.

Choudhary A K and Suri V K. 2014. Integrated nutrient management technology for direct seeded upland rice in NW Himalayas. *Communications in Soil Science and Plant Analysis* **45** (6): 777–84.

Gomez K A and Gomez A A. 1984. Statistical Procedures for Agricultural Research, 2nd Edition. Wiley-Inter-Science Publication, John Wiley & Sons, New York.

Guay R and Arseneault J L. 1996. Win/MacRHIZO Root Overlap Compensation Method, Vol 4. International Technical Note, Regent Instruments Inc.

http://software.ipni.net/article/nutrient-expert

http://software.ipni.net/package/770C5AEE1A369CD785257C430053D4CC

http://software.ipni.net/package/D56F6FAFBB9C613B85257C430053009B

http://www.ipni.net

Jat M L, Saharawa Y S, Majumdar K and Gupta R. 2011. Addressing climate change effects and meeting maize demand for Asia. (*In*) *11th Asian Maize Conference,* Nanning, China, 7-11 Nov, pp 370–2.

Jat M L, Satyanarayana T, Majumdar K, Parihar C M, Jat S L,

Majumdar K, Satyanarayana T, Pampolino M, Dutta S, Jat M L, Sulewski G and Johnston A M. 2013. Nutrient Expert for hybrid maize (version 1.1). A decision support tool for providing field specific fertilizer recommendations for tropical hybrid maize. International Plant Nutrition Institute, Gurgaon, India.

Paul J, Suri V K, Sandal S K and Choudhary A K. 2011. Evaluation of targeted yield precision model for soybean and toria crops on farmers' fields under sub-humid sub-tropical north-western Himalayas. *Communications in Soil Science and Plant Analysis* **42** (20): 2 452–60.

Pooniya V, Shivay Y S, Rana A, Nain L and Prasanna R. 2012. Enhancing soil nutrient dynamics and productivity of *Basmati* rice through residue incorporation and zinc fertilization. *European Journal of Agronomy* **41**: 28–37.

Prasad R, Shivay Y S, Kumar D and Sharma S N. 2006. Learning by doing exercises in soil fertility (A practical manual for soil fertility). Division of Agronomy, Indian Agricultural Research Institute,. New Delhi.

Saharawat Y S, Singh B, Malik R K, Ladha J K, Gathala M K, Jat M L and Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in NW IGP. *Field Crop Research* **116**: 260–7.

Satyanarayana T, Majumdar K, Pampolino M, Johnston A M and Jat M L. 2013. Nutrient Expert™: A tool to optimize nutrient use and improve productivity of maize. *Better Crops–South Asia* **97**: 21-4.

Vance E D, Brookes P C and Jenkinson D S. 1987. An extraction method for measuring soil microbial biomass carbon. *Soil Biology and Biochemistry* **19**: 703–4.