



Nutrient management in wheat (*Triticum aestivum*) production system under conventional and zero tillage in eastern sub-Himalayan plains of India

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ABSTRACT

Present study compares the impact of nutrient management along with different agronomic management practices such as conventional and zero tillage on wheat production. Nutrient Expert® (NE) decision support tool, based on the concept of 4R Nutrient Stewardship, provides nutrient recommendation to the farmers by guiding them choose the right source of fertilizer and advice the right rate, time and place or method of application. Taking due cognizance of above facts, field studies in wheat were conducted at the Instructional Farm under Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal (India) for two consecutive winter seasons of 2014–2015 and 2015–2016. The study highlights that nutrient management with balanced nutrient application, as guided by NE tool, produces significantly higher yield (3.92 and 4.01 t/ha) over other treatments under both conventional (CT) and zero tillage (ZT). Within NE, the yield was significantly higher in CT (4.01 and 3.92 t/ha) over ZT (3.71 and 3.66 t/ha). While the benefit:cost ratio suggests that ZT with NE is the best management practice with holistic consideration towards productivity enhancement and reduced cost of production, significantly higher economic nitrogen use efficiency (ENUE) values in NE was due to balanced application and optimum utilization of N leading to higher grain yield. The value was lowest in N_{rich} plots where maximum rate of N was applied without significant yield improvement. The CT resulted in higher values of ENUE compared to ZT in the NE treatment due to higher wheat yield at similar N rates. Therefore, the nutrient dose of NE with application of N, P_2O_5 and K_2O at 140, 32.9 and 65 kg/ha, respectively in collaboration with ZT management practice produced a yield with high productivity, good economics and better ENUE.

Key words: Nutrient Expert, 4R-Nutrient Stewardship, Soil fertility, Tillage

Wheat (*Triticum aestivum* L.) is a globally cultivated cereal, ranking second to maize followed by rice (Houshyar *et al.* 2010). It is the second most important cereal crop of India, next to rice, occupying about 29 mha area, and contributing to 37% of the national foodgrain production (FAOSTAT 2012). India stands second (after China) in terms of total wheat production (FAOSTAT 2013). The Indo-Gangetic Plains (IGP) of South Asia cover 42% of the

total wheat area (Pathak *et al.* 2011). The projected internal demand of wheat is between 105 and 109 million tonnes by 2020 as against 94 million tonnes of present production in India (FAOSTAT 2016). Besides, India exports more than 0.6 million tonnes of wheat to Bangladesh, Nepal, United Arab Emirates and others countries. As we look at further opportunities to improve production, it becomes evident that there still exists substantial yield gap within wheat growing regions of the country, as well as between on-station and on-farm yields (Ladha *et al.* 2003, Majumdar *et al.* 2013).

The eastern sub Himalayan plain in the eastern IGP is a potential wheat growing area that can largely contribute to wheat production of the country. The Eastern IGP is characterized by high population density, small farms, poor input and output, marketing infrastructure, poor access to new technologies and frequent climatic aberration (floods, drought and temperature), and a shorter wheat growing season compared to Western IGP. The shorter growing period coupled with delayed planting of wheat, due to late harvest of preceding rice, causes wheat grain filling stage to coincide with high ambient temperature (terminal heat) leading to large yield penalty. Wheat yield losses have been reported due to high temperature stress at grain filling stage (Farooq

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et al. 2011). Farmers in this region typically grow wheat after intensive dry tillage and planking. Repeated dry tillage to prepare the field leads to further delay in wheat seeding by almost a week compared to zero tillage (ZT) planting (Jat *et al.* 2014). ZT 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 to increase yield so as to increase profitability (Chhokar *et al.* 2007, Jat *et al.* 2009a,b, Saharawat *et al.* 2010, Jat *et al.* 2013). Experimental evidence from various production environments suggests that CA based management can have both immediate, e.g. reduced production costs, reduced erosion, stabilized crop yield, improved water productivity, adaptation to climatic variability (Jat *et al.* 2009a, Farooq *et al.* 2011) and long-term benefits, e.g. higher soil organic matter contents and improved soil quality (Kienzler *et al.* 2012).

Zero tillage based conservation agriculture (CA) practice has emerged as an important cropping system management strategy to address many of the challenges confronting intensified wheat systems in India. However, optimal nutrient management practices for wheat under Zero Tillage (ZT) are poorly understood. In the promising wheat production systems of Eastern Sub-Himalayan plains of India, intensive tillage operations and blanket fertilizer recommendations have led to higher production costs, lowered the profits, and decreased nutrient use efficiency leading towards significant environmental footprint. Inappropriate nutrient management is one of the major factors causing yield losses in wheat (Majumdar *et al.* 2012). Existing fertilizer recommendations for wheat are mostly blanket applications that often consist of predetermined rates of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) for vast areas, such as— state wide recommendation. Such recommendations assume that the nutrient need of wheat is constant over time and over large areas. However, the growth and nutrient needs of a crop generally vary among fields, seasons, and years as a result of differences in crop growing environments, crop and soil management as well as climate. Hence, the management of nutrients for wheat would require an approach that enables adjustments in nutrient applications to accommodate the field-specific needs of the crop that adequately address the spatial and temporal variation in nutrient requirement. Low nutrient use efficiencies, low profits and increased environmental footprint are some of the concerns associated with blanket fertilizer use in India (Sapkota *et al.* 2014). Change of crop management practices must be supported by appropriate nutrient management to accrue the full benefit of changing practices. There are several evidences of combined benefit of zero-till and farm specific nutrient management (Das *et al.* 2016, Sapkota *et al.* 2014) but they are mostly confined to other crops (maize) or other ecologies (North-western India).

Nutrient Expert® (NE) – Wheat is a nutrient decision support system that uses the principles of site-specific nutrient management (SSNM) and enables farm advisors to develop fertilizer recommendations tailored to a specific

field or growing environment for wheat (Chuan *et al.* 2013, Pampolino *et al.* 2012, Sapkota *et al.* 2014). In the recommendation process, NE considers the most important factors affecting nutrient management recommendations in a particular location, and provides recommendation guidelines that are suitable to that particular farming condition. The tool uses a systematic approach of capturing the site-specific information that is important for developing recommendation (Xu *et al.* 2014).

We hypothesize that converting to zero-till from conventional tillage of crop establishment, and applying nutrients on a site-specific basis using the Nutrient Expert fertilizer decision support tool may improve the wheat productivity in the eastern sub Himalayan plains.

MATERIALS AND METHODS

Field studies in wheat were conducted at the instructional farm (26°24'02.2"N latitude, 89°23'21.7"E longitude, and 43 m above mean sea level) of the Uttar Banga Krishi Viswavidyalaya, West Bengal, India, for two consecutive years, i.e. winter seasons of 2014–2015 (year 1) and 2015–2016 (year 2). Rice-wheat rotation was followed in the experimental field for the last 3 years prior to the inception of the current study. The meteorological monthly mean data for the experimental period are given in Table 1. The average annual rainfall was 2800–3000 mm of which 70–90% was received during June to September. Minimum temperature is observed during December to January that begins to rise in February to March, while reaching its peak during April to May. The relative humidity remains high throughout the year except during the winter months. The experimental soil (0–15 cm) was sandy loam in texture with good drainage facility. The physico-chemical properties of the soil are presented in Table 2.

Experimental design was set up as split plot with three replications. The treatments involve two main plots of tillage options [Conventional tillage (CT) and Zero tillage (ZT)] and each main plot had four subplots of different nutrient management practices (Table 3). For conventional tillage, the land was prepared by ploughing twice with a rotovator and soil was brought into good tilth with a power tiller. Land levelling was done with ladder. No land preparation was done for zero tillage. Seeds were sown in lines 20 cm apart with a seed rate of 100 kg/ha, manually for conventional tillage, and with 9 tyne zero-till-drill for zero tillage. The fertilizers were applied as per treatment requirement. Part of the nitrogen (N) was applied as basal (25 kg/ha N) and rest in two equal splits during first and second irrigation. Full P and 50% K were applied as basal, while the rest half K is applied along with urea during second top dressing. The fertilizer consisted of NPK complex fertilizer (10:26:26 as N:P:K), urea, SSP, and MOP. The basal fertilizer, i.e. NPK complex fertilizer (10:26:26) was furrow placed in case of zero tillage, while it is broadcasted before levelling in the conventional tillage plots. In zero tillage plots, Glyphosate 41% S.L. @ 3.75 l/ha was applied 7 days prior to sowing for smothering the existing weed flora, while the broad-leaved

Table 1 Meteorological variable during crop growing season of 2014-15 and 2015-16

Growing season	Month	Average temperature (°C)		Average relative humidity (%)		Total rainfall (mm)
		Maximum	Minimum	Maximum	Minimum	
Winter 2014-15	November	29.7	16.1	88.7	83.8	0.0 (0)*
	December	25.7	11.2	89.8	84.5	0.3 (0)
	January	24.1	10.2	90.3	78.2	23.3 (2)
	February	27.5	13.1	84.3	69.1	15.4 (2)
	March	30.9	18.2	73.7	55.9	1.6 (0)
Winter 2015-16	November	29.3	22.7	81.7	74.9	0.0 (0)
	December	25.1	18.2	83.3	79.3	0.0 (0)
	January	23.5	9.7	88.9	81.2	8.1 (2)
	February	26.1	11.5	81.4	68.9	1.2 (0)
	March	30.7	17.2	70.2	59.5	59.5 (8)

*Figure in parenthesis represents number of rainy days. *Source:* Gramin Krishi Mousam Seva Kendra, Pundibari, Cooch Behar, West Bengal, India.

weeds were controlled with 2,4-D Na salt 80% W.P. @ 1 kg a.i/ha at 4-5 weeks after sowing. In conventional tillage plots, thinning and weeding were done simultaneously with the help of manual labour at 3-4 weeks after sowing. Boron (B) was applied @ 0.20% with Solubor (20% B), at 35-40 DAS and at 55-60 DAS in both CT and ZT plots. Zinc (Zn) was applied with B in the second spray @ 0.10% with Chelated Zn (Chelamin). Four supplemental irrigations, each of 4-5 cm were given to wheat based on soil moisture status. Harvesting of the crop was done manually and yield

was estimated on net plot basis (1m × 1m) excluding the border rows. After harvesting, the produce was threshed and grains were dried to record yield.

Rice was grown in rotation with wheat in the experimental plots in the following rainy season. Puddled transplanted rice was grown in the CT plots, while wet direct seeded rice was followed in the ZT plots. Nutrients were applied at a uniform rate, 60:30:30 kg N, P₂O₅ and K₂O/ha, in all the plots.

The entire produce from the net plot area of 1m² (from demarcated portion, leaving the border area) with three replications were harvested and weighed after thorough sun drying to bring down the moisture content of grain to 12%. Average grain yield of three 1m² area was converted in per unit area basis (t/ha).

Table 2 Initial physico-chemical properties of the experimental soil (0-30 cm depth)

Parameter	Result	Methodology	Citation	Equipment used
<i>Mechanical composition</i>				
Sand (%)	56.3	International pipette method	Piper (1950)	Hydrometer
Silt (%)	26.0			
Clay (%)	17.7			
Soil texture	Sandy-loam	Textural triangular method	Brady and Weil (1996)	
pH	5.51	Potentiometric method	Jackson (1967)	Sorensen's pH meter
Organic carbon (%)	0.92	Wet oxidation method	Walkley and Black (1934)	
Mineralizable N (kg/ha)	132.3	Hot alkaline KMnO ₄ Method	Subbiah and Asija (1956)	Kjeldahl apparatus
Available P (kg/ha)	36.6	0.5 M NaHCO ₃ extract	Bray and Kurtz (1945)	Spectrophotometer
Available K (kg/ha)	214.5	Neutral N NH ₄ OAc extract	Hanway and Heidel (1952)	Flame photometer

Chemical analyses of soil and plant samples

Initial soil samples (up to 30 cm depth) from the experimental field were collected from four different places and made into a composite soil sample. At harvest, soil samples (up to 30 cm depth) were also collected from each plot to determine post-harvest soil status. Soils were air-dried, thoroughly mixed and then ground to pass through a 2 mm sieve for estimation of following properties according to standard methods (Table 2). The available nitrogen of the soils was estimated through the hot alkaline potassium permanganate method as suggested by Subbiah and Asija (1956) and estimated in Kjeldahl apparatus. The available phosphorus of the soils were extracted with 0.5 M NaHCO₃ as suggested by Olsen *et al.* (1954) and estimated through a UV-VIS spectrophotometer. Available potassium of the soil samples was extracted with neutral ammonium acetate solution as suggested by Brown and Warncke (1988) and estimated through a Flame photometer.

Chemical analyses of plant parts were done by taking random samples of aerial plant parts at harvest from different treatments during both the years of experimentation. Grain and straw portions were crushed and kept separately with suitable description and identification marks. Estimation of

total nitrogen, phosphorus and potassium contents in plant materials were done on dry weight basis. The total nitrogen content in plants was determined by modified micro-kjeldahl method (Jackson 1973). Phosphorus content of the plant materials was determined by tri-acid digestion through vanado-molybdate-orthophosphate complex of yellow colour in HNO_3 medium using a spectrophotometer at 420 nm wavelength and by using standard curve (Jackson 1973). Potassium content of the plant materials was determined by tri-acid digestion method with the help of Flame Photometer and by using standard curve described by Muhr *et al.* (1963). The total uptake of each major nutrient by wheat at harvest was determined on dry weight basis by multiplying the total dry matter of the crop with its corresponding nutrient.

Economic nitrogen use efficiencies

Economic nitrogen use efficiency (ENUE) is the grain yield obtained per unit amount of investment on nitrogen (N). It is expressed in kg grain per INR invested in N.

Economic nutrient use-efficiency = $\text{GY}_N / \text{INR}_N$ = kg grain/INR invested in N.

where, GY_N = Grain yield with given nitrogen (kg/ha), INR_N = Amount invested in the nitrogen (INR/ha).

Economics of production

Total cost of production/ha for each treatment was calculated on the basis of existing market rate of inputs by taking into account the cost of seeds, fertilizers, pesticides, hiring charges for machineries and labor use. The cost incurred for all activities starting from land preparation to harvesting and threshing was taken into consideration. Gross return was calculated on the basis of prevailing market price of the produce and net profit was calculated based on the difference between gross return and the total cost of cultivation. Benefit:cost (B:C) ratio was calculated based on the ratio of gross income to total cost of cultivation. On the basis of B:C ratio, the most beneficial treatment for the crop was determined.

Statistical analyses

Analysis of variance method was used for statistical analyses and for drawing conclusions. The significance

of various sources of variation was tested by error mean square by Fisher-Snedecor's "F" Test at probability levels 0.05 (Cochran and Cox 1955, Panse and Sukhatme 1967). For comparison of 'F' tables and for computation of critical differences, Fisher and Yates table was consulted.

RESULTS AND DISCUSSION

Wheat grain yield and total biomass production

The impact of nutrient management as well as tillage differences were observed in the wheat yield in both the years. As far as the nutrient management options were concerned, the results showed that NE, i.e. 100% of NE dose resulted in maximum grain yield (3.92 and 4.01 t/ha under CT during 2014-15 and 2015-16, respectively) closely followed by N_1 treatment (3.54 t/ha) during 2015-16 (Table 4). Nutrient application based on the NE software increased yield by 18% yield over general recommended dose of nutrient application (N_1). The biomass production trend was also similar where NE based recommendation resulted in significantly ($p \leq 0.05$) higher biomass production. Previous studies also reported that balanced nutrient management with Nutrient Expert® helped in wheat productivity enhancement over existing recommendation practices (Majumdar *et al.* 2013, Chuan *et al.* 2013, Sapkota *et al.* 2014).

In both the years, tillage had a significant effect on wheat grain yield and total biomass production. In Year I (2014-15) and Year II (2015-16), grain yields and total biomass production of CT plots were significantly ($p \leq 0.05$) higher than ZT plots across all the nutrient management options, except N_0 , for both the study years (Table 4). This result might be attributed to better crop stand, as reflected by higher number of spikes/m² with increased number of grains/spike (data not shown). In zero till plots, there was some problem with respect to seed germination, seedling emergence, as well as weed management in both the years. It is our speculation that hand weeding in CT plots more effective, particularly against *Polygonum* spp., the dominant weed flora of this region, as against the chemical weed control in zero tilled plots. Moreover, post emergence application of 2,4-D herbicide in zero tillage (ZT) temporarily suppressed

Table 3 Details of nutrient management options allotted to sub-plots

Treatment	Detail	Treatment short form
N0	Without application of any fertilizer	N0P0K0
N1	Recommended NPK (150-26.3-33.3 kg/ha): Applied 25 kg/ha N, full P and half K using NPK mixture as basal. The remaining N was applied in two equal splits at first and second irrigation and the remaining half K at second irrigation- Top dressing just before irrigation (within 24 hrs.)	N150P26.3K33.3
NE	Nutrient Expert* (140-32.9-65 kg/ha): Applied 25 kg/ha N, full P and half K using NPK mixture as basal. The remaining N was applied in two equal splits at first and second irrigation and the remaining half K at second irrigation - Top dressing just before irrigation	N140P32.9K65
Nrich	150% N and full P and K as per state recommendation (225-26.3-33.3 kg/ha): Applied 25 kg/ha N, full P and half K using NPK mixture as basal. The remaining N was applied in two equal splits at first and second irrigation and the remaining half K at second irrigation- Top dressing just before irrigation	N225P26.3K33.3

*The dose was determined by NE software based on omission plot data with a target yield of 5.5 t/ha.

Table 4 Effect of tillage practices and nutrient management options on grain yield, total biomass production, economic nitrogen use efficiency (ENUE) and production economics of wheat

Treatment combination	Grain yield (t/ha)		Total biomass production (t/ha)		Economic nitrogen use efficiency [¶] (kg grain/INR invested in N)		Benefit : cost ratio [#]	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
N0 × CT	1.82aa*	1.16aa	4.83aa	3.78aa			0.92: 1	0.64: 1
N0 × ZT	1.69aa	1.13aa	4.66ab	3.60ab			0.65: 1	0.71: 1
N1 × CT	3.29ba	3.63ba	8.14ba	8.73ba	1.70aa	1.87aa	1.31: 1	1.44: 1
N1 × ZT	3.12ba	3.59ba	7.74cb	8.54ba	1.61aa	1.85aa	1.38: 1	1.58: 1
NE× CT	3.92ca	4.01ca	9.42ca	9.71ca	2.16ba	2.21ba	1.53: 1	1.56: 1
NE× ZT	3.66cb	3.71cb	8.46db	8.66bb	2.02ba	2.05ba	1.58: 1	1.59: 1
Nrich× CT	3.01da	3.65ba	8.58da	8.55ba	1.03da	1.25da	1.15: 1	1.39: 1
Nrich× ZT	2.92ba	3.36bb	7.94cb	7.76db	1.00da	1.15da	1.23: 1	1.41: 1

CT, Conventional tillage; ZT, Zero tillage; N0, N0P0K0; N1, N150P26.3K33.3; NNE, N140P32.9K65 and Nrich, N225P26.3K33.3.

*The first letters are showing statistical difference across nutrient treatments and second letter are showing statistical difference across tillage operations both at $p \leq 0.05$. [¶]INR invested per kg of N is 12.95.

Polygonum spp., but it could not control the flush completely that affected the crop at later stages.

The optimum time of sowing of wheat in this north eastern plain zone of India is the period from 15th to 25th November. The effect of sowing time on crop yield was absent as the crop was sown at optimum time for both the years. However, higher biomass and grain yield production during 2015-16 over 2014-15 was observed, mainly due to prevalence of lower temperature, particularly during grain filling stage (first fortnight of March) of the crop as both maximum and minimum temperatures during the entire period of growth was higher in Year 1 (2014-15) than in Year 2 (2015-16). Total biomass production as well as grain yield was reduced in 2014-15 due to increased maintenance respiration particularly under higher minimum temperature (Gupta *et al.* 2010).

Nutrient management played a crucial role in the present experiment towards yield enhancement. Improved crop yield under CT compared to ZT with 150 kg/ha of N was also previously reported by Abid *et al.* (2014). A positive relation with yield and nitrogen application was reported by Mitra *et al.* (2014) in which the investigators got a positive yield response up to 150 kg/ha of N application.

Several earlier studies have shown that the Nutrient Expert[®] fertilizer decision support tool can reduce the nutrient related yield gaps by recommending optimal rates of nutrients based on the crop need at a target yield and the soil nutrient status (Majumdar *et al.* 2013, Sapkota *et al.* 2014). Application of P₂O₅ and K₂O at higher rates (75 kg P₂O₅ and 78 kg K₂O/ha) recommended by NE increased wheat yield by 0.5 t/ha over the general recommended rates of fertilizer application (N₁).

Economic Nitrogen Use Efficiency (ENUE)

Table 4 indicated the superiority of NE-based fertilizer recommendation by virtue of greater economic nitrogen use efficiency (ENUE) over the other treatments. The

significantly ($P \leq 0.05$) higher ENUE values in NE was due to balanced application and optimum utilization of N leading to higher grain yield that reduced the investment on N per unit of production. The value was lowest in N_{rich} plots where maximum rate of N was applied without significant yield improvement. This highlights the necessity of site-specific balanced nitrogen management that provides opportunities to improve nutrient use efficiencies and better return on investment. Better timing of N application, to match physiological need of crops, also improves ENUE. The most common practice in the eastern sub-Himalayan region of applying large amount of N through a single application at early crop growth stages reduces the possibility of high ENUE and increases the risk of environmental loss of applied N. With respect to tillage operations, CT resulted in higher values of ENUE compared to ZT in the NE treatment due to higher wheat yield at similar N rates. Nitrogen use efficiency was mainly enhanced by potassium application in NE based recommendation; the rate (78 kg/ha) was almost double in NE based treatments over recommended dose of K₂O (40 kg/ha). Sub-optimal dose of phosphorus with half dose of potassium in recommendation could be the reason for low nutrient efficiency values in treatments other than NE. Reduction in nitrogen use efficiency due to imbalanced application of other deficient nutrients has been reported by several authors. Higher efficiencies in CT over ZT were mainly due to yield differences which was much higher in CT than ZT. Increased values in second year of experimentation were mainly due to increased performance of the crop in both CT and ZT in 2015-16 than in 2014-15. Nutrient Expert[®] based site-specific adjustment of nutrient management guidelines was suggestive for achieving higher yield performances with increasing profit.

Production economics

The production economics of wheat cultivation in the present study (Table 4) revealed the superiority of zero

tillage (ZT) over conventional tillage (CT) across all the nutrient management options. The B:C ratio varied from 0.65 to 1.58 and 0.64 to 1.59 during first and second year of the experiment, respectively. In general, the treatments having higher gross return and net return recorded higher B:C ratio. Despite less yield, B:C ratio was recorded higher under ZT over CT. This could be attributed to its lesser cost of cultivation in ZT over CT. In present experiment, under ZT, land preparation and sowing operation saved ₹ 2600 (while cost involvement in CT and ZT were ₹ 5400 and ₹ 2800, respectively), as it does not require any land preparation and even saves extra man-days (4) required for manual sowing. Secondly, in weeding operation an amount of ₹ 1775 was saved (while cost involvement in CT and ZT were ₹ 3375 and ₹ 1600, respectively), because at least 15 man-days required for manual weeding in CT could be saved through ZT. With respect to different fertility treatments, maximum cost of cultivation was noted in NE; at the same time, maximum gross returns were obtained from the treatment NE too. This variation in gross return was attributed to the difference in yield under various set of nutrient management practices.

Data on production economics of wheat cultivation revealed the superiority of zero tillage (ZT) over conventional tillage (CT) due to its lesser cost of cultivation. In the case of ZT, no extra cost was incurred towards land preparation and at the same time, chemical measures were adopted for controlling the weed flora in zero-tilled plots that was very cheap compared to manually weeded plots under CT. For this reason, in all the treatments the ZT resulted in overall saving of around ₹ 3000/ha. The variation in gross return was attributed to the difference in yield under various set of nutrient management practices. A higher return with reduced cost for tillage under ZT was previously reported by Sah *et al.* (2014).

Nitrogen (N), phosphorus (P) and potassium (K) content and uptake by wheat

The nutrient content in the grain and straw components varied across different nutrient management treatments (Table 5). The N, P and K uptake increased with increased application of nutrients, and total uptake was highest in the NE treatment due to high biomass yield. Similar observations were reported by other authors (Kumar and Singh 2003, Devi *et al.* 2011) who also reported higher nutrient uptake with increased and balanced fertilizer application. The nitrogen (N) content varied widely with different nutrient management options and years, 2.85 to 4.29% in grain and 0.46 to 0.62% in straw during 2014-15 and 3.64 to 4.31% in grain and 0.48 to 1.09% in straw during 2015-16. The highest N content in both grain and straw was recorded with the treatment in which maximum dose of N (225 kg/ha) was applied (N_{rich}). However, the total uptake of N was highest with NE during both the years of experimentation (62.4 kg/ha during 2014-15 and 69.6 kg/ha during 2015-16) as the yield was highest in this treatment. The phosphorus (P_2O_5) content of wheat grain was found to differ with

different nutrient management practices (0.46 to 0.64% and 0.38 to 0.60 % during year I and year II, respectively). The potassium (K_2O) content in grain and straw were higher in the NE treatment, and in the ZT over CT plots.

Although not always significant ($p \geq 0.05$), the grain and straw uptake of the less mobile nutrients, P and K, were generally higher in ZT than the CT treatments (Table 5). Mackay *et al.* (1987) also reported a significantly ($P \leq 0.05$) higher P uptake by corn from the 0-7.5 cm soil layer under zero tillage than under conventional tillage. The less mobile nutrients (P and K) were found to concentrate near the soil surface under zero tillage (Follett and Peterson 1988, Duiker and Beegle 2006). The density of crop roots is usually greater near the soil surface under zero tillage compared to conventional tillage (Qin *et al.* 2004) that facilitate the higher uptake of these nutrients in zero till plots.

Soil pH, organic carbon and available nutrient status of soil after each year of experimentation

After harvest of winter wheat crop (2014-15) rice was grown during rainy season, 2015 in the first year with uniform fertilizer dose across all treatment plots. Once rice is harvested, wheat was sown with distinct treatment variation during winter, 2015-16. Therefore, the chemical properties (Table 6) were inclusive of a rice crop grown in between two wheat crop under experimentation. In summary, not much variation was observed in soil pH with respect to various tillage as well as nutrient management practices. The soil organic carbon (% OC) were also not much varied across the treatments. The N_{rich} treatment had maximum available nitrogen after each year of experimentation (146.90 and 156.70 kg/ha after year I and II, respectively) followed by NE, and N_1 (Table 6). The higher available N might be attributed to use of higher nitrogenous fertilizer. The N status in NE treatment increased to 140 kg/ha at the end of second year from the initial status of 132 kg/ha. The study also suggests that addition of increased dose of phosphorus (P_2O_5) under NE treatments (at the rate of 75 kg/ha) resulted in increased available phosphorus after each year of experimentation (39 and 40 kg/ha under NE during year I and II, respectively) over initial P_2O_5 status of the soil (36 kg/ha). In plots where no P_2O_5 was applied, resulted in decreased available P_2O_5 over years of experimentation (34 and 32.50 kg/ha during year I and II, respectively) (Table 6). Available potassium (K_2O) content of the experimental soils after 2nd year of experimentation suggested that the available K_2O decreased under all nutrient management options where less K_2O was applied. However, there was slight build up in available K_2O in NE plots where almost double of recommended K_2O dose was added (78 kg/ha). Potassium is known for its excessive uptake by the crops above its normal requirement and this resulted in negative balance of potassium in untreated plots. It is interesting to report that the difference in soil parameters were not significantly ($P \geq 0.05$) different across CT and ZT (Table 6).

With the increase in the level of fertility (N, P and K) also assured the availability of these nutrients to the crop

Table 5 Nitrogen (N), phosphorus (P), potassium (K) content and uptake by wheat as influenced by nutrient management options and tillage practices

Treatment combination	2014-15				2015-16				2014-15				2015-16				2014-15				2015-16			
	N content (%)		Total uptake (kg/ha)		N content (%)		Total uptake (kg/ha)		P ₂ O ₅ content (%)		Total uptake (kg/ha)		P ₂ O ₅ content (%)		Total uptake (kg/ha)		K ₂ O content (%)		Total uptake (kg/ha)		K ₂ O content (%)		Total uptake (kg/ha)	
	Grain	Straw	Grain + Straw	Grain + Straw	Grain	Straw	Grain + Straw	Grain + Straw	Grain	Straw	Grain + Straw	Grain + Straw	Grain	Straw	Grain + Straw	Grain + Straw	Grain	Straw	Grain + Straw	Grain + Straw	Grain	Straw	Grain + Straw	Grain + Straw
N0 × CT	3.10	0.47	29.67	24.92	0.48	0.19	3.00	2.45	0.38	0.30	2.45	0.65	0.65	0.30	2.45	25.99	0.60	0.60	2.21	25.99	0.60	0.60	2.21	52.78
N0 × ZT	2.85	0.44	25.57	19.74	0.50	0.21	2.78	2.82	0.41	0.31	2.82	0.61	0.61	0.31	2.82	23.84	0.57	0.57	2.82	23.84	0.57	0.57	2.82	58.91
N1 × CT	3.13	0.51	46.91	62.31	0.59	0.22	5.74	6.92	0.49	0.32	6.92	2.25	2.25	0.32	6.92	63.21	0.68	0.68	3.66	63.21	0.68	0.68	3.66	72.04
N1 × ZT	2.89	0.51	41.05	57.00	0.59	0.19	5.44	7.42	0.48	0.36	7.42	2.29	2.29	0.36	7.42	55.33	0.69	0.69	3.91	55.33	0.69	0.69	3.91	82.41
NE × CT	3.88	0.56	64.80	71.86	1.09	0.20	6.99	8.32	0.60	0.35	8.32	1.51	1.51	0.35	8.32	61.54	0.90	0.90	3.90	61.54	0.90	0.90	3.90	70.40
NE × ZT	3.83	0.50	59.33	67.26	0.92	0.19	6.51	7.78	0.58	0.31	7.78	1.58	1.58	0.31	7.78	52.37	0.83	0.83	3.98	52.37	0.83	0.83	3.98	84.17
Nrich × CT	4.29	0.62	61.53	70.04	0.62	0.17	4.99	6.96	0.46	0.31	6.96	2.59	2.59	0.31	6.96	59.15	0.65	0.65	2.68	59.15	0.65	0.65	2.68	70.48
Nrich × ZT	4.02	0.61	53.68	67.55	0.64	0.15	4.76	6.51	0.48	0.31	6.51	2.65	2.65	0.31	6.51	50.51	0.64	0.64	3.52	50.51	0.64	0.64	3.52	75.66

LSD ($P \leq 0.05$)

Nutrient

Tillage

CT, Conventional tillage; ZT, zero tillage; N0, N0P0K0; N1, N150P26.3K33.3; NNE, N140P32.9K65 and Nrich, N225P26.3K33.3; NS, Non-significant

Table 6 Soil pH, organic C, mineralizable N, available P₂O₅ and available K₂O status of the soil after each crop growing season

Treatment combination	Soil pH			Organic C (%)			Mineralizable N (kg/ha)			Available P ₂ O ₅ (kg/ha)			Available K ₂ O (kg/ha)		
	Initial	End of 1st year	End of 2nd year	Initial	End of 1st year	End of 2nd year	Initial	End of 1st year	End of 2nd year	Initial	End of 1st year	End of 2nd year	Initial	End of 1st year	End of 2nd year
N0 × CT	5.51	5.52	5.49	0.92	0.82	0.84	132	126	124	37	36	36	215	201	206
N0 × ZT	5.51	5.50	5.59	0.92	0.84	0.86	132	127	129	37	38	38	215	207	213
N1 × CT	5.51	5.46	5.58	0.92	0.89	0.89	132	136	136	37	39	39	215	216	219
N1 × ZT	5.51	5.48	5.67	0.92	0.93	0.95	132	134	139	37	39	40	215	219	220
NE × CT	5.51	5.50	5.64	0.92	0.93	0.95	132	140	147	37	40	41	215	218	221
NE × ZT	5.51	5.58	5.68	0.92	0.94	0.98	132	141	149	37	40	42	215	218	226
Nrich × CT	5.51	5.44	5.56	0.92	0.95	1.01	132	140	149	37	34	36	215	210	206
Nrich × ZT	5.51	5.51	5.55	0.92	0.96	1.03	132	149	157	37	35	37	215	210	213

CT, Conventional tillage; ZT, zero tillage; N0, N0P0K0; N1, N150P26.3K33.3; NNE, N140P32.9K65 and Nrich, N225P26.3K33.3

plants in adequate amount and remained in soil in substantial quantity after fulfilling the crop requirement that ultimately improved the soil fertility. These results are in agreement with the findings of Brar *et al.* (2006). The increase in P and K content might be due to an increased level of P and K fertilizers added to the soil. It was concluded that to get maximum productivity and profitability from wheat in eastern sub-Himalayan plains, the crop should be fertilized with 140-75-78 kg N-P₂O₅-K₂O kg/ha, as recommended by NE.

Overall, the study suggests that nutrient management practice based on Nutrient Expert[®] wheat recommendation in combination with zero tillage could be considered as a promising option for wheat cultivation in north eastern hill plains that has the potential for yield improvement and farm profitability, while maintaining the soil health through better nutrient use efficiencies. The nutrient dose of Nutrient Expert[®] with application of N, P₂O₅ and K₂O at 140, 32.9 and 65 kg/ha, respectively, in collaboration with zero tillage management practice produced a yield with high productivity, good economics and better economic nutrient use efficiency.

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