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Research Paper

Precision nutrient management in wheat (*Triticum aestivum*) using Nutrient Expert®: Growth phenology, yield, nitrogen-use efficiency and profitability under eastern sub-Himalayan plains

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ABSTRACT

A field experiment was conducted during the winter season (*rabi*) of 2014–15 and 2015–16 at Coochbehar, West Bengal, to assess the performance of Nutrient Expert® software on performance of wheat (*Triticum aestivum* L.) under both zero and conventional tillage. The experiment was designed in a split-plot design, with tillage options in main plot and nutrient management options in subplot. The treatment receiving 100% N-P-K through Nutrient Expert (NE) software resulted in higher plant height (90.2 cm) and leaf-area index (LAI) (4.70 at 90 days after sowing) with increased biomass (9.10 t/ha). As indicated from attainment of various phonological dates, it was revealed that the crop duration was drastically reduced due to shorter vegetative and reproductive phase under no- or minimum nutrient-application treatment. Nutrient-management options also had a significant effect on the yield components of wheat, viz. spikes/m^2, grains/spike as well as 1,000-seed weight. Treatment based on Nutrient Expert® produced significantly higher number of spikes/m^2 (382), grains/spike (55.7), spike length (11.25 cm) as well as 1,000-seed weight (41.65 g) leading to the maximum yield (3.83 t/ha), 11% higher over recommended dose of nutrient application; thus, reflecting its superiority under both conventional and zero tillage. The NE-based recommendation indicated the superiority towards greater agronomic nitrogen-use efficiency (16.74 kg grain/kg N), economic nitrogen-use efficiency (2.11 kg grain/₹ invested in N) as well as benefit: cost ratio (1.57).

Key words : Crop phenology, Economics, Nutrient Expert®, Nutrient use efficiency, Wheat productivity

Wheat is one of the major sources of calories for the rising human population in Asia. It has been projected that the demand of wheat in India by 2020 would be between 105 to 109 million tonnes as against 94 million tonnes production of present day for which balanced nutrition holds the key. Existing fertilizer recommendations for wheat are mostly blanket application which often consists of predetermined rates of nitrogen (N), phosphorus (P) and potassium (K) for vast areas. Such recommendations assume that the need of a cereal crop like wheat for nutrients is constant over time and over large areas. Hence the management of nutrients for cereals like wheat requires an approach that enables adjustments in N-P-K applications to accommodate the field-specific needs of the crop for supplemental nutrients. Nutrient Expert® (NE) is a nutrient decision support software that enables farm advisors to develop fertilizer recommendations tailored to a specific field or growing environment (Dobermann and Witt, 2004). Nutrient Expert® also follows site-specific nutrient management (SSNM) guidelines for fertilizer application and split dressings, which consider the nutrient demand of a crop at critical growth stages (Witt *et al.*, 2009). The NE does not require a lot of data nor very detailed information, even it can recommend without any soil-test data and it allows users to draw the required information from their own experience, the farmers' knowledge of the local region, and the farmers' practices. The NE was a joint development of wheat stakeholders in India including representatives from national research and extension system, private industries, CIMMYT and IPNI (Pampolino *et al.*, 2012). The recommendations of NE were extensively tested in real-farm conditions with the objective of easy implementation of improved nutrient-management practices in smallholder wheat systems of India. However, the validation of Nutrient Expert was mostly carried out over North Western Plains zone (NWPZ), the wheat bowl of

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the country. The Eastern sub-Himalayan plain also holds a potential area of wheat under North Eastern Plains Zone (NEPZ) and no work done on this aspect in this region. Opportunities exist to further enhance the yield, profitability, and resource-use efficiency of wheat production of this belt through SSNM approaches. In this backdrop, an experiment was conducted to assess the performance of NE software on wheat under both zero and conventional tillage.

MATERIALS AND METHODS

The experiment was conducted at the instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar (26°24' 02.2" N, 89°23'21.7" E, 43 m above mean sea-level), West Bengal. It was carried out during the winter (*rabi*) seasons of 2014–15 and 2015–16. The experimental soil was sandy loam, with *p*H 5.51, Organic C (%) 0.92, low in available N (132.3 kg/ha) and medium in available P (16.9 kg/ha) and K (178.8 kg/ha). The experiment was laid out in a split-plot design, having 12 treatment combinations in 3 replicates. Two levels of tillage practices, viz. conventional tillage (CT) and zero tillage (ZT), in main plot and 6 levels of nutrient-management options (Table 1) in subplots were allocated randomly. The sizes of each experimental plot were 7 m × 2 m. The wheat variety used in the experiment was 'DBW 39'. For conventional tillage, the land was prepared by ploughing twice with a rotovator and then the soil was brought into good tilth with a power tiller. Levelling was done with ladder finally. However, no land preparation was done for zero tillage. Seeds were sown in lines, 20 cm apart manually with a seed rate of 100 kg/ha for conventional tillage; while seeds were sown with 9-tyne zero-till-drill for zero-tilled plots, keeping the same seed rate. In zero tillage plots, Glyphosate 41 % SL @ 3.75 litres/ha was applied 7 days before sowing for killing the existing weed flora. Broad-leaf weeds were controlled with 2, 4-D Na salt 80% WP @ 1 kg a.i./ha at 4–5 weeks after sowing. However, in conventional tillage plots, thinning and weeding were done simultaneously with the help of manual labour at 3–4 weeks after sowing. Boron was applied twice @ 0.20% with Solubor (B 20%), once at 35–40 days after sowing (DAS) and the next at 55–60 DAS. Zinc was applied with B in the second spray, i.e. @ 0.10% with Chelated Zn (Chelamin). Half of each plot was kept undisturbed for determining yield and remaining was used for recording biometrical observations including destructive samples.

The data on plant height, leaf-area index, biomass production and tillering were taken periodically, while yield components and yield were recorded at the harvesting. Days to booting, heading, 50% flowering and physiological maturity stages were recorded by counting days from date of sowing to the date plants when attained such stages. Complete loss of the green colour of the glumes was used as indication of physiological maturity. Agronomic nitrogen-use efficiency (ANUE) was calculated as the additional grain yield produced owing to application of

Table 1. Details of nutrient-management options allotted to sub-plots

Treatment	Details
N_0	Without application of any fertilizer
N_1	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 2 equal splits–at first and second irrigation and the remaining half K at second irrigation. Top-dressing just after irrigation
N_2	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 2 equal splits–at first and second irrigation and the remaining half K at second irrigation. Top-dressing just before irrigation
$SSNM_1$	SSNM-based on 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 2 equal splits–at first and second irrigation and the remaining half K at second irrigation. Top-dressing just before irrigation
$SSNM_2$	SSNM based on Nutrient Expert with 70% N and full P and K (98–32.9–65 kg/ha) + LCC guided N (if any): Applied 25 kg/ha N, full P and half K using NPK mixture as basal and the remaining N in 2 equal splits–just before first and second irrigation completing 70% of nutrient expert recommended nitrogen. Leaf Colour Chart (Wheat LCC) guided N, if any may be applied just before the third irrigation. The remaining half K was applied just before second irrigation.
N_{rich}	150% N and full P and K as per 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 2 equal splits–at first and second irrigation and the remaining half K at second irrigation. Top-dressing just before irrigation

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

N over unfertilized control. It was expressed in kg grain/ kg N. Economic nitrogen-use efficiency (ENUE) was calculated as the grain yield obtained per unit investment on the nutrient nitrogen (N). It was expressed in kg grain/₹ invested in N. Economic analysis was carried out using the prevailing market price and expenditure incurred towards treatment differences. Benefit: cost (B: C) ratio was calculated based on the ratio of gross income to total cost of cultivation. The statistical analysis of data was done by using statistical software MSTAT-C version 2.1. Significant differences between the treatments were compared with the critical difference at (±5%) probability by LSD.

RESULTS AND DISCUSSION

Growth attributes

Nutrient-management options had a significant effect on the growth attributes as well as total biomass production of the crop (Table 2). The treatment receiving 100% N-P-K through NE software ($SSNM_1$) resulted in higher plant height and leaf-area index. In the said treatment, the tillers/m^2 was as high as 431 with a higher biomass production of 9.10 t/ha. It was closely followed by N-rich treatment where number of tillers/m^2 and total dry-matter production were 408 and 8.30 t/ha respectively. Optimum nutrient availability resulted from higher nutrient levels might be responsible for increased plant height as well as number of tillers owing to positive effects of N on cell-division and cell enlargement that ultimately lead to higher yield (Malik *et al.*, 2012). Total biomass production might be maximized in $SSNM_1$ treatment by balanced fertilizer application through NE software, which in turn resulted in higher leaf-area index (LAI) with increased plant height and more values of yield-attributing characters. Adequate nutrition of the crop at higher N levels was mainly responsible for increasing dry-matter production as well as LAI (Pande *et al.*, 2003). However, plant height, LAI as well as tiller production were found to differ non-significantly due to tillage practices, signifying similar crop environments though in all the dates of observation, conventional tillage (CT) recorded higher values over zero tillage (ZT). Total biomass production was found to be significantly higher under CT (7.90 t/ha) than ZT (7.35 t/ha). It was might be due to more vigorous vegetative growth of the crop with more number of spikes/m^2 and higher grain yield under CT.

Days to attain important phenological dates

Phenological dates (50% booting, heading, 50% flowering, physiological maturity) were studied with respect to both tillage- and nutrient-management options. There was no significant difference between CT and ZT in attaining the phenological dates under same set of nutrient management practices (Table 3). The crop raised through CT and ZT attained physiological maturity almost at a time (1 day variation in CT and ZT). The stages, viz. 50% booting, heading and 50% flowering dates were also attained almost at similar dates, signifying similar environments under both the tillage options. However, nutrient-management options had a significant influence on attaining various phenological dates of wheat. The treatments in which a good quantity of N, P and K were added (N_1, N_2, $SSNM_1$ and $SSNM_2$), the crop exhibited similar dates of 50% booting (76–77 days), heading (81–83 days), 50% flowering (86–88 days) and physiological maturity (120–122

Table 2. Growth attributes of wheat as affected by tillage and nutrient-management options (pooled data of 2 years)

Treatment	Plant height (cm)		Leaf-area index		Tillers/m^2			Biomass at harvesting (t/ha)
	60 DAS	Harvesting	60 DAS	90 DAS	45 DAS	60DAS	75 DAS	
Tillage								
CT	46.2	85.1	2.58	4.20	177	284	393	7.90
ZT	42.8	80.3	2.51	4.08	159	269	381	7.35
SEm±	0.9	1.3	0.03	0.08	1.7	2.4	2.9	0.09
CD (P=0.05)	NS	NS	NS	NS	9.3	13.2	NS	0.50
Nutrient management option								
N_0	30.7	63.5	1.33	2.65	176	149	210	4.20
N_1	46.1	86.5	2.70	4.40	183	273	389	8.10
N_2	46.7	88.1	2.72	4.42	194	286	402	8.30
$SSNM_1$	47.9	90.2	2.94	4.70	197	304	431	9.10
$SSNM_2$	44.9	87.8	2.90	4.45	174	265	397	7.90
N_{rich}	46.8	88.6	3.10	4.65	196	284	408	8.30
SEm±	0.89	1.26	0.04	0.07	3.2	4.9	7.9	0.22
CD (P=0.05)	2.7	3.8	0.12	0.21	9.6	14.8	23.7	0.65

DAS, Days after sowing, CT, conventional tillage; ZT, zero tillage. Details of nutrient-management options are given in Table 1.

days). However, in excess nitrogen applied treatments, all the dates attained later while in no-fertilizer treatments, the dates attained faster, 5–7 days earlier (Table 3). Nutrient stress in N_0 forced the crop to attain the dates earlier. With no or minimum application of nutrient the crop duration was drastically reduced on account of shorter vegetative and reproductive phase. Though, it is an established fact that crop phenology are largely dependent on genetic and environmental factors, viz. temperature, relative humidity, sun-shine hours, rainfall, etc but nutrient management also played a significant role.

Yield components and yield

Nutrient-management options had a significant effect on the yield components of wheat, viz. number of spikes/m^2, grains/spike as well as 1,000-grain weight. The $SSNM_1$ treatment produced significantly more spike/m^2, grain/spike, spike length as well as 1,000-grain weight. It was also observed that there was no significant difference in spikes/m^2 between N_1 and N_2, indicating that there was not much difference in number of spikes with respect to top-dressing of nitrogen after and before irrigation. Balanced fertilization through NE-based recommendation might be the key for this increased number of spikes/m^2, the prime yield component. Mauriya *et al.* (2013) also reported higher values of yield-attributing character in wheat under site-specific crop-management practices. There was no significant difference in spike length and grains/spike under both tillage options; however, the maximum number of spike/m^2 (324) was achieved with CT. It was probably owing to less number of tiller productions in zero-till plots resulted from non-uniform crop stand.

The crop raised with CT produced significantly higher grain yield (3.55 t/ha) over ZT (Table 4). It was probably owing to better crop stand as reflected by higher number of spikes/m^2 coupled with increased number of grains/spike. In zero-till plots, there was some problem with respect to seed germination, seedling emergence as well as weed management. Spraying of 2, 4-D in ZT treatments temporarily suppressed *Polygonum* spp. but could not control the flush completely for which the performance of the crop affected a bit at later stages. Improved crop yield under CT compared to ZT with 150 kg/ha of N was previously reported by Abid *et al*. (2014). Grain yields were appreciably and significantly influenced owing to various nutrient-management options. The results showed that $SSNM_1$, i.e. 100% of NE dose resulted in the highest grain yield (3.83 t/ha), reflecting that through balanced dose of nutrient application coming from NE ($SSNM_1$), 11% yield increment was achieved over recommended dose of nutrient application (N_1 and N_2). A positive relation with yield and nitrogen application was reported by Mitra *et al.* (2014). The NE-based fertilizer-management strategies increased yield as well as nutrient-use efficiencies in wheat (Sapkota *et al*., 2013; Majumdar *et al*., 2013; Mohanty *et al*., 2015).

Nitrogen-use efficiencies

During both the years, higher ANUE values were obtained with SSNM treatments (Table 5). This was prob-

Table 3. Effect of tillage practices and nutrient-management options on days to attain important phenological dates of wheat (pooled data of 2 years)

Treatment	Phenological dates			
	50% booting (DAS)	Heading (DAS)	50% flowering (DAS)	Physiological maturity (DAS)
Tillage				
CT	74	80	85	121
ZT	76	80	87	120
SEm±	0.9	0.9	1.1	1.2
CD (P=0.05)	NS	NS	NS	NS
Nutrient management option				
N_0	71	78	84	117
N_1	77	82	86	121
N_2	76	83	88	122
$SSNM_1$	77	81	87	121
$SSNM_2$	77	82	87	120
N_{rich}	77	83	90	123
SEm±	1.5	1.5	1.6	1.7
CD (P=0.05)	4.7	4.7	4.8	5.2

DAS, Days after sowing, CT, conventional tillage; ZT, zero tillage. Details of nutrient-management options are given in Table 1.

Table 4. Yield attributes and yields of wheat as affected by tillage and nutrient-management options (pooled data of 2 years)

Treatment	Spikes/m^2	Grains/ spike	Spike length (cm)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Tillage							
CT	324	47.2	10.65	42.35	3.55	4.54	40.90
ZT	308	45.1	10.45	40.70	3.37	4.17	41.30
SEm±	2.6	0.65	0.07	0.13	0.03	0.07	0.12
CD (P=0.05)	14.3	NS	NS	0.70	0.16	NS	NS
Nutrient management option							
N_0	159	30.5	8.55	38.90	1.45	2.74	34.10
N_1	347	47.8	10.70	41.10	3.44	4.72	42.20
N_2	353	47.2	11.15	41.40	3.41	4.87	41.15
$SSNM_1$	382	55.7	11.25	41.65	3.83	5.21	42.30
$SSNM_2$	318	48.1	10.80	41.20	3.46	4.89	41.40
N_{rich}	324	45.3	10.65	41.15	3.24	5.31	37.80
SEm±	10.4	1.4	0.12	0.28	0.16	0.42	1.93
CD (P=0.05)	31.4	4.3	0.35	0.85	0.48	1.25	5.78

CT, conventional tillage; ZT, zero tillage. Details of nutrient-management options are given in Table 1.

ably because of more uniform and more availability of N throughout the growing season as well as avoiding excess single application at early stages, the most common practice. The ANUE value under N_1 (13.06 kg grain/kg N) and N_2 (12.84 kg grain/kg N) treatments was significantly lower than SSNM treatments (16.74 and 18.88 kg grain/kg N under $SSNM_1$ and $SSNM_2$ respectively). Despite lesser yield under $SSNM_2$ than $SSNM_1$, ENUE value was higher under $SSNM_2$ (2.72 kg grain/₹ invested in N), indicating higher grain yield per rupee investment on N. It was due to lesser rate of N application (98 kg/ha); though the yield drop due to less application of N was not significant compared with recommended dose of N application (150 kg/ha for N_1 and N_2) or $SSNM_1$ (140 kg/ha) rates. Higher nitrogen-use efficiency through SSNM treatments in rice-wheat cropping system was previously reported by Bharadwaj *et al*. (2008), Singh *et al.* (2008) and Mohanty *et al*. (2015).

Table 5. Effect of tillage and nutrient-management options on grain yield, agronomic and economic nitrogen use efficiencies (pooled data of 2 years)

Treatment	Grain yield (t/ha)	ANUE (kg grain/kg N)	ENUE (kg grain/ invested in N)
Tillage			
CT	3.55	14.46	1.95
ZT	3.37	13.27	1.84
SEm±	0.03	0.28	0.05
CD (P=0.05)	0.16	NS	NS
Nutrient management option			
N_1	3.44	13.06	1.77
N_2	3.41	12.84	1.76
$SSNM_1$	3.83	16.74	2.11
$SSNM_2$	3.46	18.88	2.72
N_{rich}	3.24	7.80	1.11
SEm±	0.16	0.42	0.07
CD (P=0.05)	0.48	1.20	0.20

CT, conventional tillage; ZT, zero tillage; ANUE, Agronomic nitrogen use efficiency; ENUE, economic nitrogen-use efficiency. Details of nutrient-management options are given in Table 1.

Production economics of wheat cultivation

Data on production economics of wheat cultivation (Table 6) revealed the superiority of ZT to CT owing to its lesser cost of cultivation. As in ZT, no extra cost was incurred towards land preparation and weeding was performed through herbicides application, the treatments comprising zero tillage resulted in overall saving of ₹3,500/ha. However, with respect to different fertility treatments, higher cost of cultivation was noted in $SSNM_1$ treatment (₹31,775/ha) as compared to recommended dose of fertilizer application due to extra cost involvement for the additional P and K fertilizer application under SSNM treatments.

The maximum gross returns of ₹49,725/ha was obtained from the treatment receiving 100% of SSNM dose ($SSNM_1$), being significantly higher than the other fertility treatments. It was followed by N_1 (₹44,743/ha), N_2 (₹44,317/ha) and N_{rich} (₹42,062/ha) treatments, being at par with each other. This variation in gross returns was attributed to the difference in yield under various set of nutrient-management practices. In all the cases, gross returns were higher in CT than ZT owing to higher economic

Table 6. Production economics of wheat under various tillage and nutrient-management options in interactive way (pooled data of 2 years)

Treatment	Total cost of cultivation (×10³ ₹/ha)	Gross return (×10³ ₹/ha)	Net return (×10³ ₹/ha)	Benefit: cost ratio
Tillage				
CT	31.492	41.544	10.052	1.30
ZT	27.955	38.859	10.904	1.35
SEm±	0.58	0.47	0.34	0.02
CD (P=0.05)	3.12	2.52	NS	NS
Nutrient management option				
N_0	20.950	16.153	-4.798	0.78
N_1	31.058	44.743	13.685	1.45
N_2	31.058	44.317	13.259	1.43
$SSNM_1$	31.775	49.725	17.950	1.57
$SSNM_2$	30.926	44.210	13.284	1.43
N_{rich}	32.574	42.062	9.488	1.30
SEm±	1.21	1.56	0.55	0.04
CD (P=0.05)	3.56	4.58	1.62	0.11

CT, conventional tillage; ZT, zero tillage

Details of nutrient-management options are given in Table 1.

yield obtained under CT (Table 6). Higher returns with reduced cost for tillage under ZT was previously reported by Sah *et al*. (2014).The trend was similar for net return also where $SSNM_1$ treatment resulted in significantly higher net return (₹17,950/ha).

Benefit: cost (B: C) ratio varied from 0.78 to 1.57 under different treatments taken under the experiment. In general, the treatments having higher gross returns and net returns showed higher benefit: cost ratio. Despite lower yields, benefit: cost ratio was recorded higher under ZT (1.35) over CT (1.30). Lesser yield was superseded by the curtailment of extra cost of land preparation and weeding in ZT. The NE-based recommendation significantly improved wheat yield and economics (Majumdar *et al*., 2013).

It can be concluded that Nutrient Expert® (NE) was very effective tool for nutrient recommendation of wheat for this zone based on the principles of SSNM. This easy-to-use computer-based decision-support tool could rapidly provide nutrient recommendations bringing more balance towards fertilization and wheat grown under both ZT and CT responded well to NE- based recommendation.

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