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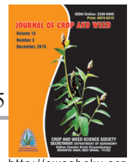

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Yield maximization through higher fertilization and lodging management in irrigated timely sown wheat (*Triticum aestivum* L.) under eastern sub-Himalayan plains

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ABSTRACT

An experiment was conducted during rabi season of 2016-17 and 2017-18 under eastern sub-Himalayan plains of West Bengal, India with the objective to maximize grain yield of wheat (Triticum aestivum L.) through higher fertilization and lodging management. The design of the experiment was split-plot with 4 nutrient management options viz. No application of fertilizer (F0); Recommended dose(RD) (150, 60, 40kg N, P_2O_5, K_2O ha-1) (F1); 150% RD(225, 90, 60 kg N,P_2O_5,K_2O kg ha^{-1})(F2); 150% RD (225, 90, 60 N, P_2O_5, K_2O kg ha-1) + 15 t ha^{-1} FYM(F3)in main-plotsand 4 growth regulator spraying optionsviz.No spaying of chemicals, spraying of water twice (G_0); spraying of chlormequat chloride twice (G_1); spraying oftebuconazole twice (G_2); spraying of chlormequat chloride + tebuconazole twice (G_3)in sub-plots each replicated thrice. It was revealed that 150% RD + 15 t ha^{-1} FYM treatment recorded the highest grain yield (5.61 t ha^{-1}) followed by 150% RDonly (5.30 t ha^{-1}). Chlormequat chloride (0.2%) + tebuconazole(0.1%) spray at 1st node and flag leaf development stageprovided lowest lodging score(1.65) reflecting its reliability in lodging management. Thus 150% RD with lodging management through chlormequat chloride (0.2%) + tebuconazole(0.1%) sprayingtwiceat 1st node and flag leaf stage indicated its superiority in terms ofbenefit:costratio (B:C) (2.51:1) with higheragronomic N use efficiency(ANUE) (23.84 kg grain kg N^{-1}) and economic N use efficiency(ENUE) (2.80 kg grain invested in N^{-1}).

Keywords: Chlormequat chloride, fertilization, lodging management, wheat and tebuconazole

The yield of wheat (*Triticum aestivum* L.), the most important *rabi* food grain crop of India, has started stagnating or even declining from mid-eighties. There has been a wide gap between the target and actual wheat production of the country (Pathak *et al*., 2003). The potential yield of irrigated wheat is about 5-7 t ha^{-1} in the state of West Bengal but the actual yield obtained is much lower, thereby indicating a scope of its improvement through appropriate crop management practices (Bhattacharyya *et al*., 2008). Nitrogen (N) is the key nutrient behind this yield reduction which actually controls the crop development in cereal based cropping systems (Samborski *et al*., 2009). Phosphorus (P) is also an important plant nutrient next only to N and classed as a major plant nutrient along with N and potassium (K). Farm yard manure (FYM) incorporation along with inorganic nutrients considerably increased all the growth and yield attributing parameters along with yield and nutrient uptake *vis-à-vis* highest nutrient recovery (Bhaduri and Gautam, 2012).

Lodging, the wind induced permanent displacement of cereal stems from the vertical, can cut the profitability of a cereal crop drastically through lower grain yield (Sterling *et al*., 2003).Lodging was induced with increasing N fertility beyond certain limit which in turn decreased grain yield and its components (Fischer and Stapper, 1987). After stem lodging, the cells on the lower side of the node elongate and force the stem erect. As plants mature, the stem cells mature and are no longer capable of elongation to enable plant recovery (Telkar *et al*., 2017). Plant growth regulators (PGRs) are often used to improve lodging traits, protect yield potentials and restrain elongation of internodes which are associated with reduction of plant height (Zhang *et al*., 2017). It is well perceived that for harnessing full potential of genetic makeup higher dose of fertilization is adopted, however, at the same time appropriate lodging management is essential as plants are susceptible to lodging with increased fertilization. With this backdrop, a two-year investigation was undertaken to assess the effects of higher level of nutrition towards yield maximization and to manage lodging due to higher doses of fertilizer application in timely sown, irrigated wheat.

MATERIALS AND METHODS

Field trials were conducted during two winter seasons in 2016-17 and 2017-18 at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari, Cooch Behar, West Bengal under eastern sub-Himalayan plains located at 26°24'02.1"N latitude, 89°23'21.5"E longitude and at 43 m above mean sea level (MSL). The experimental soil (0-15 cm soil layer) was sandy loam in texture with pH 5.51, soil organic carbon (C) 0.79%,

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mineralizable N 175.70 kg ha^{-1}, Bray I P 23.30 kg ha^{-1}and NH_4OAc extractable K 86.60 kg ha^{-1}.

The experiment was laid out in split plot design with three replications. Four levels of nutrition *viz*. No application of fertilizer (F_0); Recommended dose (RD) (150, 60, 40 kg N, P_2O_5, K_2O ha^{-1}) (F_1); 150% RD (225, 90, 60 kg N,P_2O_5,K_2O kg ha^{-1}) (F_2); 150% RD (225, 90, 60 N, P_2O_5, K_2O kg ha^{-1}) + 15 t ha^{-1} FYM (F_3) were randomly allotted inthe main-plots and four treatments consisting of various lodging arresting chemicals *viz*. no spaying of chemicals, spraying of water twice (G_0); spraying of chlormequat chloride (0.2%) twice at first node and flag leaf stage (G_1); spraying of tebuconazole (0.1%) twice at first node and flag leaf stage (G_2); spraying of chlormequat chloride(0.2%) + tebuconazole(0.1%) twice at first node and flag leaf stage (G_3)were randomly allocated in the sub-plots. The one-third of nitrogen fertilizers was applied as basal along with full P and half K fertilizers. The remaining N was applied in two equal splits, once 20-22 days after sowing (DAS) and other at 40-42 DAS with remaining half K. The individual sub-plot size was 8 × 1.8 m (14.4 m2). Wheat was cultivated after puddled transplanted rice in both the years of experiment. Wheat variety HD 2967 was used in this experiment. Seeds were sown in rows 20 cm apart with a seed rate of 100 kg ha^{-1} during November 18 and 20 in first year and second year, respectively. Nutrients were applied as per treatment. In the treatment consisting of FYM, it was applied 15 days before the final land preparation. Among the micronutrients, boron (B) was applied @0.2% with Solubor (B 20%), once at 35-40 days after sowing (DAS) and the subsequent one at 55-60 DAS and zinc (Zn) was applied with B in the 2nd spray, *i.e*., @0.1% with chelated Zn (Zn-EDTA 12%).Lodging score at harvest was calculated by the following formula (Fischer and Stapper, 1987).

$$\text{Lodging score} = \frac{(\text{\% plot area lodged} \times \text{angle of lodging from the vertical})}{90}$$

Agronomic nitrogen use efficiency (ANUE) and economic nitrogen use efficiency (ENUE) of wheat were calculated by the following formula of Nyborg et al. (1995) and Ahmad *et al*. (2012), respectively.

$$\text{ANUE} = \frac{(\text{Grain yield with given N} - \text{Grain yield without N})}{\text{N application rate}} \text{kg grain kg N}^{-1}$$

$$\text{ENUE} = \frac{(\text{Grain yield with given N} - \text{Grain yield without N})}{\text{Value of N application rate}} \text{ kg grain ? invested in N}^{-1}$$

Wheat was harvested manually from the ground level by sickle. Net plot area was harvested skipping the border rows approximately 7-10 days after physiological maturity for estimating grain and straw yield of wheat. Gross return, net return and benefit-cost (B:C) ratio were calculated by taking the prevailing market price of wheat grain (Rs. 16.00 kg^{-1}) and wheat straw (Rs. 1.50 kg^{-1}) during that period. Data followed the homogeneity test and pooling was done over two years. Statistical analysis of data was done with the help of SPSS software.

RESULTS AND DISCUSSION

Growth attributes

Plant height at harvest was increased by 5.43% in 150% of recommended NPK treatment over the treatment receiving only recommended dose (RD). Lodging arresting chemicals had significant effect on plant height and two sprays of chlormequat chloride (0.2%) + tebuconazole (0.1%) at first node and flag leaf stage showed lowest plant height (81.44 cm) among all the PGR spraying options (Table 1). In case of plant height at harvest, significant interaction effect between fertilization rates and growth regulator spraying options was recorded. It was also revealed that fertilization significantly enhanced tiller and biomass production. Highest tiller density was achieved in combined application of 150% RD and 15 t ha^{-1}FYM (466 m^{-2} at 90 DAS) and lowest tiller density was observed in no fertilizer treated plots (208 m^{-2} at 90 DAS) (Table 1). Higher N rate was mainly responsible for the enhancement in tiller production. This finding is in agreement with the finding of Balkcom and Burmester (2015). Grain + straw biomass (t ha^{-1}) was enhanced by 18.56-32.40% in NPK-rich plots over 100% RD plots. It was mainly due to N, being an important constituent of amino acids, proteins and protoplasm, which highly influenced grain + straw biomass through increase in shoot number, cell expansion and better photosynthate utilization under more N availability (Kumar *et al*., 2017). Leaf area index (LAI) at 90 days after sowing (DAS) was significantly increased due to higher NPK rates over recommended rate of NPK and it was increased by 23.11-30.41%. However, the PGR spray had no significant effect on LAI of wheat at anthesis. Toyota *et al.* (2010) reported similar observations about chlormequat chloride (0.2%) spray in wheat.

Physiological maturity and lodging score at harvest

Physiological maturity dates were studied with respect to both fertilization and foliar application of growth regulators. There was significant increase in the duration for attaining the physiological maturity with higher doses of nutrient application than no NPK applied treatment (Table 1). Similar observations were reported by Mondal *et al*. (2018). This was mainly because of sufficient distribution of N to flag leaf in N-rich treatments which increased stay-green duration (Gaju *et al*., 2014) while plants attended forced maturity under N starvation. It was observed that higher lodging in wheat occurred with 225 kg N ha^{-1}, previously reported by Hobbs *et al*. (1998). Higher NPK treated plots showed significantly higher lodging scores (4.29 in 150% recommended NPK and 7.54 in 150% recommended NPK with 15 t ha^{-1} FYM treatment) than the fertilized plots with recommended dose of NPK (1.40 in recommended NPK treatment). No lodging was recorded in the plots having no fertilizer application. Growth regulators had significant effect on lodging score. Least lodging score (1.60) was estimated from the treatment where combined spraying of 0.2% chlormequat chloride and 0.1% tebuconazole was adopted twice at 1st node and flag leaf stage of wheat. In case of lodging score at harvest, interaction effect was found significant between fertilization treatments and lodging arresting chemical treatments (Table 1).

Table 1: Growth attributes, physiological maturity and lodging score of wheat as affected by fertilization and growth regulator (mean over 2 years)

Treatments	Growth attributes				Physiological maturity (DAS)	Lodging score* at harvest
	Plant height at harvest (cm)	Tiller density m^{-2} at 90 DAS	LAI at 90 DAS	Grain + Straw biomass (t ha^{-1})		
Fertilization (F)						
F_0	67.52	208	1.64	4.38	120.00	0.00
F_1	90.13	384	4.11	9.32	124.50	1.40
F_2	95.02	429	5.06	11.05	125.88	4.29
F_3	92.97	466	5.36	12.34	126.96	7.54
SEm (±)	**0.65**	**6.28**	**0.12**	**0.20**	**0.41**	**0.57**
LSD (0.05)	**4.41**	**32.78**	**0.81**	**1.42**	**1.74**	**3.28**
Growth regulator (GR) spraying						
G_0	90.72	363	3.92	9.20	124.04	5.84
G_1	84.23	369	3.97	9.06	124.29	2.29
G_2	89.25	373	4.02	9.19	124.42	3.44
G_3	81.44	383	4.27	9.64	124.58	1.65
SEm (±)	**0.63**	**4.24**	**0.17**	**0.12**	**0.31**	**0.40**
LSD (0.05)	**2.68**	**NS**	**NS**	**NS**	**NS**	**2.37**
F × GRS.Em(±)	**1.30**	**12.57**	**0.25**	**0.40**	**0.82**	**1.03**
LSD (0.05)	**5.36**	**NS**	**NS**	**NS**	**NS**	**4.74**
GR × FS.Em(±)	**1.13**	**13.25**	**0.38**	**0.65**	**0.92**	**1.26**
LSD (0.05)	**4.62**	**NS**	**NS**	**NS**	**NS**	**3.96**

*Note: DAS: Days after sowing, *Angle of stem lodging was 45°*

Yield attributes and yield

Nutrient management options had significant effect on yield attributes *viz*., number of spike m^{-2}, number of filled grain spike-1, spike length and 1000-grain weight as previously reported by Mondal *et al*. (2018). Highest number of spike m^{-2}(339 m^{-2})was noted in treatments with 225, 90, 60 kg N,P_2O_5,K_2O kg ha^{-1}+ 15 t ha^{-1} FYM (Table 2). Application of higher N rate increased effective tiller production rate (Yang *et al*., 2019) which ultimately increased the spike density in wheat. Although 150% recommended NPK application recorded the highest spike length (10.59 cm) but highest number of filled grain spike^{-1} was recorded from 150% recommended NPK +15 t ha^{-1} FYM treatment (43.58). This increment in number of filled grain spike^{-1} was due to combined application of organic manure and inorganic fertilizers as reported previously by Singh *et al*. (2011). Foliar application of growth regulators also imposed significant influence on spike length. It was revealed that1000-grain weight (42.48 g) was recorded highest from 150% RD treatment. This was due to higher N application rate as reported previously by Krylov and Pavlov (1989). Fertilization significantly influenced grain yield, straw yield and harvest index. Highest grain yield was obtained under 150% RD along with 15 t ha^{-1} FYM treatments (5.61 t ha^{-1}). This was also due to combined application of organic manure and inorganic fertilizers which resulted in higher number of yield attributes under a better nutritional environment. The findings were in conformity with the report of Singh *et al*. (2011).Straw yield followed similar trend of grain yield and was recorded highest under 150% RD + 15 t ha^{-1}FYMtreatment (7.34 t ha^{-1}) with maximum harvest index(45.49%)under 150% RD treatment.

ANUE, ENUE and production economics

The ANUE and ENUE values were lower in N-rich plots, similar with the previous report of Mondal *et al*. (2018). Highest ANUE values were recorded in recommended N based treatments as compared to excess N applied treatments. The trend was similar for ENUE also (Table 3). The data revealed that there was yield enhancement under higher N doses; however, it was not a proportionate enhancement as reflected by ANUE and ENUE values. Excess N application under 150% RD treatments, particularly during initial stages, may not always put the plant to use it efficiently. That is why the ANUE *vis-à-vis* ENUE did not result in enhanced values over 100% RD treatment, rather it reflected its misuse through which there was higher loss of N. Under recommended N treatments, the N rate of application was much lower than the treatments comprising 150% RD and in this case N was effectively utilized by the wheat crop. That is why plant nitrogen use efficiency including ANUE and ENUE was gradually decreased due to over application of N (Yang *et al*., 2019). Mondal *et al*. (2018) and Mitra *et al*. (2019) also reported higher N use efficiencies with lower or recommended N levels in wheat at eastern sub-Himalayan plains as compared to N rich plots which actually reflected the need of site specific nutrient management.

Table 2: Yield attributes, grain yield, straw yield and harvest index of wheat as affected by fertilization and growth regulator (mean over 2 years)

Treatments	Yield attributes				Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
	No. of spike m^{-2}	Spike length (cm)	No. of filled grain $spike^{-1}$	Test weight (g)			
Fertilization (F)							
F_0	128	7.01	34.17	36.50	1.81	3.14	37.00
F_1	269	10.27	42.92	41.95	4.27	5.64	43.08
F_2	318	10.59	43.13	42.48	5.30	6.35	45.49
F_3	339	10.23	43.58	42.05	5.61	7.34	43.32
SEm (±)	**5.10**	**0.048**	**1.09**	**0.27**	**0.13**	**0.17**	**1.157**
LSD (0.05)	**32.78**	**0.39**	**5.30**	**1.04**	**0.91**	**0.96**	**4.58**
Growth regulator (GR) spraying							
G_0	259	9.70	40.50	40.52	4.14	5.62	42.42
G_1	260	9.39	40.38	40.60	4.14	5.52	42.86
G_2	260	9.67	41.25	40.91	4.25	5.57	43.28
G_3	274	9.34	41.67	40.95	4.46	5.77	43.60
SEm (±)	**4.07**	**0.04**	**1.54**	**0.37**	**0.13**	**0.25**	**1.43**
LSD (0.05)	**NS**	**0.21**	**NS**	**NS**	**NS**	**NS**	**NS**
F × GR $S.E_m$(±)	**10.28**	**0.07**	**2.38**	**0.54**	**0.26**	**0.34**	**2.59**
LSD (0.05)	**NS**	**0.39**	**NS**	**NS**	**NS**	**NS**	**NS**
GR × F $S.E_m$(±)	**12.34**	**0.08**	**2.59**	**0.72**	**0.24**	**0.50**	**2.90**
LSD (0.05)	**NS**	**0.45**	**NS**	**NS**	**NS**	**NS**	**NS**

The data on production economics revealed the superiority of the treatments consisting of 150% RDF. The highest net return (Rs. 60693 ha^{-1}) and benefit-cost ratio (2.51:1) were recorded from 150% RDF with chlormequat chloride (0.2%) + tebuconazole (0.1%) spraying treatment combination (Table 3). Highest net return and benefit-cost ratio reflected the reliability of this treatment combination towards achieving higher profitability. Although grain yield was highest under 150% RDF + 15 t ha^{-1} FYM treated plots but the benefit-cost ratio were very poor in 150% RDF + 15 t ha^{-1}FYM - chlormequat chloride (0.2%) + tebuconazole (0.1%) spraying treatment combination reflecting that the extra cost incurred for FYM was much higher than its proportionate return. However, FYM had a carry-over effect on subsequent crop in the rotation with better soil health.

Table 3: ANUE, ENUE and economics (net returns and benefit cost ratio) of wheat as affected by fertilization - growth regulator spraying treatment combinations (mean of 2 years)

Treatment combinations	ANUE* (kg grain kg N^{-1})	ENUE** (kg grain Rs. invested in N^{-1})	Net return (Rs. ha^{-1})	B:C
F_0-G_0	-	-	5563	1.20:1
F_0-G_1	-	-	3523	1.12:1
F_0-G_2	-	-	3695	1.13:1
F_0-G_3	-	-	3767	1.12:1
F_1-G_0	27.29	3.03	39179	2.13:1
F_1-G_1	27.58	3.06	38107	2.05:1
F_1-G_2	28.88	3.21	42076	2.19:1
F_1-G_3	30.21	3.36	43957	2.18:1
F_2-G_0	20.79	2.56	54144	2.42:1
F_2-G_1	20.98	2.45	48921	2.23:1
F_2-G_2	22.96	2.65	56422	2.46:1
F_2-G_3	23.84	2.80	60693	2.51:1
F_3-G_0	18.50	0.27	30630	1.45:1
F_3-G_1	18.56	0.27	31774	1.46:1
F_3-G_2	18.84	0.27	30417	1.44:1
F_3-G_3	19.60	0.28	33063	1.47:1

*Note: *FYM contains 0.40% N, 0.20% P_2O_5 and 0.18% K_2O (after chemical analysis of FYM); **Rs. invested per kg of N were 19.57 for RDF, 150% RDF and 72.21 for 150% RDF + 15 t ha^{-1} FYM*

The study unveiled that increased fertilization through 150% of recommended NPK not only increased grain yield of wheat but also resulted in higher economic benefit. Inclusion of FYM @ 15 t ha^{-1}along with 150% of recommended NPK may increase the yields further, but may not be economic. However, higher N application recorded lower values of ANUE and ENUE indicating the wastage of nitrogen. Among the lodging arresting chemical treatments, spraying of chlormequat chloride @0.2% + tabuconazole @0.1% showed good control of lodging. Therefore, 150% recommended rate of NPK through chemical fertilizers along with combined spraying of chlormequat chloride (0.2%) and tebuconazole(0.1%) twice at 1st node and flag leaf stage of wheat could maximize grain yield in wheat with better control of lodging and increased profitability in eastern sub-Himalayan plains.

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