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Impact of precision nitrogen management practices on nitrogen use efficiencies and nitrogen balance in emmer wheat (*Triticum dicoccum* L.)

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Abstract
Blanket application of recommended dose of nitrogen fertilizers leads to over or under fertilization. There is need to synchronize the N fertilizer application with plant demand. Field experiment was undertaken at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad during *rabi* season of two consecutive years (2020-21 and 2021-22) to assess the nitrogen use efficiencies and nitrogen balance in the soil under precision nitrogen management compared to fixed time N application. Experiment was laid out in RCBD with thirteen treatments (Control, N-Omission, RDN, LCC, SSNM, STCR and NE) and three replications. On the basis of two year pooled results showed that nitrogen management through recommended dose of nitrogen recorded significantly higher NUE, AE_N, PE_N and PFP_N (60.1%, 30.2 kg kg^{-1}, 35.2 and 38.4 kg kg^{-1}, respectively). However, higher RE_N was observed in basal application of 30 kg N ha^{-1} along with top dressing of 20 kg N ha^{-1} through leaf colour chart ≤ 5 (87.0%). The nitrogen balance sheet showed negative nitrogen balance in all the treatments during both the years due to decline in nitrogen content and uptake in grain and straw.

Keywords: Emmer wheat, nitrogen use efficiency, nitrogen balance, precision nitrogen management

Introduction
In recent years, the potential to mitigate climate change by improving nutrient use efficiency in croplands has received considerable attention in the agricultural research and policy agendas (Carlson *et al.*, 2017) [3]. The use of chemical fertilizers, nitrogen (N) in particular, in crop production is at the center of managing both food security and environmental problems (Spiertz, 2009) [21]. Enhancing crop yields through increased use of nutrients is essential to meet current as well as future food demand (Garnett *et al.*, 2013) [8]. Moreover, excess and improper use of nutrients in crop production have large cost implications for the farmers. Therefore, improving NUE in croplands provides the opportunity to address the triple challenge of food security, farmers' livelihood and environmental protection, globally.

Wheat is the most important and strategic cereal crop for the majority of the habitants on the earth. Cultivation of wheat dates back to more than 5000 years, during the period of Indus valley civilization during which the original species *Triticum sphaerococcum*, traditionally known as Indian wheat has vanished and replaced by modern day cultivars like *Triticum aestivum* (Bread wheat), *Triticum durum* (Macaroni wheat or Kathia wheat) and *Triticum dicoccum* (Emmer wheat or Khapli). The Emmer wheat (*Triticum dicoccum* L.) is reported to be grown on a very restricted scale in Gujarat, Maharashtra and Karnataka, where it is known under the names *Popathiya*, *Khapli*, and *Samba*, respectively. In general emmer wheat varieties are rich source of protein and complex carbohydrate (dietary fibre) compared to bread wheat. It possesses excellent grain quality traits and is rich source of dietary fibres of more than 16 percent, protein (11.8 to 15.3%) and total carbohydrates (78.7 to 83.2%). The traditional products of emmer wheat varieties have better taste, texture and flavour (Singh, 2015) [20]. Nutrition management is one of the most important approach to improve the crop yield. Wheat depletes soil nutrients, so if it isn't adequately fertilized, soil fertility starts to decline (Ramachandran and Biswas, 2016) [18].

Therefore, fertilizer applications are essential to maintain a positive nutrient balance by replacing nutrients that are taken and lost during cropping. However, increasing nutrient use efficiency (NUE) is critical in order to achieve expected production while using as little fertilizer as possible. The use of the proper fertilizer in the right amount is one of the most important management strategies for increasing fertilizer efficiency and maximize crop productivity (Jan *et al*., 2007) [12]. The application of synthetic fertilizers in wheat field increases available nitrogen, phosphorus, and potassium in soil (Barthwal *et al*., 2013) [2]. Optimum dose of fertilizer improves wheat yield (Rawal *et al*., 2016) [19] and fertilizer use efficiency, and reducing pollution. Moreover, right combination of primary nutrients is also important to enhance wheat yield and NUE. Improved nutrient use efficiency will not only help to lower the cost of crop production by reducing fertilizer use, but also help to reduce fertilizer contamination (Good *et al*., 2007) [10]. Despite the fact that using less fertilizer increases nutrient use efficiency, farmers are concerned about optimizing profit (Ghosh *et al*., 2015) [9]. So, it is essential to find a balance between nutrient efficiency and crop productivity.

Materials and Methods

A field experiment was carried out on "Impact of Precision nitrogen management practices on nitrogen use efficiencies and nitrogen balance in emmer wheat (*Triticum dicoccum* L.)" at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, Karnataka, during *rabi* 2020-21 and 2021-22. The soil of the experimental site was black clayey in texture, alkaline in pH (7.76) with normal in electrical conductivity (0.28 dS m^{-1}), low in organic carbon content (0.45%), low in available nitrogen (257 kg ha^{-1}), high in phosphorus (32.6 kg ha^{-1}) and potassium (348 kg ha^{-1}). The treatments consist of precision nitrogen management practices *viz*., T_1: N Omission, T_2: Recommended dose of N as per package of practices, T_3: Nitrogen management through SSNM for targeted yield of 4.0 t ha^{-1}, T_4: Nitrogen management through SSNM for targeted yield of 5.0 t ha^{-1}, T_5: Nitrogen management through SSNM for targeted yield of 6.0 t ha^{-1}, T_6: STCR based N management for targeted yield of 4.0 t ha^{-1}, T_7: STCR based N management for targeted yield of 5.0 t ha^{-1}, T_8: STCR based N management for targeted yield of 6.0 t ha^{-1}, T_9: Nitrogen management through nutrient expert for targeted yield of 4.0 t ha^{-1}, T_{10}: Nitrogen management through nutrient expert for targeted yield of 5.0 t ha^{-1}, T_{11}: Nitrogen management through nutrient expert for targeted yield of 6.0 t ha^{-1}, T_{12}: 30 kg N ha^{-1} basal+LCC≤5+20 kg N ha^{-1}, T_{13}: Absolute control and replicated thrice in randomized block design. The recommended dose of fertilizers for emmer wheat is 60-30-20 kg N-P_2O_5-K_2O ha^{-1} and FYM 7.5 t ha^{-1}. Nitrogen was applied as per the treatments (Table 1), recommended dose of phosphorus, potassium and farm yard manure were applied at the time of sowing.

Calculation of nitrogen use efficiencies

To evaluate the nitrogen use efficiencies of applied fertilizers, nitrogen use efficiency, recovery efficiency (%), agronomic efficiency (kg kg^{-1}), physiological efficiency (kg kg^{-1}) and partial factor productivity (kg kg^{-1}) are typically adopted (Crasswell and Godwin, 1984) [5].

Agronomic efficiency (AE_N): Increased grain yield (kg) per unit of applied fertilizer (kg)

$$AE = \frac{\text{Grain yield of fertilized crop} - \text{Grain yield of unfertilized crop}}{\text{Quantity of nutrient applied}}$$

Physiological efficiency (PE_N): The ratio of kg grain yield to kg nutrient uptake in above-ground dry matter production.

$$PE = \frac{\text{Grain yield of fertilized crop} - \text{Grain yield of unfertilized crop}}{\text{Total N uptake by fertilized crop} - \text{Total N uptake by unfertilized crop}}$$

Recovery efficiency (RE_N): Increase in crop uptake of a nutrient in the aboveground parts of the plant as a result of its application. Scientists evaluating the nutrient response of the crop frequently prefer NUE expression.

$$RE = \frac{\text{N uptake in N fertilized crop} - \text{N uptake in unfertilized crop}}{\text{Quantity of nutrient applied}}$$

Partial Factor Productivity (PFP_N)

$$PFP = \frac{\text{Grain yield in fertilized crop}}{\text{Total N uptake in fertilized crop}}$$

Nitrogen use efficiency (NUE): Crop yield (kg) per unit of applied nutrient (kg).

$$NUE = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Quantity of nutrient applied (kg ha}^{-1}\text{)}}$$

Data generated from experiments were analyzed following analysis of variance (ANOVA) using MS office excel and mean comparisons were performed based on Duncan's multiple range test (DMRT) at 5% probability level to separate treatment means.

Table 1: The total amount of nitrogen (kg ha^{-1}) applied in different treatments

Treatments	Basal		Top dressing						Total N	
			2020-21			2021-22				
	2020	2021	1st (20-25 DAS)	2nd (35-40 DAS)	3rd (50-55 DAS)	1st (20-25 DAS)	2nd (35-40 DAS)	3rd (50-55 DAS)	2020	2021
T_1	-	-	-	-	-	-	-	-	-	-
T_2	30	30	30 (30 DAS)	0	0	30 (30 DAS)	0	0	60	60
T_3	29	29	29	29	29	29	29	29	116	116
T_4	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	146	146
T_5	43.8	43.8	43.8	43.8	43.8	43.8	43.8	43.8	175	175
T_6	28	26	28	28	28	26	26	26	112	104
T_7	46.7	45	46.7	46.7	46.7	45	45	45	187	179
T_8	65.5	64	65.5	65.5	65.5	64	64	64	262	254
T_9	31.7	31.7	31.7	31.7	0	31.7	31.7	0	95	95
T_{10}	36.6	36.6	36.6	36.6	0	36.6	36.6	0	110	110
T_{11}	41.7	41.7	41.7	41.7	0	41.7	41.7	0	125	125
T_{12}	30	30	20	20	20	20	20	20	90	90
T_{13}	-	-	-	-	-	-	-	-	-	-

Results and Discussion

Effect on nitrogen use efficiency

Different precision nitrogen management practices significantly influenced the nitrogen use efficiencies. Nitrogen management through RDN (60.1%) recorded significantly higher nitrogen use efficiency and it was followed by basal application of 30 kg N ha^{-1} along with top dressing of 20 kg N ha^{-1} through leaf colour chart ≤ 5 and Nutrient Expert for targeted yield of 4.0 t ha^{-1} (47.3 and 44.7%, respectively). Significantly lower nitrogen use efficiency was noticed in nitrogen management through STCR for targeted yield of 6.0 t ha^{-1} (20.2%).

Significantly higher agronomic efficiency was recorded in RDN (30.2 kg kg^{-1}) and it was found on par with basal application of 30 kg N ha^{-1} along with top dressing of 20 kg N ha^{-1} through leaf colour chart ≤ 5 (27.4 kg kg^{-1}). Significantly, lower agronomic efficiency was noticed in nitrogen management through STCR for targeted yield of 6.0 t ha^{-1} (13.2 kg kg^{-1}).

Physiological efficiency and partial factor productivity was significantly influenced by different precision nitrogen management practices. RDN (35.2 and 38.4 kg kg^{-1}, respectively) has recorded significantly higher physiological efficiency and partial factor productivity and it was found on par with nitrogen management through Nutrient Expert for targeted yield of 4.0 t ha^{-1} (32.8 and 36.2 kg kg^{-1}, respectively) and basal application of 30 kg N ha^{-1} along with top dressing of 20 kg N ha^{-1} through leaf colour chart ≤ 5 (31.5 and 35.3 kg kg^{-1}, respectively). However, significantly lower physiological efficiency and partial factor productivity was noticed in nitrogen management through STCR for targeted yield of 6.0 t ha^{-1} (27.3 and 31.1 kg kg^{-1}, respectively).

Recovery efficiency was significantly influenced by different precision nitrogen management practices. Significantly higher recovery efficiency was observed in basal application of 30 kg N ha^{-1} along with top dressing of 20 kg N ha^{-1} through leaf colour chart ≤ 5 (87.0%). It was found on par with nitrogen management through Nutrient Expert for targeted yield of 4.0 t ha^{-1} (78.9%). Whereas, significantly lower recovery efficiency was noticed in nitrogen management through STCR for targeted yield of 6.0 t ha^{-1} (48.4%).

Precision nitrogen management using decision support systems in emmer wheat was significantly influenced on the nitrogen use efficiencies. Significantly higher nitrogen use efficiency, agronomic efficiency (AE_N), physiological efficiency (PE_N), partial factor productivity (PFP_N) (Tables 2) was observed in recommended dose of nitrogen (60.1%, 30.2 kg kg^{-1}, 35.2 and 38.4 kg kg^{-1}, respectively) due to lower rate of N application. However, higher grain yield treatment produced lower nitrogen use efficiencies. This indicates that the efficiency may not always mean effective. Among decision support systems, basal application of 50 kg N ha^{-1} along with top dressing of 30 kg N ha^{-1} through leaf colour chart ≤ 5 and nitrogen management through Nutrient Expert for targeted yield of 4.0 t ha^{-1} recorded higher nitrogen use efficiencies. This is due to lesser fertilizer application coupled with more appropriate rate, split application of fertilizer at critical growth stages and it is a measure of the ability of a plant to transform the amount of fertilizer or nutrient applied into economic yield. However, significantly higher recovery efficiency was observed basal application of 50 kg N ha^{-1} along with top dressing of 30 kg N ha^{-1} through leaf colour chart ≤ 5 and recommended dose of nitrogen (87.0 and 86.0%, respectively). This was due to application of lesser quantity of nitrogen and higher grain yield per unit quantity of nitrogen applied. Achievable levels of RE_N depend on crop demand for N, supply of N from indigenous sources, fertilizer rate and mode of application. Similar observations shown by previous works of Peng and Cassman (1998) [16] in paddy, Chen *et al*. (2015) [4] in maize, Khurana *et al*. (2008) [13] in wheat and Neha (2017) [15] in maize. Lower nitrogen use efficiencies were recorded in nitrogen management through STCR for targeted yield of 6.0 t ha^{-1} due to higher application of nitrogen beyond the plant requirement.

Table 2: Nitrogen use efficiency (%), Agronomic efficiency (AE_N), Physiological efficiency (PE_N), Partial factor productivity (PFP_N) and Recovery efficiency (RE_N) of emmer wheat as influenced by precision nitrogen management practices

Treatments	Nitrogen use efficiency (%)	Agronomic efficiency (kg kg^{-1})	Physiological efficiency (kg kg^{-1})	Partial factor productivity (kg kg^{-1})	Recovery efficiency (%)
T_1: N omission (N-0)	-	-	-	-	-
T_2: Recommended dose of N as per package of practices	60.1^{a}	30.2^{a}	35.2^{a}	38.4^{a}	86.0^{a}
T_3: Nitrogen management through SSNM for targeted yield of 4.0 t ha^{-1}	37.7^{d}	22.3^{d}	30.1^{bc}	34.2^{b-d}	74.1^{bc}
T_4: Nitrogen management through SSNM for targeted yield of 5.0 t ha^{-1}	32.3^{ef}	20.1^{d-f}	29.5^{bc}	33.3^{b-d}	68.1^{cd}
Nitrogen management through SSNM for targeted yield of 6.0 t ha^{-1}	28.8^{f}	18.5^{ef}	29.0^{bc}	32.7^{b-d}	63.8^{d}
T_6: STCR based N management for targeted yield of 4.0 t ha^{-1}	40.2^{cd}	23.7^{cd}	30.8^{bc}	34.7^{b-d}	76.8^{b}
T_7: STCR based N management for targeted yield of 5.0 t ha^{-1}	28.0^{f}	18.2^{f}	28.7^{bc}	32.3^{cd}	63.6^{d}
T_8: STCR based N management for targeted yield of 6.0 t ha^{-1}	20.2^{g}	13.2^{g}	27.3^{c}	31.1^{d}	48.4^{e}
T_9: Nitrogen management through Nutrient Expert for targeted yield of 4.0	44.7^{bc}	25.9^{bc}	32.8^{ab}	36.2^{ab}	78.9^{ab}
T_{10}: Nitrogen management through Nutrient Expert for targeted yield of 5.0 t ha^{-1}	39.5^{d}	23.3^{cd}	31.1^{bc}	34.9^{bc}	74.8^{bc}
T_{11}: Nitrogen management through Nutrient Expert for targeted yield of 6.0 t ha^{-1}	36.2^{de}	21.9^{de}	29.8^{bc}	33.7^{b-d}	73.7^{bc}
T_{12}: 30 kg N ha^{-1} Basal + LCC ≤ 5 + 20 kg N ha^{-1}	47.3^{b}	27.4^{ab}	31.5^{a-c}	35.3^{a-c}	87.0^{a}
T_{13}: Absolute control	-	-	-	-	-
S. Em±	1.5	1.1	1.3	1.1	2.6

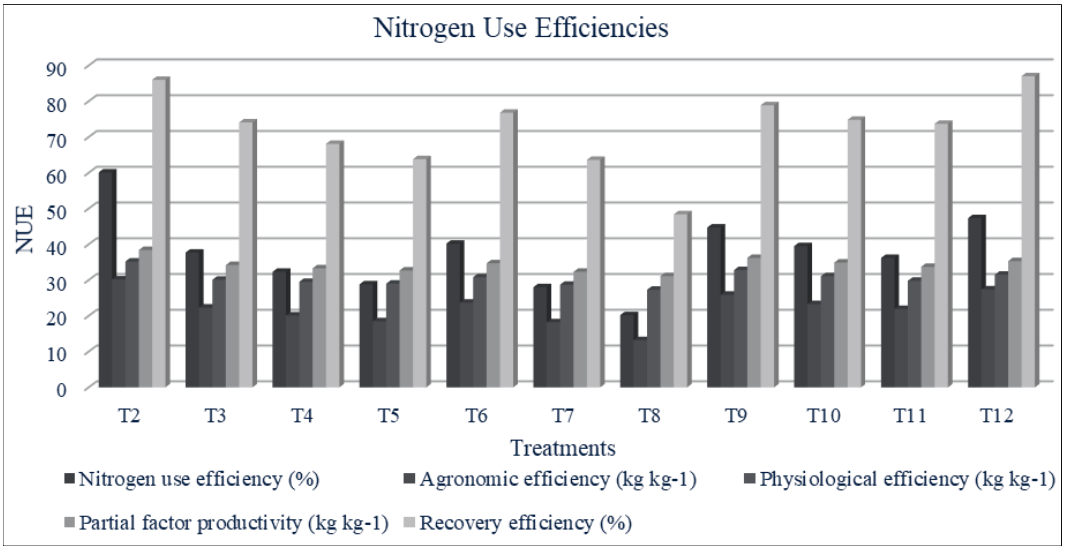

Fig 1: Nitrogen use efficiency (%), Agronomic efficiency (AE_N), Physiological efficiency (PE_N), Partial factor productivity (PFP_N) and Recovery efficiency (RE_N) of emmer wheat as influenced by precision nitrogen management practices

Nitrogen balance

The initial status of the soil nitrogen before sowing of emmer wheat was analysed randomly and recorded. The removal of nitrogen by emmer wheat was quantified after the harvest of the crop. The nitrogen balance and net gain or loss of nitrogen was calculated during both the seasons and presented in Table 3.

During first season (2020-21) the initial nitrogen status in the soil before sowing the crop was 257 kg ha^{-1}. Addition of inorganic fertilizer was varied from 60 kg ha^{-1} to 262 kg ha^{-1}, the total nitrogen in soil during crop growing season was ranged from 257 to 519 kg ha^{-1}. Among the treatments, nitrogen uptake by emmer wheat was ranged from 44.8 to 170.9 kg ha^{-1} but the higher (170.9 kg ha^{-1}) with nitrogen management through STCR for targeted yield of 6.0 t ha^{-1}. The expected nitrogen balance after the harvest of crop ranged from 199.1 to 348.1 kg ha^{-1} but the actual nitrogen balance was ranged from 175.2 to 294.6 kg ha^{-1}. Nitrogen loss or gain was ranged from -23.9 to-53.5 kgha^{-1}.

During second season (2021-22) the initial nitrogen status in the soil before sowing the crop was 268 kg ha^{-1}. Addition of inorganic fertilizer was varied from 60 kg ha^{-1} to 254 kg ha^{-1}, the total nitrogen in soil during crop growing season was ranged from 268 to 522 kg ha^{-1}. Among the treatments, nitrogen uptake by emmer wheat was ranged from 39.7 to 163.3 kg ha^{-1} but the higher (163.3 kg ha^{-1}) with nitrogen management through STCR for targeted yield of 6.0 t ha^{-1}. The expected nitrogen balance after the harvest of crop ranged from 216.6 to 358.7 kg ha^{-1} but the actual nitrogen balance was ranged from 171.2 to 291.6 kg ha^{-1}. Nitrogen loss or gain was ranged from -38.5 to -67.1 kgha^{-1}.

To measure the N loss or gain under different N management treatments, a nitrogen balance sheet was drawn up by considering initial and final N status of soil as well as N added through fertilizer and N removal by crop. Among the treatments, total nitrogen uptake by emmer wheat after harvest ranged from 44.8 to 170.9 kg ha^{-1} during first year and 39.7 to 163.3 kg ha^{-1} nitrogen during second year. All the treatments indicated negative nitrogen balance during both the years. The negative nitrogen balance was due to decline in nitrogen content and uptake in grain and straw. Nitrogen uptake was peak at flowering stage but the amount of nitrogen uptake during flowering stage was not recorded. It is well known fact that, when nitrogen is applied to the soil through different sources, the surplus nitrogen is lost through nitrification, leaching, denitrification and volatilization processes. Good agreements were found when comparing our results with findings of Dobermann and Cassman (2005) [6], Ladha *et al*. (2016) [14], Prakasha (2018) [17], Goudra (2018) [11] and Ashwini (2021) [1].

Table 3: Nitrogen (N) balance (kg ha^{-1}) of emmer wheat as influenced by precision nitrogen management practices

Treatments	2020-21							2021-22						
	Initial N (kg ha^{-1})	N through fertilizer (kg ha^{-1})	Total (kg ha^{-1})	Uptake of N by crop (kg ha^{-1})	Expected balance (kg ha^{-1})	Actual balance (kg ha^{-1})	Net gain (+) or loss (-)	Initial N (kg ha^{-1})	N through fertilizer (kg ha^{-1})	Total (kg ha^{-1})	Uptake of N by crop (kg ha^{-1})	Expected balance (kg ha^{-1})	Actual balance (kg ha^{-1})	Net gain (+) or loss (-)
	A	B	C=A+B	D	E=C-D	F	G=F-E	A	B	C=A+B	D	E=C-D	F	G=F-E
T_1	257	0	257	57.9	199.1	175.2	-23.9	268	0	268	51.4	216.6	171.2	-45.4
T_2	257	60	317	96.4	220.6	185.4	-35.2	268	60	328	91.2	236.8	182.4	-54.4
T_3	257	116	373	132.8	240.2	214.3	-25.9	268	116	384	123.5	260.5	210.3	-50.2
T_4	257	146	403	145.3	257.7	225.2	-32.5	268	146	414	138.0	276.0	221.2	-54.8
T_5	257	175	432	157.6	274.4	243.9	-30.5	268	175	443	150.8	292.2	239.9	-52.3
T_6	257	112	369	130.5	238.5	209.4	-29.1	268	104	372	119.9	252.1	205.4	-46.7
T_7	257	187	444	161.8	282.2	256.7	-25.5	268	179	447	155.8	291.2	252.7	-38.5
T_8	257	262	519	170.9	348.1	294.6	-53.5	268	254	522	163.3	358.7	291.6	-67.1
T_9	257	95	352	119.2	232.8	203.5	-29.3	268	95	363	115.2	247.8	199.5	-48.3
T_{10}	257	110	367	128.5	238.5	212.6	-25.9	268	110	378	120.6	257.4	208.6	-48.8
T_{11}	257	125	382	137.9	244.1	217.8	-26.3	268	125	393	130.9	262.1	213.8	-48.3
T_{12}	257	90	347	123.8	223.2	196.4	-26.8	268	90	358	117.3	240.7	192.4	-48.3
T_{13}	257	0	257	44.8	212.2	180.3	-31.9	268	0	268	39.7	228.3	176.3	-52.0

Conclusion
Results of the study have demonstrated that recommended dose of nitrogen has recorded higher nitrogen use efficiency, Agronomic efficiency, physiological efficiency and partial factor productivity. However, nitrogen management through leaf colour chart has recorded higher recovery efficiency due to lesser fertilizer application coupled with more appropriate rate, split application of fertilizer at critical growth stages and it is a measure of the ability of a plant to transform the amount of fertilizer or nutrient applied into economic yield. Negative nitrogen balance was observed due to decline in nitrogen uptake and content in grain and straw in dicoccum wheat.

References

1. Ashwini TR. Spectral characterization and optimization of response and sufficiency index through optical sensor based nitrogen management practices in Bt. Cotton. PhD Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India; c2021.
2. Barthwal A, Bhardwaj AK, Chaturvedi S, Pandiaraj T. Site specific NPK recommendation in wheat (*Triticum aestivum*) for sustained crop and soil productivity in mollisols of Tarai region. Indian Journal of Agronomy. 2013;58(2):208–14.
3. Carlson K, Gerber J, Mueller N, Herrero M, MacDonald G, Brauman K, *et al*. Greenhouse gas emissions intensity of global croplands. Nature Climate Change. 2017;7:63–78.
4. Chen Y, Xiao C, Wu D, Xia T, Chen Q, Chen F. Effects of nitrogen application rate on grain yield and grain nitrogen concentration in two maize hybrids with contrasting nitrogen remobilization efficiency. European Journal of Agronomy. 2015;62:79–89.
5. Crasswell ET, Godwin DC. The efficiency of nitrogen fertilizers applied to cereals in different climates. In: Advances in plant nutrition. Praeger Publishers, New York, 1984:55.
6. Dobermann A, Cassman KG. Cereal area and nitrogen use efficiency are drivers of future nitrogen fertilizer consumption. Science in China Series C Life Sciences. 2005;48(2):745–758.
7. Fageria NK. The use of nutrients in crop plants. CRC press; 2016. Apr 19.
8. Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, *et al*. Sustainable intensification in agriculture: Premises and policies. Science. 2013;341:33–34.
9. Ghosh BN, Singh RJ, Mishra PK. Soil and input management options for increasing nutrient use efficiency. Nutrient use efficiency: from basics to advances. 2015:17–27.
10. Good AG, Johnson SJ, De Pauw M, Carroll RT, Savidov N, Vidmar J. Engineering nitrogen use efficiency with alanine aminotransferase. Botany. 2007;85(3):252–62.
11. Goudra S. Precision nitrogen management in aerobic rice (*Oryza sativa* L.) using crop sensors. MSc (Agri.) Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India. 2018.
12. Jan T, Jan MT, Arif M, Akbar H, Ali S. Response of wheat to source, type and time of nitrogen application. Sarhad Journal of Agriculture. 2007;23(4):871.
13. Khurana HS, Phillips SB, Singh B, Alley MM, Dobermann A, Sidhu AS, *et al*. Agronomic and economic evaluation of site-specific nutrient management for irrigated wheat in northwest India. Nutrient Cycling Agroecosystem. 2008;82:15-31.
14. Ladha JK, Tirol-Padre A, Reddy CK, Cassman KG, Verma S, Powlson DS. Global nitrogen budgets in cereals: A 50-year assessment for maize, rice and wheat production systems. Scientific Reports. 2016;6(1):1–9.
15. Neha J. Precision nutrient management in maize to achieve target yield under Northern transition zone of Karnataka. MSc (Agri.) Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India. c2017.
16. Peng S, Cassman KG. Upper thresholds of nitrogen uptake rates and associated nitrogen fertilizer efficiencies in irrigated rice. Agronomy Journal. 1998;90:178-185.
17. Prakasha. Precision nitrogen management in maize (*Zea mays* L.) using crop sensors. PhD Thesis, University of Agricultural Sciences, Bengaluru, Karnataka. 2018.
18. Ramachandran S, Biswas DR. Nutrient management on crop productivity and changes in soil organic carbon and fertility in a four–year-old maize-wheat cropping system in Indo-Gangetic plains of India. Journal of Plant Nutrition. 2016;39(8):1039–56.
19. Rawal N, Chalise D, Khatri N. Response of the Most Promising Wheat Genotypes with Different Nitrogen Levels. International Journal of Applied Sciences and Biotechnology. 2016;4(4):489-497.
20. Singh SK. Cultivation of dicoccum wheats in India. Krishisewa. 2015:1-4.
21. Spiertz JHJ. Nitrogen, sustainable agriculture and food security: A review. Sustainable Agriculture. 2009;30:635–651.