COMPARATIVE STUDY ON PRECISION NITROGEN MANAGEMENT FOR WHEAT USING GREENSEEKER, CHLOROPHYLL METER AND LEAF COLOR CHART BASED ON SPECTRAL CHARACTERISTICS OF LEAVES

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ABSTRACT

Collecting results on nitrogen (N) uptake throughout the growing season using tools such as GreenSeeker optical sensor, chlorophyll meter and Leaf Color Chart (LCC) holds great promise for optimizing N fertilizer management in cereal crops. To investigate this further, field experiments were conducted over two consecutive winter seasons (2017/2018 and 2018/2019) on wheat at the Experimental Farm of the Faculty of Agriculture, Cairo University, located in Giza Governorate, Egypt. The primary objective of these experiments was to develop effective strategies for managing N fertilizer in wheat during the growing season using GreenSeeker optical sensor, chlorophyll meter or LCC. The goal was to enhance N-use efficiency, reduce the N fertilizer input and achieve optimal results. In the first season, various rates of N fertilizer were applied to create diversity in the readings obtained from the three tools: GreenSeeker optical sensor, chlorophyll meter and LCC. Based on the findings from the first season, a strategy was proposed for refining the application of N fertilizer during the jointing growth stage of wheat. This strategy was guided by the readings obtained from the three tools and implemented in the second season. For the GreenSeeker optical sensor, chlorophyll meter and LCC, an initial application of prescriptive N fertilizer (100 kg N ha^{-1} in two splits) was recommended, followed by corrective doses based on the guidance provided by the three tools. The results of this study were remarkable. The N recovery efficiency that correlated with higher yield values achieved using the GreenSeeker optical sensor, chlorophyll meter, and LCC was 74.1%, 67.4%, and 55.4%, respectively, compared to only 50.5% with the general recommendation treatment. Also, the rate of nitrogen application decreased to 160, 180, 190 Kg N ha^{-1} with the use of GreenSecker, chlorophyll meter and LCC, compared to 240 Kg N ha^{-1} with the treatment of general recommendations without affecting grain yield. These findings clearly demonstrate that the utilization of tools such as the GreenSeeker optical sensor, chlorophyll meter, and LCC can significantly improve the N-use efficiency and decrease N application rate without compromising grain yields.

INTRODUCTION

The application of nitrogen (N) fertilizer is widely recognized as a crucial factor in promoting the growth, yield, and quality of crops. Nitrogen plays a vital role in the formation of various compounds necessary for plant development, including chlorophyll and enzymes. Nitrogen fertilizer management in wheat production in Egypt is typically based on a general recommendation that is applied across large areas. However, to achieve high yields, farmers often exceed the recommended N application rates. This practice is influenced by the temporal and spatial variability of N requirements, which leads to either over or under-application of fertilizer, ultimately reducing its efficiency. It is worth noting that the global nitrogen recovery efficiency in cereals is estimated to be around 35% (Omara et al., 2019). This indicates that a significant portion of the N fertilizer applied is susceptible to losses from the soil-plant system. Consequently, substantial amounts of N fertilizer are lost from the soil, leading to both environmental degradation and increased costs. The low recovery efficiency of N fertilizer not only contributes to environmental concerns but also imposes financial burdens (Bijay and Yadvinder, 2003; Fageria and Baligar, 2005 and Ali and Habib, 2022). Therefore, it is crucial to address this issue to enhance both the sustainability and profitability of wheat production in Egypt. Advanced technologies such as GrS, ChM and LCC have emerged as promising tools for efficient N management (Ali et al., 2020; Singh et al., 2022 and Ram et al., 2022). These cutting-edge tools offer farmers real-time, non-destructive measurements of plant health, empowering them to apply N with precision according to the specific needs of their crops. By utilizing these technologies, farmers gain the ability to closely monitor the temporal and spatial variations of N levels across their fields. This invaluable insight allows for the optimization of fertilizer usage, minimizing the risk of nutrient losses that could harm the environment. In essence, these advanced tools not only provide farmers with accurate and timely information about their plants' N requirements, but also enable them to make informed decisions that promote sustainable farming practices. By harnessing the power of technology, farmers can enhance their productivity while minimizing the environmental impact of their operations.

The primary objective of this study was to develop effective strategies for managing N fertilizer in wheat during the growing season using GreenSeeker, chlorophyll meter, or LCC. The goal was to enhance N-use efficiency, reduce the N fertilizer input and achieve optimal wheat yield.

MATERIALS AND METHODS

The experimental site

In two successive winter seasons (2017/2018 and 2018/2019), field experiments were carried out on wheat (Triticum aestivum L.) variety Giza 171 at the Experimental Farm of the Faculty of Agriculture, Cairo University, Giza Governorate, Egypt, latitude 30.0861N, and longitude 31.2122E. Initial soil samples were taken from the experimental site and analyzed using the procedures outlined by Page et al. (1982) for some physical and chemical properties. Soil texture was clay loam, pH in soil saturation past was 7.91, EC in soil saturation past was 4.53, organic matter was 2.3% and available N, P and K were 100.9, 18.5 and 354.0 mg kg^{-1}, respectively.

Experimental design and treatments

The soil has been ploughed and levelled prior to sowing. In both seasons, in mid-November, wheat (Triticum aestivum L.) of the variety Giza 171 grains was mechanically sown in rows 15 cm apart and divided into 15 m^2 parcels. N fertilizer levels of 0, 40, 80, 120, 160, 200, 240, 280 and 320 kg N ha^{-1} were added in three equal split doses in the first season as ammonium sulphate. This range was used to determine plots with great variability in the wheat uptake and yield of N. The second season was developed to validate the effectiveness of the GreenSeeker optical sensor, chlorophyll meter, and LCC for the application of N fine-tuning fertilizer. The treatment consisted of setting various prescriptive N application scenarios at the early growth stage, followed by a corrective dose at the joint growth stage, as directed by GreenSeeker optical sensor, chlorophyll meter or LCC. The experiments were performed with three replications in a randomized complete block design. Following the general recommendation, phosphorus (as a single superphosphate) was applied for sowing. Potassium fertilizer was avoided because enough available K (354 mg kg^{-1}) were present in the soil.

Plant measurements

The greenness of plant was measured by portable GreenSeeker optical sensor, chlorophyll meter, and LCC. The GreenSeeker accurately detected spectral reflectance and presented it as NDVI (Normalized Difference Vegetation Index). The sensor unit was positioned approximately 1 meter above the plant canopy during the measurement procedure. To ensure precision, the sensor recorded NDVI measurements at a rate of 10 per second while moving at a slow walking pace. The chlorophyll meter measured transmittance at wavelengths of 660 and 940 nm. The procedure entailed inserting the central section of the most fully developed leaf into the aperture of the meter. From each plot, three plants were randomly selected, and their measurements were collected and averaged for subsequent analysis. The LCC with six green shades the greenness of plants. The topmost fully expanded leaf was placed on the LCC and the color of the middle part of the leaf was matched with greenness of the panels on the LCC.

Plant sampling and analysis

At the joint growth stage, over ground plant samples from an area of 1 m^2 were collected from each plot immediately after obtaining the tools' readings. The wheat production was manually collected from a net area of 6 m^2 at maturity from the center of each plot. Grain and straw samples were dried in a hot air oven set at 70º C until they reached a constant weight. Dried samples were digested in a mixture of H_2SO_4-H_2O_2, and total N was determined using the micro-Kjeldahl method (Kalra, 1997).

Calculations and statistical analysis

Using Microsoft excel program (a component in Microsoft Office 2016), regression models were mounted. Variance analysis (ANOVA) has been used to evaluate the effect of N treatments on the data collected. As described by Gomez and Gomez (1984), Duncan's multiple range test (DMRT) at probability value < 0.05 was used to examine the difference between means. As described by Cassman et al. (1998), the recovery efficiency of N (RE_N) was computed as:

$$RE_N(\%) = \frac{Total\ N\ uptake\ in\ fertilized\ plot - Total\ N\ uptake\ in\ zero\ N\ plot}{Quantity\ of\ applied\ N\ fertilizer}$$

RESULTS AND DISCUSSION

Effect of N fertilizer application rate on grain yield of wheat

The relationship between increasing N fertilizer rate and grain yields of wheat collected from the first season exhibited a second-degree response function ($y = -0.1064\ x^2 + 45.922\ x + 3926.2$). Function derivation analysis showed that the highest grain yield of 8881 kg ha^{-1} was achieved by applying N fertilizer rate of 215.8 kg N ha^{-1}. Approximately 155 kg N ha^{-1} was calculated as the N fertilizer rate required for economic grain yield (8437 kg ha^{-1}, 95% of maximum yield). The widely adopted general N fertilizer recommendation for wheat in the area is 180-240 kg N ha^{-1}. These results suggest that there is a need to establish site-specific management strategies in the season that can adjust the rate of application of N fertilizer according to the actual need for the crop.

Prediction of N uptake at jointing growth stage

Rapid acquisition of N uptake information where plants can respond to N inputs prior to harvesting is essential for the development of a successful N fertilizer management plan for precision N management. Variation in N uptake at the joint growth stage of wheat was created by the increasing rate of N fertilizer applied in the first season experiment. This variability has been reflected in grain yield increases. The data derived from the relationship between grain yield and N wheat uptake were as follow: the estimated maximum uptake was 373 kg N ha^{-1}, the estimated maximum yield was 7981 kg grain ha^{-1}, the optimum grain yield (95% of the maximum grain yield) was 7582 kg grain ha^{-1} and the optimum N uptake = 275 kg N ha^{-1}.

a. Sufficiency index approach for managing N fertilizer using GreenSeeker

By many varietal groups, seasons or regions, leaves greenness may vary. Consequently, one GreenSeeker fixed threshold value may not work effectively. The strategy to the sufficiency index (calculated as the ratio of NDVI reading of the evaluated plot and that of a reference N-rich plot) allows dynamic values instead of a fixed threshold value to be used for precision N management. According to the variability of soil properties and seasons, this strategy has the potential to be self-calibrating. The sufficiency index can be calculated as follow:

SI= NDVI of the meausred treatment / NDVI of the reference treatment

The SI was used to calculate the corrective N fertilizer dose in the second season at jointing stage (Feekes 6) of wheat, as steered by the GreenSeeker algorithm created in first season as follow:

$$\textbf{N fertilizer dose (kg N ha}^{-1}\textbf{)} = \frac{275 - 291.47 \times SI\ NDVI^{1.686}}{0.65}$$

b. Sufficiency index approach for managing N fertilizer using chlorophyll meter

To determine the N nutrition index and sufficiency index of the chlorophyll meter, a calculation was conducted by dividing the N uptake and chlorophyll meter readings in the tested plot by reference values. These reference values were established using boxplot diagrams, specifically identifying the upper interquartile values. The resulting reference values for the N nutrition index and sufficiency index were determined to be 63 and 54.5 kg N ha^{-1}, respectively. Upon analyzing the relationship between both indexes, a highly significant linear correlation (R^2= 0.6) was obtained. This correlation strongly suggests that the sufficiency index, derived from the chlorophyll meter, effectively captures variations in the N nutrition index. Based on this finding, a strategy was developed to optimize the application of N during the jointing stage of wheat in the second season. This strategy is based on recommended amounts of N fertilizer that should be applied based on the value of sufficiency index of the chlorophyll meter as follow: if the sufficiency index: >0.95, 0.95 – 0.85, 0.85 – 0.75 and < 0.75, the corrective N dose will be 0, 80, 120, 160, respectively.

c. Establishment of fertilizer N management strategies using LCC

The utilization of different N fertilizer rates has led to significant variations in measurements of LCC, grain yield, and total nitrogen uptake. A box-and-whisker diagram was constructed to display the LCC readings at Feekes 6, revealing a threshold score of 4. However, as the leaf greenness approaches an LCC score below 4, a higher amount of N (120 kg N ha^{-1}) is necessary to achieve optimal yield levels. It is recommended to apply a moderate dose of N fertilizer (90 kg N ha^{-1})

within the range of scores 4-4.5. Additionally, when the leaf greenness corresponds to an LCC score of 4.5 or more, fertilizer nitrogen application may be omitted (0 kg N ha^{-1}).

Validation of GreenSeeker, chlorophyll meter and Leaf Color Chart in managing N fertilizer

The experiment performed during the second season has been used to assess the GreenSeeker sensor, Chlorophyll meter and LCC performance as proposed in this study. Various doses and timings of N fertilizer were added prior to applying the corrective dose as steered by each one of the three tools to make growth variance in biomass and N uptake in wheat.

The data presented in table (1) show that the wheat grain yields obtained from Treatment 3 with the GreenSeeker, chlorophyll meter, and LCC, they were recorded at 7989, 8141, and 7971 kg ha^{-1}, respectively, with statistically equivalent values. However, there was a significant variance in the corrective dosage recommendations. While the GreenSeeker proposed a corrective dosage of 60 kg N ha^{-1}, the Chlorophyll meter and LCC advocated for 80 and 90 kg N ha^{-1}, respectively.

The utilization of the Green Seeker sensor, chlorophyll meter, and LCC has yielded N efficiencies of 74.1%, 67.4%, and 55.4%, respectively, in comparison to the general recommendation's modest 50.5%. These findings underscore the superior performance and reliability of these advanced tools in optimizing N fertilizer utilization for enhanced crop productivity. This discrepancy indicates the superiority of the GreenSeeker, as it necessitated the least nitrogen input for the same yield, thereby positively impacting nitrogen recovery efficiency. This outcome could be attributed to the GreenSeeker's utilization of red and near-infrared rays to compute the Normalized Difference Vegetation Index (NDVI), along with its capability to average readings across the entire plot. This feature renders it a more dependable indicator compared to the Chlorophyll meter and Leaf Color Chart, contributing to enhanced precision in nitrogen fertilizer management practices.

CONCLUSIONS

The standard recommendation for applying a fixed rate of fertilizer N over large areas is not optimal for achieving high N use efficiency in wheat grown in diverse soils in Egypt. Field experiments were conducted to investigate the use of tools such as Green Seeker optical sensor, chlorophyll meter and LCC for managing N fertilizer in wheat crops. The results showed that the N recovery efficiency achieved using the tools were higher compared to the general recommendation, with the GreenSeeker optical sensor achieving the highest efficiency. This study demonstrates that using these tools can significantly improve N-use efficiency without affecting grain yields.

The Green Seeker sensor, chlorophyll meter, and LCC have been validated as dependable tools for accurately predicting N uptake in wheat and effectively guiding N fertilizer applications. The strategies proposed in this study have demonstrated exceptional proficiency in N fertilizer management, resulting in remarkable yield levels and substantial savings in N fertilizer usage.

Furthermore, the utilization of these advanced tools not only improves N efficiencies but also contributes to sustainable agriculture practices. By accurately measuring the crop's nitrogen status, farmers can apply fertilizers more precisely, reducing unnecessary nitrogen application and minimizing environmental pollution.

Table 1. Wheat grain yields, total N uptake, and N use efficiencies as influenced by different N fertilizer treatments as guided by GreenSeeker sensor, chlorophyll meter and LCC.
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Treatment	N fertilizer rate at 0 DAS*	N fertilizer rate at 30 DAS	Tools' Sufficiency index	Corrective dose kg N ha^{-1} at feekes 6**	Total amount of N fertilizer kg N ha^{-1}	Grain yield kg ha^{-1}	Total N uptake kg ha^{-1}	RE_N*** %
N fertilizer treatments as guided by GreenSeeker sensor								
T1 (zero-N)	0	0	-	0	0	3118 d	109.6 c	-
T2 (general recommendation)	80	80	0.75	80 (fixed)	240	8023 a	233.4 a	51.5 c
T3	40	60	0.74	60.9	160.9	7989 a	228.9 a	74.1 a
T4	100	0	0.72	77.3	177.3	7373 b	238.7 a	72.8 a
T5	0	100	0.71	85.3	185.3	7742 a	243.2 a	72.1 a
T6	0	0	0.68	109.1	109.1	6114 c	183.5 b	67.7 b
T7	100	100	0.80	10.1	210.1	7871 a	224.6 a	54.7 c
N fertilizer treatments as guided by chlorophyll meter								
T1 (zero-N)	0	0	-	0	0	3208 d	96.6 c	-
T 2 (general recommendation)	80	80	-	80 (fixed)	240	8172 a	225.1 a	53.5 c
T3	40	60	0.91	80	180	8141 a	218.6 a	67.4 a
T4	100	0	0.82	120	220	7413 b	230.1 a	60.6 b
T5	0	100	0.87	80	180	7642 b	215.2 a	65.7 a
T6	0	0	0.73	160	160	6215 c	177.3 b	50.4 c
T7	100	100	0.96	0	200	7613 b	199.4 b	51.4 c
N fertilizer treatments as guided by LCC								
T1 (zero-N)	0	0	-	0	0	3118 e	105.2 c	-
T 2 (general recommendation)	80	80	4.5	80 (fixed)	240	7942 a	217.1 a	46.6 d
T3	40	60	4.5	90	190	7971 a	210.5 a	55.4 c
T4	100	0	4.5	90	190	7283 c	222.4 a	61.7 b
T5	0	100	4.5	90	190	7452 c	235.1 a	68.4 a
T6	0	0	4	120	120	6015 d	179.3 b	61.8 b
T7	100	100	5	200	200	7671 b	198.5 b	46.7 d

* DAS = days after sowing. ** Feekes 6 = around 50-60 days after sowing

*** RE_N = Recovery efficiency of nitrogen fertilizer

Means followed by the same letter within the same column are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

REFERENCES

Ali, A.M. and Habib, A.A. (2022). Estimation of the economic optimum rates of nitrogen fertilizer for maize grown in a calcareous soil in combination with organic manure applications. Communications in Soil Science and Plant Analysis, 53(18):2484-2496.

Ali, A.M.; Ibrahim, S.M. and Bijay, S. (2020). Wheat grain yield and nitrogen uptake prediction using atLEAF and Green Seeker portable optical sensors at jointing growth stage. Information Processing in Agriculture, 7(3):375-383.

Bijay, S. and Yadvinder, S. (2003). Environmental implications of nutrient use and crop management in rice-based ecosystems. In: Rice Science: Innovations and Impact for Livelihood (Eds. Mew, T.W.; Brar, D.S.; Peng, S.; Dawe, D. and Hardy, B.), IRRI, Los Banos, Philippines. pp.463-477.

Fageria, N.K. and Baligar, V.C. (2005). Enhancing nitrogen use efficiency in crop plants. Adv. Agron., 88:97-185.

Gomez, K.A. and Gomez, A.A., 1984. Statistical procedures for agricultural research. John Wiley & Sons.

Page, A.L. and Page, A.L., 1982. Methods of soil analysis: chemical and microbiological proerpteis. Amen Society of Agronomy.

Omara, P.; Aula, L.; Oyebiyi, F. and Raun, W.R. (2019). World cereal nitrogen use efficiency trends: review and current knowledge. Agrosystems, Geosciences & Environment, 2(1):1-8.

Ram, H.; Kaur, H. and Sikka, R. (2022). Need-based nitrogen management of wheat through the use of green seeker and leaf color chart for enhancing grain yield and quality. J. Plant Nutr., 45(17):2655-2671

Singh, V.; Singh, M. and Singh, B. (2022). Spectral indices measured with proximal sensing using canopy reflectance sensor, chlorophyll meter and leaf color chart for in-season grain yield prediction of basmati rice. Pedosphere, 32(6):812-822.