CHLOROPHYLL METER BASED PRECISION NITROGEN MANAGEMENT IN MAIZE GROWN IN ALLUVIAL SOIL IN EGYPT
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ABSTRACT

Precision nitrogen (N) management is essential for profitable crop production and to minimize N losses to the environment that are a consequence of an excessive N supply. Chlorophyll meter-based N management can help to achieve high N use efficiency, as aquick and non-destructive spectral characteristics of leaves, which can be used to diagnose plant N deficiency and graduate N fertilization with improve N use efficiency. Field experiments were conducted during two consecutive years, 2019 and 2020 on maize (Zea mays L), Triple-cross hybrid 321 grown in an alluvial soil at the Experimental Farm of Faculty of Agriculture, Cairo University, Giza Governorate, Egypt to study the visibility of using chlorophyll meter (AtLeaf) for precision management of N in maize. In the first growing season, an increasing rate of N fertilizer (0, 70, 110, 150, 180, 190, 220, 240 and 280 kg N ha^{-1}) add in three equal split doses as ammonium nitrate was applied to establish the chlorophyll Index value with different yield potentials. In second growing season the validity of the established chlorophyll index was tested. The results of the first growing season revealed that at relative grain yields of 100, 80, and 70%, the Cate-Nelson graph technique was employed to determine the critical chlorophyll index value. These values were proposed for applying N fertilizer in increment dosages. The suggested critical values of chlorophyll index at 100, 80 and 70 % relative grain yield of maize were 60, 55 and 40, respectively. Accordingly, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter. The suggested strategy is applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to chlorophyll index values of more than 60, 60-55, 55-40 and less than 40. The result of second growing season indicted that grain yields obtained as guided by the chlorophyll meter is statistically higher than the other treatments. Meter-based N management was able to overcome variability in maize growth induced by varied prescriptive N management while using less N fertilizer. For instance, applying a total of 142 kg N ha^{-1} as prescriptive in two doses (71 and 71 kg ha^{-1}) then applying a corrective dose as guided by the chlorophyll meter at growth stage resulted in grain yield of 9734 kg ha^{-1}. Data pertaining to N recovery efficiency (REN) showed that the meter-guided N treatments resulted in higher use efficiency as compared to the general recommendation treatment. When appropriate prescriptive N fertilizer was applied (71 and 71 kg N ha^{-1}) followed by corrective dose, an average increase of REN by 10.7% compared with the general recommendation rate. In conclusion, using the chlorophyll meter to guide N management can help farmers manage N fertilizer more efficiently, resulting in greater yields, less N fertilizer application and higher N use efficiency.

INTRODUCTION

Nitrogen (N) fertilizer in maize in Egypt is managed in large areas following a prescriptive general recommendation. Yet, to ensure high yields, farmers often apply N fertilizer in quantities greater than the general guideline. Temporal and spatial variability, however, results in the application of N fertilizer more or less than the actual crop requirement. Maize in Egypt consumes about 23.8% of N fertilizer, representing the nation's largest N-consuming crop (Heffer, 2013). Based on worldwide assessment, the N fertilizer recovery efficiency has been found to be about 33% for maize (Krupink et al., 2004). It means that significant amounts of N fertilizer are lost from the soil. In addition to environmental degradation, the low recovery efficiency of N fertilizer is responsible for high costs (Bijay-Singh and Yadvinder-Singh, 2003; Fageria and Baligar, 2005).

To optimize nitrogen (N) fertilizer application, it is necessary to match the N supply to the N demand (Meisinger, et. al, 2008; Monostori, et. al, 2006). A potentially very effective approach would be the rapid and frequent on-farm assessment of crop N status that permits rapid adjustment of the N supply (Gianquinto, et. al, 2004; Padilla, et. al, 2015; Thompson, et. al, 2017). Proximal optical sensors are a broad group of non-destructive monitoring tools that can be used to assess crop N status (Thompson, et. al, 2017; Fox and Walthall, 2008; Padilla, et. al, 2008). One particularly promising group of proximal optical sensors are leaf chlorophyll meters.

Chlorophyll meters are relatively simple proximal optical sensors that indirectly assess relative leaf chlorophyll content by measuring the differential absorbance and transmittance of different radiation wavelengths by the leaf (Gianquinto, et. al, 2004; Padilla, et. al, 2008; Khoddamzadeh and Dunn, 2016). The leaf chlorophyll content is usually related to crop N content (Fox and Walthall, 2008; Schepers, et. al, 1996; Mastalerczuk, et. al, 2017), these measurements can be used to assess crop N status (Gianquinto, et. al, 2004; Padilla, et. al, 2008). The atLEAF+ (FT Green LLC, Wilmington, DE, USA) is cheapest commercially available chlorophyll meter (Thompson, et. al, 2017; Padilla, et. al, 2008; Padilla, et. al, 2018). It measures absorbance at 660 nm and 940 nm. Using the two absorbance values, the meter calculates a dimensionless numerical value, which is related to chlorophyll content (Padilla, et. al, 2018). The major practical advantages of chlorophyll meters as indicators of crop N status are that they are easy to use, do not require any training, and they make measurements very rapidly, with no or very little data processing (Gianquinto, et. al, 2004; Padilla, et. al, 2015; Padilla, et. al, 2008; Minotti, et. al, 1994).

Chlorophyll meter measurements do not directly indicate crop N status, so interpretation is required (Padilla, et. al, 2008). Two broad approaches have been proposed to interpret chlorophyll meter measurements to assess crop N status. First approach is the use of so-called “reference plots” (Westerveld, et. al, 2004; Zhu, et. al, 2011). This approach divides the measured values of the crop by those from a well-fertilized reference plot that has no N limitation (Tremblay, et. al, 2011). This is considered to isolate the effect of relative N status from other confounding factors that are common to both areas (Samborski, et. al, 2009), which could greatly facilitate the adoption of chlorophyll meters on farms. Second approach is the use of absolute sufficiency values based on direct measurement. The sufficiency value is an absolute value, below which the crop is deficient and responds to additional N fertilizer (Gianquinto, et. al, 2004; Padilla, et. al, 2017), and above which yield is not affected (Gianquinto, et. al, 2004) and the immediate N supply may be excessive (Thompson, et. al, 2017). Sufficiency values provide information on whether adjustments in N fertilization are required when absolute measurements deviate from sufficiency values (Olivier, et. al, 2006).

Therefore, the objectives of this research were to develop a logarithm to use chlorophyll meter readings in real-time N management for maize, to define the optimum prescriptive N applications preceding the corrective dose as guided by the chlorophyll meter sensor and to compare the developed strategies with the current general recommendation in terms of grain yield and N use efficiency under the experimental conditions.

MATERIALS AND METHODS

Two field experiments were carried out during 2019 and 2020 summer seasons on Maize (Zea mays L., Triple-cross hybrid 321) grown in an alluvial soil at the Experimental Farm of Faculty of Agriculture, Cairo University, Giza, Egypt. Prior to sowing, the soil was ploughed twice and divided into $15m^2$ plots. Maize was sown in a row spacing of 25 cm × 70 cm. In First season, maize plants were grown in field from 14 May to 20 September 2019. The N fertilizer treatments in this experiment varied from 0 to 280 kg N ha^{-1} (0, 70, 110, 150, 180, 190, 220, 240 and 280 kg N ha^{-1}) applied as ammonium nitrate (33.5 % N) in three equal split doses at 14, 30 and 50 days after sowing (DAS). This range aimed to create wide variability in yield potentials to create an algorithm that would translate the reading of the atLeaf sensors into equivalent quantities of N fertilizer, which will be used to develop management strategies in the second season using chlorophyll meter (atLeaf). The atLeaf readings were collected around 50 DAS at V9 growth stage (leaf 9 stage). The experiment in the second season was conducted to validate the developed sensor algorithm. Maize plants were grown in field from 17 May to 14 September 2020. A prescriptive N dosage of 95, 190, and 142 kg N ha^{-1} was combined with corrective N dose as indicated by the developed algorithm of atLeaf chlorophyll meter during the V9 growth stage of maize, in addition to control (zero-N) and the general recommendation (285 kg N ha^{-1}). The total rates as guided by the sensor were 315, 338, 260, 277, 277, 243, and 300 kg N ha^{-1}. In this experiment, the N-rich strip was maintained by applying 380 kg N ha^{-1} to ensure that N was not limited while calculating the sufficiency index (SI) of atleaf sensor. The experimental design in both seasons was a randomized complete block design with three replications. The Least Significant Test (LSD) was applied to test the mean differences at $P < 0.05$.

RESULTS AND DISCUSSION

Relationship between grain yield of maize and N uptake

The increasing rate of N fertilizer created a great grain yield and N uptake variability in the first season of the experiment. The relationship between N uptake and maize grain yield was best explained by a quadratic function. The maximum N uptake for maximum yield was determined by setting the first quadratic equation derivative to zero, and the result was 248 kg N ha^{-1} at around 8406 kg ha^{-1} grain yield. By setting the optimal yield at 95 % of the maximum yield, grain yields of 7986 kg ha^{-1} can be attained with N uptake of 260 kg ha^{-1}. As a result, the target uptake for which the N fertilizer application level can be estimated using the technique suggested in this work is 260 kg N ha^{-1}.

Establishment of threshold critical values of chlorophyll meter

At relative grain yields of 100, 80, and 60%, the Cate-Nelson graph technique was employed to determine the critical chlorophyll index values. These values were proposed for applying N fertilizer in increment dosages. For instance, when predicting 100% of maximum grain yield, there is no need to apply N fertilizer. While at 80 and 70% relative grain yield medium and high doses of N fertilizer need to be applied, respectively. The graph suggested that the critical values of chlorophyll index at 100, 80 and 60 % relative grain yield of wheat were 60, 55 and 40, respectively.

Accordingly, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter. The suggested strategy was applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to chlorophyll index values of more than 60, 60-55, 55-40 and less than 40, respectively. These N application dosage levels were proposed to oppose the existing blinded general recommendation, which ignores differences in field-to-field soil properties and other management practices that influence N fertilizer requirements.

Validation of the established threshold critical values of chlorophyll meter

The experiment conducted in the second season was designed to evaluate the performance of the critical threshold values of chlorophyll meter defined from the first season data. To create plant variability in biomass and N uptake at V9 growth stage of maize, different doses and timings of N fertilizer were practiced before applying the corrective dose as guided by the chlorophyll meter.

The data listed in Table 1 show that grain yields obtained as guided by the chlorophyll meter is statistically higher than the other treatments. Meter-based N management was able to overcome variability in maize growth induced by varied prescriptive N management while using less N fertilizer. For instance, applying a total of 142 kg N ha^{-1} as prescriptive in two doses (71 and 71 kg ha^{-1}) then applying a corrective dose as guided by the chlorophyll meter at V9 growth stage resulted in grain yield of 9734 kg ha^{-1}. Data pertaining to N recovery efficiency show that the meter-guided N treatments results in higher use efficiency as compared to the general recommendation. When appropriate prescriptive N fertilizer was applied (71and 71 kg N ha^{-1}) followed by corrective dose, an average increase of 10.7% REN compared with the general recommendation. As a result, utilizing the chlorophyll meter to guide N management should help farmers manage N fertilizer more efficiently, resulting in greater yields and higher N use efficiency.

Table 1. Maize grain yields, total N uptake and N recovery efficiency as influenced by different N fertilizer treatments as guided by the critical threshold values of chlorophyll meter.

Treatment	Prescriptive doses of N (kg ha^{-1})		Chlorophyll index at 50 DAS	Corrective dose (kg ha^{-1})	Total rate of N fertilizer applied (kg ha^{-1})	Grain yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	RE_N (%)
	0 DAS	30 DAS		V9 50 DAS				
Treatment 1 (control)	0	0	44.3	0	0	3671 e	96 e	-
Treatment 2 (gen. recommendation)	95	95	56.0	95 (fixed)	285	9812 a	269 a	60.7 b
Treatment 3	95	0	47.4	95	190	7318 c	195 c	52.1 d
Treatment 4	47	47	48.1	95	189	8162 b	207 b	58.7 c
Treatment 5	142	0	55.8	47	189	8438 b	223 b	67.2 a
Treatment 6	71	71	51.1	95	237	9734 a	262 a	70.0 a
Treatment 7	0	0	44.1	95	95	6074 d	147 d	53.7 d
LSD ($P < 0.05$)	-	-	-	-	-	401	21.1	6.5

Sufficiency index approach

Varietal groups, seasons, and regions may all have different levels of leaf greenness. Therefore, a single set threshold value for a chlorophyll meter may not be effective. The sufficiency index technique (defined as the ratio of a tested plot's chlorophyll reading to that of a reference plot) allows precision N management to be practiced using dynamic values rather than a set threshold value. This method can self-calibrate in response to changes in soil conditions and seasons.

Keeping up these findings, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter in the second season. An N-rich strip was maintained as a reference by applying N fertilizer at a rate of 380 kg N ha^{-1}. The suggested strategy is applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to sufficiency index of chlorophyll meter values of more than 0.95, 0.95-0.75, 0.75-0.55 and less than 0.55. These ranges of N application doses were suggested to challenge the current general recommendation that does not account for the variation in field-to-field soil properties.

Validation of sufficiency index

The experiment in the second season was utilized to assess the performance of the sufficiency index of the chlorophyll meter, which was proposed in this study. To create growth variability in biomass and N uptake at jointing growth stage of maize, different doses and timings of N fertilizer were applied preceding applying the corrective dose as guided by the chlorophyll meter. The data listed in Table 2 show that grain yields obtained in Treatment #6 (applying 71 and 71 kg N ha^{-1} at 0 and 30 DAS, respectively, followed by a corrective dose as guided by the chlorophyll meter) is statistically comparable to the yield attained in the general recommendation, but takes 48 kg N ha^{-1} less fertilizer. Other treatments demonstrated the meter's ability to increase or decrease N fertilizer levels according to the plant's needs during the V9 growth stage. Meter-based N management was successful in overcoming variation in maize growth induced by varied prescriptive N management while using less N fertilizer. Data pertaining to recovery efficiency show that the meter-guided N treatments resulted in higher N recovery efficiency as compared to the general recommendation. For example, when the appropriate prescriptive N fertilizer was administered (Treatment #6), followed by a correction dose, the recovery efficiency increased by 23.2 % over the general recommendation.

Table 2. Maize grain yields, total N uptake and N recovery efficiency as influenced by different N fertilizer (kg N ha^{-1}) treatments as guided by Chlorophyll sufficiency index.

Treatment	Prescriptive doses of N (kg ha^{-1})		Chlorophyll sufficiency index at 50 DAS	Corrective dose (kg N ha^{-1})	Total rate of N fertilizer applied (kg ha^{-1})	Grain yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	RE$_N$ (%)
	0 DAS	30 DAS		at V9 50 DAS				
Treatment1 (control)	0	0	0.61	0	0	3463 e	89 d	-
Treatment2 (gen. recommendation)	95	95	0.83	95 (fixed)	285	9815 a	249 a	56.1 c
Treatment 3	95	0	0.72	95	190	6919 c	179 b	47.4 d
Treatment 4	47	47	0.69	95	189	7453 b	194 b	55.6 c
Treatment 5	142	0	0.74	95	237	7978 a	243 a	65.0 b
Treatment 6	71	71	0.79	47	189	9844 a	239 a	79.3 a
Treatment 7	0	0	0.63	95	95	5894 d	137 c	50.5 d
LSD ($P < 0.05$)	-	-	-	-	-	342	18.8	5.8

It can be concluded that, using the chlorophyll meter in guiding N management could effectively manage N fertilizer to obtain higher yield along applying less N fertilizer. As a result, the use of sensor-guided N-management could effectively prevent yield losses with using lower total N fertilizer rate.

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