Optical-sensors improve nitrogen utilization efficiency

Subjects: Agriculture, Dairy & Animal Science
Contributor: Lawrence Aula

Nitrogen use efficiency (NUE) for cereal crops grown around the world is low with an estimated value of 33%. This means that a considerable amount of nitrogen (N) is not recovered in the grain. As a result, several independent studies have been conducted to evaluate active optical sensors as an approach for N management. These studies reported benefits that range from N saving to higher NUE and sustaining grain yield in comparison to conventional methods of N management. This work reviewed and documented the extent to which the use of active optical sensors impacted winter wheat grain yield and NUE. In particular, the amount of N saved, NUE, and grain yield were reviewed and results presented by N management approach and region.

Keywords: Active optical sensors ; Nitrogen use efficiency ; Winter wheat grain yield

1. Introduction

Fertilizer nitrogen (N) is an integral part of the modern crop production system. This is particularly true in cereal crop production where these systems rely heavily on external N inputs. This has led to a significant portion of N used in cereal crops to be applied from inorganic fertilizer sources. As producers aim to increase crop yields through the application of more N, there has also been a growing call from environmentalists and other scientists to improve its recovery efficiency in the grain [1]. This is because of the increasing concern over the environmental fate of excess N that is not recovered in the grain [2]. World cereal nitrogen use efficiency (NUE), computed as (N uptake from (fertilized plot−check plot)N applied) [3], averages 33% [4]. This indicates that nearly 67% of fertilizer N applied for cereal crop production may not be recovered in the grain. This has led to an intensive research effort to find the best approaches to improve NUE and make crop production more environmentally friendly [1][4][5].

2. Improvement nitrogen utilization efficiency

Despite the fact that split application, in-season estimated N, crop rotation, and other sound agronomic management practices have been found to improve NUE to varying degrees [4][5][6][7], many producers still apply the entire N amount preplant based solely on either yield goals or soil test recommendations. Cui et al. [7] further reported that some producers in China apply, on average, 325 kg N ha^{-1} without any substantial yield difference from the one achieved with 128 kg N ha^{-1} applied using the midseason approach evaluated for the region. This could lead to a substantial build-up of N in the soil with the potential of being lost to the environment [8]. The amount of N applied determined based on yield goal or an average yield of the last 3 to 5 years plus 20% [9] was found not to be an effective means of estimating crop N requirements [10]. The authors evaluated data from three long-term experiments and reported that yield goal, on average, explained approximately 5.1% of the variability in winter wheat grain yield. However, Raun et al. [11] proposed combining both predicted yield level and crop response or response index [12][13] to arrive at an accurate N recommendation. This may be achieved by adopting optical sensor-based technology that accurately predicts yield potential and N requirements midseason. Raun et al. [5] reported an improvement in NUE by 15% through the use of in-season optical sensor-based N estimates compared to conventional methods. Optical sensors could, therefore, be more precise in determining crop N needs and save as much as 32.5 kg N ha^{-1} when compared to conventional methods [14]. This could result in the saving of excess N which would otherwise play no major role in yield improvement [15]. Worldwide, it has been reported that a 1% improvement in NUE could save up to 489,892 Mg of fertilizer N [4]. Considering the suggested vital role in NUE improvement [16], active optical sensors may play a major role in N optimization. Additionally, optical sensors may offer an added benefit of attaining grain yield which exceeds that obtained with conventional methods. For instance, Morris et al. [13] found that applying 90 kg N ha^{-1} preplant followed by the midseason sensor-based recommended rate of 60 kg N ha^{-1} resulted in 0.5 Mg ha^{-1} more grain yield than the 5.2 Mg ha^{-1} obtained by sole application of 90 kg N ha^{-1}, and this difference was significant. This is an illustration that optical sensors do not only improve NUE but also grain yield. However, some studies have reported little to no added yield benefit and profitability of optical sensors relative to conventional methods of N management [17][18][19].

Conventional methods of N management entail applying a predetermined amount of N preplant or in-season [20][21]. In some cases, the amount is split into equal or varying amounts and applied preplant and midseason [22][23]. Because this approach does not consider N supplied from the soil during the crop growing season, a considerable amount of residual N may be found in the soil [24]. In addition, spatial and temporal variations may not be considered and, thus, a recommendation suitable for a specific site is made for the entire region [24].

Optical sensors, on the other hand, emit and record reflectance of radiation within the visible and near infrared regions of the electromagnetic spectrum [25]. This has been shown to have a good relationship with crop biomass and crop N status with r^2 as high as over 80% [26]. One commonly used index, called normalized difference vegetation index (NDVI), is derived from reflectance values recorded by the sensor in the visible and near infrared regions with specific wavelengths varying for each sensor. How NDVI is used to make N recommendation may vary depending on the sensor used [27]. For instance, with the GreenSeeker™ (Trimble Inc., Sunnyvale, California, USA), the NDVI values are divided by growing degree days (GDD) to obtain midseason estimated yield, and this is related to the final winter wheat grain yield [5]. When this is combined with the response index (NDVI in N rich stripNDVI in plot with less N applied), the prediction of yield potential and recommendation for N are made. As such, crop canopy sensing provides a mechanism to estimate crop N needs based on real time assessment of crop N status.

Even though active optical sensors have previously been the subject of review studies, this work has not exhaustively addressed the extent to which NUE is improved by making use of active optical sensors such as GreenSeeker™. Furthermore, having a clear basis for comparison of sensors to other N management approaches may improve our understanding of the contribution of optical sensors to NUE and grain yield improvement. This can best be achieved by extensively reviewing the literature to document the extent to which active optical reflectance sensors have contributed to enhanced grain NUE and yield for winter wheat. Specifically, limiting the review to winter wheat crops may lead to a deeper understanding of the crop-specific impact of active optical sensor technology on grain NUE and yield than when multiple crops are considered simultaneously. Generally, wheat is a very important crop that occupies more than a quarter of the global land production area (780 million ha) under cereal crops [28]. This possibly means it consumes a significant portion of the 61.2 million Mg of N applied in 2015 [29]. It is, therefore, vital that a review is undertaken regarding the use of optical sensors in winter wheat and document potential evidence that advances in N management technology are contributing to NUE and grain yield improvement.

Therefore, the objective of this work was to investigate the impact of active optical sensors on winter wheat grain NUE and yield through an extensive review of published research articles.

References

1. Cassman, K.G.; Dobermann, A.; Walters, D.T. Agroecos[5]ystems, nitrogen-use efficiency, and nitrogen management. AMBIO 2002, 31, 132–140.

2. Zhu, Z.; Chen, D. Nitrogen fertilizer use in China–Contributions to food production, impacts on the environment and bes t management strategies. Nutr. Cycl. Agroecosyst. 2002, 63, 117–127.

3. Rao, A.; Smith, J.; Parr, J.; Papendick, R. Considerations in estimating nitrogen recovery efficiency by the difference an d isotopic dilution methods. Fert. Res. 1992, 33, 209–217.

4. Raun, W.R.; Johnson, G.V.J.A.j. Improving nitrogen use efficiency for cereal production. Agron. J. 1999, 91, 357–363.

5. Raun, W.R.; Solie, J.B.; Johnson, G.V.; Stone, M.L.; Mullen, R.W.; Freeman, K.W.; Thomason, W.E.; Lukina, E.V. Impro ving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. Agron. J. 2002, 94, 815–820.

6. Xia, L.; Lam, S.K.; Chen, D.; Wang, J.; Tang, Q.; Yan, X. Can knowledge-based N management produce more staple gr ain with lower greenhouse gas emission and reactive nitrogen pollution? A meta-analysis. GCB Bioenerg. 2017, 23, 19 17–1925.

7. Cui, Z.; Zhang, F.; Chen, X.; Miao, Y.; Li, J.; Shi, L.; Xu, J.; Ye, Y.; Liu, C.; Yang, Z. On-farm evaluation of an in-season nitrogen management strategy based on soil Nmin test. Field Crop. Res. 2008, 105, 48–55.

8. Omara, P.; Aula, L.; Raun, W.R. Nitrogen uptake efficiency and total soil nitrogen accumulation in long-term beef manur e and inorganic fertilizer application. Int. J. Agron. 2019, 2019, doi: 10.1155/2019/9594369

9. Dahnke, W.; Swenson, L.; Goos, R.J.; Leholm, A. Choosing a Crop Yield Goal; North Dakota State University: Fargo, N D, USA, 1988; SF–822.

10. Raun, W.; Figueiredo, B.; Dhillon, J.; Fornah, A.; Bushong, J.; Zhang, H.; Taylor, R. Can yield goals be predicted? Agron. J. 2017, 109, 2389–2395.

11. Raun, W.R.; Solie, J.B.; Stone, M.L. Independence of yield potential and crop nitrogen response. Precis. Agric. 2011, 12, 508–518.

12. Johnson, G.; Raun, W. Nitrogen response index as a guide to fertilizer management. J. Plant Nutr. 2003, 26, 249–262.

13. Morris, K.B.; Martin, K.; Freeman, K.; Teal, R.; Girma, K.; Arnall, D.; Hodgen, P.; Mosali, J.; Raun, W.; Solie, J. Mid-season recovery from nitrogen stress in winter wheat. J. Plant Nutr. 2006, 29, 727–745.

14. Godwin, R.; Wood, G.; Taylor, J.; Knight, S.; Welsh, J. Precision farming of cereal crops: a review of a six year experiment to develop management guidelines. Biosyst. Eng. 2003, 84, 375–391.

15. Butchee, K.S.; May, J.; Arnall, B. Sensor based nitrogen management reduced nitrogen and maintained yield. Crop Manag. 2011, 10, 1–5.

16. Li, F.; Miao, Y.; Zhang, F.; Cui, Z.; Li, R.; Chen, X.; Zhang, H.; Schroder, J.; Raun, W.; Jia, L. In-season optical sensing improves nitrogen-use efficiency for winter wheat. Soil Sci. Soc. Am. J. 2009, 73, 1566–1574.

17. Colaço, A.F.; Bramley, R.G. Do crop sensors promote improved nitrogen management in grain crops? Field Crop. Res. 2018, 218, 126–140.

18. Zillmann, E.; Graeff, S.; Link, J.; Batchelor, W.D.; Claupein, W. Assessment of cereal nitrogen requirements derived by optical on-the-go sensors on heterogeneous soils. Agron. J 2006, 98, 682–690.

19. Boyer, C.N.; Brorsen, B.W.; Solie, J.B.; Raun, W.R. Profitability of variable rate nitrogen application in wheat production. Precis. Agric. 2011, 12, 473–487.

20. Alcoz, M.M.; Hons, F.M.; Haby, V.A.J.A.J. Nitrogen fertilization timing effect on wheat production, nitrogen uptake efficiency, and residual soil nitrogen. Agron. J. 1993, 85, 1198–1203.

21. Brown, B.D.; Petrie, S. Irrigated hard winter wheat response to fall, spring, and late season applied nitrogen. Field Crop. Res. 2006, 96, 260–268.

22. Dhillon, J.; Eickhoff, E.; Aula, L.; Omara, P.; Weymeyer, G.; Nambi, E.; Oyebiyi, F.; Carpenter, T.; Raun, W. Nitrogen management impact on winter wheat grain yield and estimated plant nitrogen loss. Agron. J. 2019, 112, 564–577.

23. Sowers, K.E.; Pan, W.L.; Miller, B.C.; Smith, J.L. Nitrogen use efficiency of split nitrogen applications in soft white winter wheat. Agron. J. 1994, 86, 942–948.

24. Yadav, S.N.; Peterson, W.; Easter, K.W. Do farmers overuse nitrogen fertilizer to the detriment of the environment? Resour. Econ. 1997, 9, 323–340.

25. Erdle, K.; Mistele, B.; Schmidhalter, U. Comparison of active and passive spectral sensors in discriminating biomass parameters and nitrogen status in wheat cultivars. Field Crop. Res. 2011, 124, 74–84.

26. Flowers, M.; Weisz, R.; Heiniger, R. Quantitative approaches for using color infrared photography for assessing in-season nitrogen status in winter wheat. Agron. J. 2003, 95, 1189–1200.

27. Stamatiadis, S.; Schepers, J.; Evangelou, E.; Tsadilas, C.; Glampedakis, A.; Glampedakis, M.; Dercas, N.; Spyropoulos, N.; Dalezios, N.; Eskridge, K. Variable-rate nitrogen fertilization of winter wheat under high spatial resolution. Precis. Agric. 2018, 19, 570–587.

28. Aula, L.; Dhillon, J.S.; Omara, P.; Wehmeyer, G.B.; Freeman, K.W.; Raun, W.R. World Sulfur Use Efficiency for Cereal Crops. . Agron. J. 2019, 111, 2485–2492.

29. Omara, P.; Aula, L.; Oyebiyi, F.; Raun, W.R.; Environment World cereal nitrogen use efficiency trends: Review and current knowledge. Agrosyst. Geosci. Environ. 2019, 2, 1–8.