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Variable nitrogen rate determination from plant spectral reflectance in soft red winter wheat

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Abstract

Variable rate nitrogen (N) application based on in-season remote sensing can potentially improve wheat (*Triticum aestivum* L.) N management and N use efficiency (NUE). The goal of this study was to evaluate the potential of improving in-season soft red winter wheat (SRWW) variable rate N recommendations based on crop canopy reflectance. Small-plot N rate response calibration studies guided development of the Virginia Wh Algorithm (VWA) for grain yield prediction and variable rate N fertilizer rate determination for SRWW. plot, replicated validation studies conducted for 15 site-years included an N-rich strip installed at growth stage

(GS) 25 and various treatments at GS 30; four or five fixed-rate treatments applied to evaluate site N response, a variable rate based on the VWA applied using a GreenSeeker® RT 200 system and a “standard” fixed rate based on GS 30 wheat tissue N concentration. All sites responded positively to GS 30 N application. When data from one site were excluded, rates were 8 and 3 kg ha^{-1} below the economically optimal N rate (EONR) for the VWA and standard methods, respectively. Based on these data, the GreenSeeker® RT 200 system employing the VWA was equivalent to the current standard method and offers real-time rate prescriptions with less labor and less delay than the current tissue N concentration sufficiency standard.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Abbreviations

AONR:

Agronomically optimum nitrogen rate

EONR:

Economically optimum nitrogen rate

GDD:

Growing degree day

GS 25:

Zadoks growth stage 25

GS 30:

Zadoks growth stage 30

HRWW:

Hard red winter wheat

INSEY:

In-season estimated yield

NDVI:

Normalized difference vegetation index

NIR:

Near-infrared

NUE:

Nitrogen use efficiency

RI:

Response index

SRWW:

Soft red winter wheat

VI:

Vegetation index

VWA:

Virginia wheat algorithm

YPI:

Yield prediction index

References

1. Alley, M. M., Scharf, P., Brann, D. E., Baethgen, W. E., & Hammons, J. L. (1996). Nitrogen fertilization for winter wheat: principles and recommendations. Pub. No. 424-206. Virginia Cooperative Extension, Blacksburg, VA, USA.

2. Aparicio, N., Villegas, D., Casadesus, J., Araus, J. L., & Royo, C. (2000). Spectral vegetation indices as nondestructive tools for determining durum wheat yield. *Agronomy Journal, 92*(1), 83–91.

   Article Google Scholar

3. Baethgen, W. E., & Alley, M. M. (1989). Optimizing soil and fertilizer use by intensively managed winter wheat. II. Critical levels and optimum rates of nitrogen fertilizer. *Agronomy Journal, 81*, 120–125.

   Article Google Scholar

4. Batal, A., & Dale, N. (2009). Ingredient analysis table: 2009 edition. *Feedstuffs, Sept. 10 2009*.

5. Blackmer, T. M., & Schepers, J. S. (1995). Use of a chlorophyll meter to monitor nitrogen status and schedule fertigation for corn. *Journal of Production Agriculture, 8*, 56–60.

   Google Scholar

6. Brann, D. E., Holshouser, D. L., & Mullins, G. L. (2000). Agronomy handbook. Pub. No. 424-100. Virginia Cooperative Extension, Blacksburg, VA, USA.

7. Flowers, M., Weisz, R., & Heiniger, R. (2001). Remote sensing of winter wheat tiller density for early nitrogen application decisions. *Agronomy Journal, 92*, 783–789.

   Article Google Scholar

8. Hong, N., Scharf, P. C., Davis, J. G., Kitchen, N. R., & Sudduth, K. A. (2007). Economically optimal nitrogen rate reduces soil residual nitrate. *Journal of Environmental Quality, 36*(2), 354–362. doi:10.2134/jeq2006.0173.

   PubMed Article CAS Google Scholar

9. Johnson, G. V., & Raun, W. R. (2003). Nitrogen response index as a guide to fertilizer manageme
   Journal of Plant Nutrition, 26, 249–262.

   Article CAS Google Scholar

10. Li, F., Miao, Y., Zhang, F., Cui, Z., Li, R., Chen, X., et al. (2009). In-season optical sensing improves nitrogen-use efficiency for winter wheat. *Soil Science Society of America Journal, 73*(5), 1566–1574. doi:10.2136/sssaj2008.0150.

    Article CAS Google Scholar

11. Lukina, E. V., Freeman, K. W., Wynn, K. J., Thomason, W. E., Mullen, R. W., & Johnson, G. V. (2001). Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. *Journal of Plant Nutrition, 24*, 885–898.

    Article CAS Google Scholar

12. Lukina, E. V., Raun, W. R., Stone, M. L., Solie, J. B., Johnson, G. V., Lees, H. L., et al. (2000). Effect of row spacing, growth stage, and nitrogen rate on spectral irradiance in winter wheat. *Journal of Plant Nutrition, 23*, 103–122.

Article CAS Google Scholar

13. Montandon, L. M., & Small, E. E. (2008). The impact of soil reflectance on the quantification of the green vegetation fraction from NDVI. *Remote Sensing of Environment, 112*(4), 1835–1845.

Article Google Scholar

14. Mullen, R. W., Freeman, K. W., Raun, W. R., Johnson, G. V., Stone, M. L., & Solie, J. B. (2003). Identifying an in-season response index and the potential to increase wheat yield with nitrogen. *Agronomy Journal, 95*, 347–351.

Article Google Scholar

15. Pena-Yewtukhiw, E. M., Schwab, G. J., & Murdock, L. W. (2006). Univariate distribution analysis to evaluate variable rate fertilization. *Agronomy Journal, 98*(3), 554–561. doi:10.2134/agronj2005.0164.

Article Google Scholar

16. Penuelas, J., & Filella, I. (1998). Visible and near-infrared reflectance techniques for diagnosing plant physiological status. *Trends in Plant Science, 3*(4), 151–156.

Article Google Scholar

17. Phillips, S. B., Keahey, D. A., Warren, J. G., & Mullins, G. L. (2004). Estimating winter wheat tiller density using spectral reflectance sensors for early-spring, variable-rate nitrogen applications. *Agronomy Journal, 96*, 591–600.

Article Google Scholar

18. Raun, W. R., & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal, 91*, 357–363.

Article Google Scholar

19. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Lukina, E. V., Thomason, W. E., et al. (20 season prediction of potential grain yield in winter wheat using canopy reflectance. *Agronomy Jo* 131–138.

Article Google Scholar

20. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Mullen, R. W., Freeman, K. W., et al. (2002). Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. *Agronomy Journal, 94*, 815–820.

Article Google Scholar

21. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Whitney, R. W., Lees, H. L., et al. (1998). Microvariability in soil test, plant nutrient, and yield parameters in bermudagrass. *Soil Science Society of America Journal, 62*, 683–690.

Article CAS Google Scholar

22. Raun, W. R., Solie, J. B., Stone, M. L., Martin, K. L., Freeman, K. W., Mullen, R. W., et al. (2005). Optical sensor based algorithm for crop nitrogen fertilization. *Communications in Soil Science and Plant Analysis, 36*, 2759–2781.

Article CAS Google Scholar

23. Roggenbuck, R. M., Robert, P. C., Mulla, D. J., & Malzer, G. L. (2004). Spatial variation in economic optimum nitrogen rate for corn in South-Central Minnesota. In D. J. Mulla (Ed.), *Proceedings of the 7th international conference on precision agriculture and other precision resources management* (pp. 945–960). Minneapolis, MN, USA: American Society of Agronomy.

24. SAS Inst. (2004). *SAS/STAT 9.1 users guide*. Cary, NC, USA: SAS Inst.

Google Scholar

25. Schmidt, J. P., Dellinger, A. E., & Beegle, D. B. (2009). Nitrogen recommendations for corn: An on-the-go sensor compared with current recommendation methods. *Agronomy Journal, 101*(4), 916–924. doi:10.2134/agronj2008.0231x.

Article CAS Google Scholar

26. Serrano, L., Filella, I., & Penuelas, J. (2000). Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. *Crop Science, 40*, 723–731.

Article Google Scholar

27. Solie, J. B., Raun, W. R., & Stone, M. L. (1999). Submeter spatial variability of selected soil and bermudagrass production variables. *Soil Science Society of America Journal, 63*, 1724–1733.

Article CAS Google Scholar

28. Solie, J. B., Stone, M. L., Raun, W. R., Johnson, G. V., Freeman, K. W., Mullen, R. W., et al. (2002). Real-time sensing and fertilization with a field scale GreenSeeker applicator. In *Proceedings of the 6th international conference on precision agriculture*. Minneapolis, MN, USA: American Society of Agronomy, [CD-ROM].

29. Sripada, R. P., Farrer, D. C., Weisz, R., Heiniger, R. W., & White, J. G. (2007). Aerial color infrared photography to optimize in-season nitrogen fertilizer recommendations in winter wheat. *Agronomy Journal, 99*(6), 1424–1435. doi:10.2134/agronj2006.0258.

Article CAS Google Scholar

30. Trimble Agriculture. (2010). *GreenSeeker 505 handheld sensor user guide*. Westminster, CO, USA: Trimble Agriculture.

Google Scholar

31. USDA Economic Research Service. (2009). U.S. fertilizer use and price. Available at www.ers.usda.gov/Data/FertilizerUse/. (last accessed 30 Oct. 2009). ERS, Washington, DC.

32. Wanjura, D. F., & Hatfield, J. L. (1987). Sensitivity of spectral vegetative indices to crop biomass. *Transactions of the American Society of Agricultural Engineers, 30*(3), 810–816.

Google Scholar

33. Wood, G. A., Taylor, J. C., & Godwin, R. J. (2003). Calibration methodology for mapping within-field crop variability using remote sensing. *Biosystems Engineering, 84*(4), 409–423.

Article Google Scholar

34. Zadoks, J. C., Chang, T. T., & Konzak, D. F. (1974). A decimal code for the growth stages of cereals. *Weed Research, 14*, 415–421.

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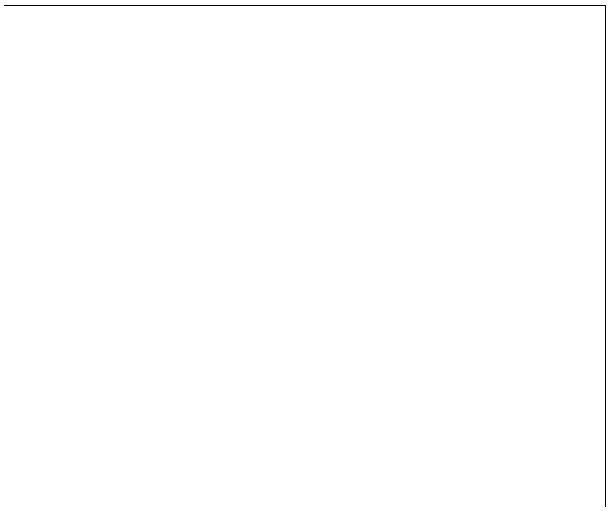

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1. Alley, M. M., Scharf, P., Brann, D. E., Baethgen, W. E., & Hammons, J. L. (1996). Nitrogen fertilization for winter wheat: principles and recommendations. Pub. No. 424-206. Virginia Cooperative Extension, Blacksburg, VA, USA.

2. Aparicio, N., Villegas, D., Casadesus, J., Araus, J. L., & Royo, C. (2000). Spectral vegetation indices as nondestructive tools for determining durum wheat yield. *Agronomy Journal, 92*(1), 83–91.
   - Article
   - Google Scholar

3. Baethgen, W. E., & Alley, M. M. (1989). Optimizing soil and fertilizer use by intensively managed winter wheat. II. Critical levels and optimum rates of nitrogen fertilizer. *Agronomy Journal, 81*, 120–125.
   - Article
   - Google Scholar

4. Batal, A., & Dale, N. (2009). Ingredient analysis table: 2009 edition. *Feedstuffs, Sept. 10 2009*.

5. Blackmer, T. M., & Schepers, J. S. (1995). Use of a chlorophyll meter to monitor nitrogen status and schedule fertigation for corn. *Journal of Production Agriculture, 8*, 56–60.
   - Google Scholar

6. Brann, D. E., Holshouser, D. L., & Mullins, G. L. (2000). Agronomy handbook. Pub. No. 424-100. Virginia Cooperative Extension, Blacksburg, VA, USA.

7. Flowers, M., Weisz, R., & Heiniger, R. (2001). Remote sensing of winter wheat tiller density for nitrogen application decisions. *Agronomy Journal, 92*, 783–789.
   - Article
   - Google Scholar

8. Hong, N., Scharf, P. C., Davis, J. G., Kitchen, N. R., & Sudduth, K. A. (2007). Economically optimal nitrogen rate reduces soil residual nitrate. *Journal of Environmental Quality, 36*(2), 354–362. doi:10.2134/jeq2006.0173.
   - PubMed
   - Article
   - CAS
   - Google Scholar

9. Johnson, G. V., & Raun, W. R. (2003). Nitrogen response index as a guide to fertilizer management. *Journal of Plant Nutrition, 26*, 249–262.

- Article
- CAS
- Google Scholar

10. Li, F., Miao, Y., Zhang, F., Cui, Z., Li, R., Chen, X., et al. (2009). In-season optical sensing improves nitrogen-use efficiency for winter wheat. *Soil Science Society of America Journal, 73*(5), 1566–1574. doi:10.2136/sssaj2008.0150.

- Article
- CAS
- Google Scholar

11. Lukina, E. V., Freeman, K. W., Wynn, K. J., Thomason, W. E., Mullen, R. W., & Johnson, G. V. (2001). Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. *Journal of Plant Nutrition, 24*, 885–898.

- Article
- CAS
- Google Scholar

12. Lukina, E. V., Raun, W. R., Stone, M. L., Solie, J. B., Johnson, G. V., Lees, H. L., et al. (2000). Effect of row spacing, growth stage, and nitrogen rate on spectral irradiance in winter wheat. *Journal of Plant Nutrition, 23*, 103–122.

- Article
- CAS
- Google Scholar

13. Montandon, L. M., & Small, E. E. (2008). The impact of soil reflectance on the quantification of the green vegetation fraction from NDVI. *Remote Sensing of Environment, 112*(4), 1835–1845.

- Article
- Google Scholar

14. Mullen, R. W., Freeman, K. W., Raun, W. R., Johnson, G. V., Stone, M. L., & Solie, J. B. (2003). Identifying an in-season response index and the potential to increase wheat yield with nitrogen. *Agronomy Journal, 95*, 347–351.

- Article
- Google Scholar

15. Pena-Yewtukhiw, E. M., Schwab, G. J., & Murdock, L. W. (2006). Univariate distribution analysis to evaluate variable rate fertilization. *Agronomy Journal, 98*(3), 554–561. doi:10.2134/agronj2005.0164.

- Article
- Google Scholar

16. Penuelas, J., & Filella, I. (1998). Visible and near-infrared reflectance techniques for diagnosing plant physiological status. *Trends in Plant Science, 3*(4), 151–156.

- Article
- Google Scholar

17. Phillips, S. B., Keahey, D. A., Warren, J. G., & Mullins, G. L. (2004). Estimating winter wheat till density using spectral reflectance sensors for early-spring, variable-rate nitrogen applications. *Agr Journal, 96*, 591–600.

- Article
- Google Scholar

18. Raun, W. R., & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal, 91*, 357–363.

    - Article
    - Google Scholar

19. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Lukina, E. V., Thomason, W. E., et al. (2001). In-season prediction of potential grain yield in winter wheat using canopy reflectance. *Agronomy Journal, 93*, 131–138.

    - Article
    - Google Scholar

20. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Mullen, R. W., Freeman, K. W., et al. (2002). Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. *Agronomy Journal, 94*, 815–820.

    - Article
    - Google Scholar

21. Raun, W. R., Solie, J. B., Johnson, G. V., Stone, M. L., Whitney, R. W., Lees, H. L., et al. (1998). Microvariability in soil test, plant nutrient, and yield parameters in bermudagrass. *Soil Science Society of America Journal, 62*, 683–690.

    - Article
    - CAS
    - Google Scholar

22. Raun, W. R., Solie, J. B., Stone, M. L., Martin, K. L., Freeman, K. W., Mullen, R. W., et al. (2005). Optical sensor based algorithm for crop nitrogen fertilization. *Communications in Soil Science and Plant Analysis, 36*, 2759–2781.

    - Article
    - CAS
    - Google Scholar

23. Roggenbuck, R. M., Robert, P. C., Mulla, D. J., & Malzer, G. L. (2004). Spatial variation in econ optimum nitrogen rate for corn in South-Central Minnesota. In D. J. Mulla (Ed.), *Proceedings of international conference on precision agriculture and other precision resources management* (pp. 945–960). Minneapolis, MN, USA: American Society of Agronomy.

24. SAS Inst. (2004). *SAS/STAT 9.1 users guide*. Cary, NC, USA: SAS Inst.

    - Google Scholar

25. Schmidt, J. P., Dellinger, A. E., & Beegle, D. B. (2009). Nitrogen recommendations for corn: An on-the-go sensor compared with current recommendation methods. *Agronomy Journal, 101*(4), 916–924. doi:10.2134/agronj2008.0231x.

    - Article
    - CAS
    - Google Scholar

26. Serrano, L., Filella, I., & Penuelas, J. (2000). Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. *Crop Science, 40*, 723–731.

- Article
- Google Scholar

27. Solie, J. B., Raun, W. R., & Stone, M. L. (1999). Submeter spatial variability of selected soil and bermudagrass production variables. *Soil Science Society of America Journal, 63*, 1724–1733.

- Article
- CAS
- Google Scholar

28. Solie, J. B., Stone, M. L., Raun, W. R., Johnson, G. V., Freeman, K. W., Mullen, R. W., et al. (2002). Real-time sensing and fertilization with a field scale GreenSeeker applicator. In *Proceedings of the 6th international conference on precision agriculture*. Minneapolis, MN, USA: American Society of Agronomy, [CD-ROM].

29. Sripada, R. P., Farrer, D. C., Weisz, R., Heiniger, R. W., & White, J. G. (2007). Aerial color infrared photography to optimize in-season nitrogen fertilizer recommendations in winter wheat. *Agronomy Journal, 99*(6), 1424–1435. doi:10.2134/agronj2006.0258.

- Article
- CAS
- Google Scholar

30. Trimble Agriculture. (2010). *GreenSeeker 505 handheld sensor user guide*. Westminster, CO, USA: Trimble Agriculture.

- Google Scholar

31. USDA Economic Research Service. (2009). U.S. fertilizer use and price. Available at www.ers.usda.gov/Data/FertilizerUse/. (last accessed 30 Oct. 2009). ERS, Washington, DC.

32. Wanjura, D. F., & Hatfield, J. L. (1987). Sensitivity of spectral vegetative indices to crop biomass. *Transactions of the American Society of Agricultural Engineers, 30*(3), 810–816.

- Google Scholar

33. Wood, G. A., Taylor, J. C., & Godwin, R. J. (2003). Calibration methodology for mapping within crop variability using remote sensing. *Biosystems Engineering, 84*(4), 409–423.

- Article
- Google Scholar

34. Zadoks, J. C., Chang, T. T., & Konzak, D. F. (1974). A decimal code for the growth stages of cereals. *Weed Research, 14*, 415–421.

- Article
- Google Scholar