# SENSOR-BASED TECHNOLOGIES FOR NITROGEN MANAGEMENT IN SPRING WHEAT

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## ABSTRACT

Crop sensor-based systems with developed algorithms for making mid-season fertilizer nitrogen (N) recommendations are commercially available to producers in some parts of the world. Although there is growing interest in these technologies by grain producers in Montana, use is limited by the lack of local research under Montana's semiarid conditions. A field study was carried out at two locations in 2011, three locations in 2012, and two locations in 2013 in North West Montana. The objectives of this research were: 1) to evaluate two optical sensors – GreenSeeker© (model 505) and Pocket Sensor (a prototype GreenSeeker Handheld Crop Sensor), 2) to assess whether the algorithms developed in other regions can be successfully utilized under Montana conditions, and 3) determine whether sensor-based recommendations need to be adjusted depending on what N fertilizer source - liquid urea ammonium nitrate (UAN), or granular urea - is used. Two remote sensors and three N optimization algorithms were evaluated. Two out of three algorithms did not prescribe any topdress N fertilizer to be applied at any of the experimental sites in both growing seasons. The topdress rates prescribed by the third algorithm ranged from of 0 lb N ac$^{-1}$ to 122 lb N ac$^{-1}$ depending on the NDVI values. A strong linear relationship was observed between NDVI values obtained with two remote sensors. GreenSeeker and Pocket Sensor NDVI readings predicted 70% and 81% of variation in spring wheat grain yields respectively across site-years ($R^2$ = 0.70 and 0.81). In all three growing season, the rates generated by the algorithm were not appropriate for grain yield optimization. Results indicated that both sensors performed well and were useful in predicting mid-season spring wheat grain yield potential. In addition, algorithms developed in other regions did not provide the appropriate topdress N rates for Montana spring wheat varieties and growing conditions. Lastly, because there were no substantial differences in grain yields associated with topdress fertilizer N source (urea vs. UAN) at any of 7 site-years, fertilizer rates do not need to be adjusted based on N fertilizer source, urea or UAN.

## INTRODUCTION

Nitrogen is considered the most common nutrient limiting yield of spring wheat and other cereal crops in Montana (Engel, 1993). On the other hand, N is regarded as the most effective of all inputs for increasing profits in cereal crop production. Specifically, N nutrition significantly impacts spring wheat production profitability. Late-season N fertilizer application has been found to boost spring wheat protein level by 0.5-2.0%. When wheat yield potential (YP) is higher-than-average, early-season N application may not be adequate for sufficient protein accumulation (Wescott et al., 1997).). Great demand for up-to-date information on crop-specific and site-specific fertilizer use is strongly apparent among Montana crop producers. In general, N fertilizer rates for cereal crops in Montana are determined as following: NR = YP x 2.5-3.0, where: NR – N fertilizer rate (lbs/bu), YP – yield potential (bu/a). Precision agriculture tools such as remote sensors enable us to evaluate crop health through vigor, biomass production and canopy greenness. Knowledge of crop nutrient status and its yield potential mid-season enables growers to adjust topdress N rates accordingly. Normalized difference vegetation index (NDVI) derived from measurements of canopy reflectance has been commonly used for in-season estimation of yield potential in various crops. Raun et al. (2001) developed a simple, effective and non-destructive method for accurate prediction of yield potential utilizing canopy reflectance measurements.Although there is growing interest in these technologies by grain producers in Montana, use is limited by the lack of local research under Montana's semiarid conditions.

## METHODS

This project was initiated in 2011, in 2012 and 2013, this study was repeated at three experimental locations: two dryland sites - at Western Triangle Agricultural Research Center (WTARC) near Conrad, MT and in cooperating producer's field (Martin, Pendroy, MT) and one irrigated site at Western Agricultural Research Center (WARC) near Corvallis, MT, using the spring wheat variety Choteau. Four preplant N rates - 20, 40, 60, and 80 lb N ac$^{-1}$ were applied as broadcasted urea. Treatment 1 was established as an unfertilized check plot. Treatment 2 received 220 lb N ac$^{-1}$ preplant as urea and served as a non-limiting N-rich reference. Each treatment was replicated 4 times. The plot size was 5'x 25'. Wheat crop reflectance measurements (NDVI) from each plot were collected at Feekes 5 growth stage. Feekes 5 - early jointing (beginning of stem elongation, prior to first visible node) - has been identified in a course of multiple field studies as the most appropriate sensing time for wheat because it provides reliable prediction of both N uptake and biomass. The GreenSeeker (model 505) and Pocket Sensor were used to collect the NDVI measurements. Topdress N fertilizer was applied as urea (as dry prills, manually broadcasted) or as UAN (as a foliar spray, using a battery operated backpack sprayer with a fan nozzle). Topdress N recommendations for Treatments 2-10 were made using algorithms experimentally developed specifically for spring wheat: 1. Spring Wheat (Canada), 2. Spring Wheat (US, Canada, Mexico), and 3. Generalized Algorithm. (Available at: http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php). At maturity, spring wheat was harvested with Wintersteiger classic plot combine (Wintersteiger Ag, Ried, Austria). The harvested grain was dried in the drying room for 14 days at the temperature of 95 F°; then, the by-plot grain yield was determined. The by-plot subsamples were analyzed by the Agvise Laboratories (Northwood, ND) for total N content utilizing near infrared reflectance spectroscopy (NIR) with a Perten DA 7250 NIR analyzer (Perten Instruments, Inc., Springfield, IL). The effects of preplant N rate, topdress N source, on spring wheat grain yield, grain protein content, protein yield, and N use efficiency (NUE), were assessed. Grain N uptake was calculated by multiplying yield by total N concentration. N use efficiency was determined using the difference method (Varvel and Peterson, 1990) by deducting the total N uptake in wheat from the N-unfertilized treatment (check plot) from total N uptake in wheat from fertilized plots and then divided by the rate of N fertilizer applied. The analysis of variance was conducted using the PROC GLM procedure in SAS v9.3 (SAS Institute, Inc., Cary, N.C.). Mean separation was performed using the Orthogonal Contrasts method at a significance level of 0.05.

## RESULTS AND DISCUSSION

Spring wheat grain yield data for each site-year is reported in Table 1. A wide variety of grain yields was observed among treatments at different site-years ranging from 14 bu ac$^{-1}$ to 114 bu ac$^{-1}$. A strong linear relationship was observed between NDVI values obtained with GreenSeeker and with Pocket Sensor ($R^2$=0.70) (Figure 1). Table 2 helps to examine how the algorithm were tested. The algorithm's data inputs were: 1) NDVI from trt 2 (non-limiting N reference) or the highest NDVI value, 2) NDVI from all other treatments, 3) Seeding date, 4) Date of sensing, and 5) Yield goal (determined based on the average yield goal for the area). Based on the provided input data, the algorithm software has generated the following outputs: 1) Yield potential without added topdress N, 2) Yield potential with added topdress N, and 3) Recommended N fertilizer topdress rate. The Spring Wheat (Canada) and the Generalized algorithm did not prescribe any topdress N rate to be applied at any of 8 site-years, even when the differences in crop stand and nutrient level (substantiated by the obtained NDVI sensor readings) were clearly apparent. The US-Canada-Mexico Algorithm has prescribed topdress N rates ranging from 0 to 122 lb N ac$^{-1}$ depending on the yield goal for the location and the obtained NDVI values (data not shown). It's clear from Table 2 that in some cases (WTARC, 2012 [Case 1], and MARTIN, 2012 [Case 2]), the prescribed N rates were excessive. A 24 lb N ac$^{-1}$ rate prescribed for trt 6 resulted in a total of 104 lb N ac$^{-1}$ applied to that trt (compared to 62 lb N ac$^{-1}$ topdress N, and a total N rate of 282 lb N ac$^{-1}$ for trt 2) has resulted in a significantly higher grain yield (88 bu ac$^{-1}$ vs only 74 bu ac$^{-1}$ for trt 2 (Table 2). In some instances, the prescribed N rates did not make sense (WTARC, 2011 [Case 3]), and in some instances – the rates seemed appropriate (WTARC, 2012 [Case 4]) (Table 2). At all site-years, N fertilizer rates recommended by the USA/Canada/Mexico Algorithm were not appropriate for grain yield optimization. For example, much higher top-dress N rates were prescribed for WARC (the irrigated site) compared to those for the dryland sites WTARC and Martin. This makes sense since the expected yield potential at the irrigated site was much greater. On the other hand, grain yields obtained at WTARC were just as high as at WARC, indicating that the yield potential was either overestimated at WARC or underestimated at WTARC. This puts forward a question of whether there is a need for two separate algorithms, one developed for dryland spring wheat, and another for irrigated spring wheat production systems. Spring wheat grain yield responded significantly to application of N fertilizer (5 out of 8 site-years), and grain protein content – in 6 out of 8 site-years (Table 3). In 6 out of 8 site-years, there were no significant differences in grain yields and grain protein content values associated with topdress fertilizer N source (urea vs. UAN) (Table 3). This shows that topdress N fertilizer rates do not need to be adjusted based of fertilizer sources used, i.e. the same N rates should be prescribed whether urea or UAN is applied.

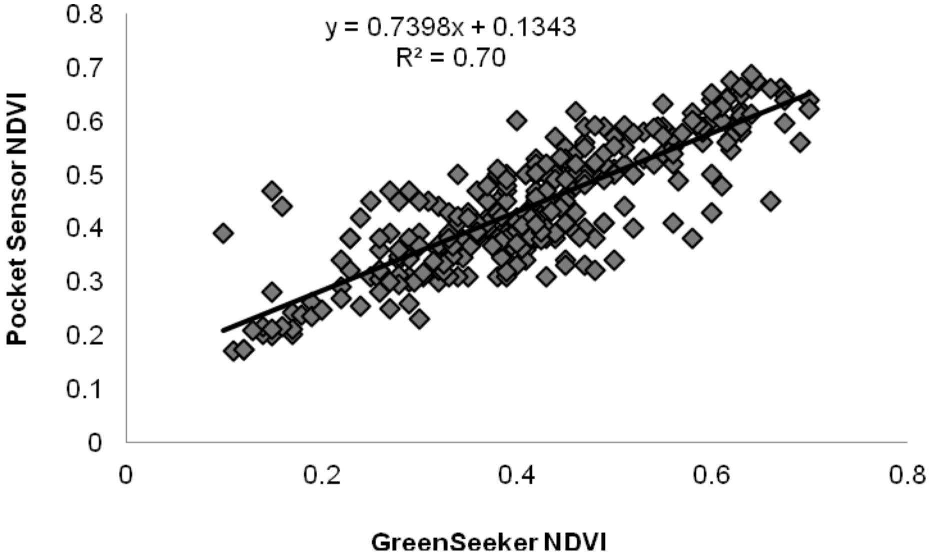

Figure 1. Relationship between GreenSeeker NDVI and Pocket Sensor NDVI, for 8 site-years in Montana.

Table 1. Treatment structure and spring wheat grain yields for 8 site-years in Montana.

| Trt | *Preplant N Fertilizer Rate, lb N ac$^{-1}$ | **Topdress N Fertilizer Source | Spring wheat grain yield, bu ac$^{-1}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | | 2012 | | | 2013 | | |
| | | | WTARC | WARC | WTARC | WARC | MARTIN | WTARC | WARC | MARTIN |
| 1 | 0 | - | 14 (f) | 30 (f) | 87 (d) | 58 (f) | 34 (ab) | 64 (ab) | 51 (a) | 50 (a) |
| 2 | 200 | urea | 40 (a) | 55 (abc) | 92 (d) | 96 (d) | 33 (ab) | 61 (b) | 59 (a) | 50 (a) |
| 3 | 20 | urea | 23 (e) | 41 (d) | 99 (c) | 100 (cd) | 35 (a) | 63 (ab) | 59 (a) | 53 (a) |
| 4 | 40 | urea | 23 (e) | 51 (bc) | 104 (abc) | 103 (bcd) | 31 (ab) | 64 (ab) | 60 (a) | 51 (a) |
| 5 | 60 | urea | 28 (cd) | 57 (abc) | 105 (abc) | 111 (ab) | 34 (ab) | 68 (ab) | 59 (a) | 52 (a) |
| 6 | 80 | urea | 32 (b) | 59 (a) | 108 (a) | 102 (bcd) | 30 (b) | 70 (ab) | 60 (a) | 53 (a) |
| 7 | 20 | UAN | 22 (e) | 48 (cd) | 99 (c) | 107 (abcd) | 31 (ab) | 66(ab) | 51 (a) | 49 (a) |
| 8 | 40 | UAN | 24 (de) | 52 (abc) | 100 (bc) | 110 (abcd) | 33 (ab) | 67 (ab) | 51 (a) | 50 (a) |
| 9 | 60 | UAN | 29 (bc) | 50 (bc) | 103 (abc) | 113 (a) | 34 (ab) | 72 (a) | 51 (a) | 50 (a) |
| 10 | 80 | UAN | 32 (b) | 53 (abc) | 106 (ab) | 114 (a) | 33 (ab) | 68 (ab) | 51 (a) | 52 (a) |

Table 2. Four cases illustrating the recommendations developed by US-Canada-Mexico algorithm and grain yield results obtained following the application of prescribed topdress N rates.

| Case | Site-year | Trt | Preplant N rate, lb N ac$^{-1}$ | GS NDVI | Recommended topdress N rate, lb N ac$^{-1}$ | Total N rate, lb N ac$^{-1}$ | N rate difference, lb N ac$^{-1}$ | Grain yield, bu ac$^{-1}$ | Yield gain, bu ac$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | WTARC, 2012 | 2 | 220 | 0.3 | 62 | 282 | - 178 | 74 (d) | + 14 |
| | | 6 | 80 | 0.5 | 24 | 104 | | 88 (a) | |
| 2 | Martin, 2012 | 5 | 60 | 0.3 | 0 | 60 | + 37 | 35 | ± 0 |
| | | 6 | 80 | 0.4 | 17 | 97 | | 35 | |
| 3 | WTARC, 2011 | 7 | 20 | 0.3 | 27 | 47 | + 42 | 22 (e) | +10 |
| | | 6 | 80 | 0.4 | 9 | 89 | | 32 (b) | |
| 4 | WTARC, 2012 | 3 | 20 | 0.5 | 13 | 33 | + 91 | 80 (c) | + 8 |
| | | 6 | 80 | 0.5 | 24 | 124 | | 88 (a) | |

Table 3. Effect of preplant N rate and topdress N source on spring wheat grain yield and protein content for 8 site-years in Montana.

| Effects | Growing Season 2011 | | | | Growing Season 2012 | | | | | | Growing Season 2013 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein | Grain Yield | Protein |
| | bu/a | % | bu/a | % | bu/a | % | bu/a | % | bu/a | % | bu/a | % | bu/a | % | bu/a | % |
| | Preplant N Rate | | | | | | | | | | | | | | | |
| 0 | 30 | 14 | 14 | 9.5 | 58 | 11 | 87 | 9.6 | 34 | 14.3 | 51 | 14.3 | 64 | 12.4 | 50 | 15.4 |
| 20 | 45 | 15 | 22 | 9.5 | 104 | 13 | 99 | 10.5 | 33 | 15.5 | 55 | 17.3 | 64 | 14.0 | 51 | 15.7 |
| 40 | 51 | 13 | 24 | 9.6 | 106 | 14 | 102 | 11.1 | 32 | 15.7 | 55 | 16.6 | 65 | 14.6 | 51 | 16.1 |
| 60 | 54 | 15 | 29 | 9.5 | 112 | 14 | 104 | 11.8 | 34 | 15.9 | 55 | 17.1 | 70 | 15.2 | 51 | 16.2 |
| 80 | 56 | 15 | 32 | 9.6 | 108 | 14 | 107 | 14.3 | 32 | 16.3 | 55 | 17.2 | 69 | 15.7 | 52 | 16.3 |
| 220 | 55 | 16 | 40 | 9.7 | 96 | 15 | 92 | 15.4 | 33 | 16.7 | 59 | 17.4 | 61 | 17.2 | 50 | 16.9 |
| F test | *** | ** | ** | ns | *** | *** | *** | ns | ** | ** | ns | *** | ns | *** | ns | *** |
| | Topdress N Source | | | | | | | | | | | | | | | |
| Urea | 52 | 14.5 | 26 | 9.6 | 89 | 14.1 | 85 | 11.5 | 34 | 15.8 | 59 | 17.2 | 66 | 15.2 | 52 | 15.9 |
| UAN | 51 | 14.4 | 27 | 9.5 | 96 | 13.6 | 83 | 11.6 | 34 | 16.0 | 51 | 16.9 | 68 | 14.6 | 51 | 16.3 |
| F test | ns | ns | ns | ns | *** | *** | ns | ns | ns | ns | *** | ns | ns | *** | ns | ns |

## SUMMARY

In conclusion, results indicated that both sensors performed well and were useful in predicting mid-season spring wheat grain yield potential. In addition, algorithms developed in other regions did not provide the appropriate top-dress N rates for Montana. These findings emphasize the importance of a state-wide collaborative research currently being conducted in Montana to develop improved sensor-based N optimization algorithms for Montana spring wheat and winter wheat varieties and growing conditions.

Figure 2. Robin Christiaens, Research Associate, and Jeff Jerome, Research Assistant, obtaining spring wheat reflectance measurements using GreenSeeker Sensor (2A) and Pocket Sensor (2B), Western Triangle Agricultural Research Center, Conrad, MT, Spring 2012.

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