PRECISION SENSORS FOR IMPROVED NITROGEN RECOMMENDATIONS IN 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 two dryland sites at the Western Triangle Agricultural Research Center (WTARC) and the Martin farm (Martin) near Conrad, MT, and one irrigated site at the Western Agricultural Research Center (WARC) near Corvallis, MT. The spring wheat variety Choteau was grown at all sites. 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. The experimental design included ten treatments, an unfertilized check treatment (0 kg N ha^{-1}), a non-limiting N-rich reference treatment (247 kg N ha^{-1}), and four preplant N application treatment rates of 22, 45, 67, and 90 kg N ha^{-1} applied as broadcasted granular urea. The preplant N application treatments were repeated twice, once for in-crop application of UAN and another for granular urea. Individual plot size was 1.5 m x 7.6 m and each treatment was replicated 4 times. Wheat crop reflectance measurements – Normalized Difference Vegetative Index (NDVI) from each plot were collected at Feekes 5 growth stage. The 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 two GreenSeeker crop sensors (Trimble Navigation Ltd., Sunnyvale, CA) were used to collect the NDVI measurements. According to treatment structure topdress N fertilizer was applied as broadcast urea, or as surface applied UAN (using a backpack sprayer with a fan nozzle). Topdress N recommendations were generated using algorithms experimentally developed for spring wheat: 1. Spring Wheat (Canada),

2. Spring Wheat (US/Canada/Mexico), and 3. Generalized Algorithm. The algorithms are available at: http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php. Generalized 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 Spring Wheat (US/Canada/Mexico) algorithm ranged from of 0 kg N ha^{-1} to 111 kg N ha^{-1} depending on the NDVI values measured. The prescribed N rates were applied to experimental plots, and harvested grain yields were measured at crop maturity. A strong linear relationship was observed between NDVI values obtained with GreenSeeker and with Pocket Sensor (R^2=0.82). 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 USA/Canada/Mexico 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. Currently, additional research is being conducted state-wide in Montana to develop improved sensor-based N optimization algorithms for both spring wheat and winter wheat varieties for Montana growing conditions.

Keywords: Sensor-based technologies, crop sensors, Normalized Difference Vegetative Index, nitrogen, spring wheat, algorithm, nitrogen use efficiency, mid-season fertilization, urea, urea ammonium nitrate

INTRODUCTION

Nitrogen (N) 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 (Westcott 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 1.1-1.4, where: NR – N fertilizer rate (kg ha^{-1}), YP – yield potential (kg ha^{-1}) (Engel, 1993).

Precision agriculture tools such as sensor-based technologies make it possible to accurately access the crop’s nutrient status and account for spatial and temporal variability. This enables adjusting fertilizer application rates according to site-specific conditions which results in more efficient, profitable, and sustainable crop production. Remote sensing is a precision agriculture technique that quantitatively measures vegetation indices such as the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979). A non-destructive methodology has been developed for precise estimation of crop's YP mid-season using spectral measurements which are used to develop an algorithm for mid-season topdress N fertilization. The precision sensing approach helps to address the limitations of diagnostic N tools in terms of accuracy, labor requirements, and cost. The diagnostic tools utilizing soil tests tissue N concentration and chlorophyll concentration to determine crop's need for N are time consuming, expensive, and require multiple samplings. Also, yield estimates determined using the multiple-year yield average are often inaccurate because the yield goal approach assumes that spatial and temporal homogeneity exist in the field.

Crop sensor-based systems with developed algorithms for making mid-season fertilizer N recommendations are commercially available to producers in some parts of the world. The growing interest in sensor-based technologies among Montana producers is offset by the lack of Montana-based research and limited knowledge of how well these systems would perform in Montana's semiarid conditions. In addition, one of the frequent questions asked by the growers is whether sensor-based derived N recommendations should be adjusted based on the source of topdress fertilizer N used. Two most commonly used sources of N in Montana are urea (granular, broadcasted, or applied with the seed) and urea ammonium nitrate (UAN) (liquid, often sprayed to boost protein content). Research showed that liquid N sources might be more appropriate when coupled with precision sensor-based technologies, because application of N in a liquid form allows for more accurate fertilizer delivery. The main controversy involves the discussion as to whether application of N in a liquid form provides higher N use efficiency (NUE) because N is fed directly to the plant via crop canopy.

MATERIALS AND METHODS

A field study was carried out at 2 locations in 2011 and 3 locations in 2012 in Northwest Montana: two dryland sites at the Western Triangle Agricultural Research Center (WTARC) and Martin farm (Martin) near Conrad, MT, and one irrigated site at the Western Agricultural Research Center (WARC) near Corvallis, MT, using the spring wheat variety Choteau. The objectives of this research were: 1) to evaluate two optical sensors – GreenSeeker (model 505) and Pocket Sensor (a prototype GreenSeeker Handheld Crop Sensor), and 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 UAN, or granular urea - is used.

The experimental design included 10 treatments, an unfertilized check treatment (0 kg N ha^{-1}), a non-limiting N-rich reference treatment (247 kg N ha^{-1}), and 4 preplant N application treatment rates of 22, 45, 67, and 90 kg N ha^{-1} applied as broadcasted granular urea. Individual experimental plot size was 1.5 m x 7.6 m with each treatment replicated 4 times. Treatment structure is reported in Table 1.

Table 1. Treatment structure.

Treatment	Preplant fertilizer N (urea) rate, kg N ha^{-1}	Topdress fertilizer N source
1	0	-
2	247	Urea
3	22	Urea
4	45	Urea
5	67	Urea
6	90	Urea
7	22	UAN
8	45	UAN
9	67	UAN
10	90	UAN

Wheat crop reflectance measurements – NDVI - were collected from each plot at Feekes 5 growth stage. The 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 (prototype of GreenSeeker Handheld Crop Sensor) (Trimble Navigation Ltd., Sunnyvale, CA) were used to collect the NDVI measurements (Figure 1).

Figure 1. R. Christiaens, Research Associate, and J. Jerome, Research Assistant, obtaining spring wheat reflectance measurements using GreenSeeker Sensor (left) and Pocket Sensor (right), Conrad, MT, Spring 2012.

According to treatment structure topdress N fertilizer was applied as broadcast urea, or as surface applied UAN (using a backpack sprayer with a fan nozzle). Topdress N recommendations were generated using algorithms experimentally developed for spring wheat: 1. Spring Wheat (Canada), 2. Spring Wheat (US/Canada/Mexico), and 3. Generalized Algorithm. The algorithms are available at: http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php. The Spring Wheat (Canada) and Generalized 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 Spring Wheat (US/Canada/Mexico) algorithm ranged from of 0 kg N ha^{-1} to 111 kg N ha^{-1} depending on the NDVI values measured. The NDVI values, the prescribed N rates were applied to experimental plots and harvested grain yields measured at crop maturity (Table 2 for 2011, Tables 3 and 4 for 2012, and Table 5 for 2013, respectively).

Table 2. GreenSeeker and Pocket Sensor NDVI, topdress N rate (kg ha^{-1}), and spring wheat grain yield (kg ha^{-1}), WTARC and WARC, 2011.

Trt	WTARC				WARC			
	GS	PS	N	GY	GS	PS	N	GY
1	0.3	0.3	-	928 (f)	0.4	0.4	-	2041 (f)
2	0.5	0.5	20	2663 (a)	0.5	0.5	21	3735 (abc)
3	0.3	0.3	20	1533 (e)	0.5	0.5	29	2787 (d)
4	0.4	0.4	20	1555 (e)	0.6	0.6	7	3428 (bc)
5	0.4	0.4	20	1861 (cd)	0.6	0.5	15	3867 (abc)
6	0.4	0.4	10	2156 (b)	0.6	0.6	21	3985 (a)
7	0.3	0.3	30	1454 (e)	0.5	0.5	29	3256 (cd)
8	0.4	0.4	20	1641 (de)	0.6	0.6	7	3512 (abc)
9	0.4	0.5	10	1984 (bc)	0.6	0.6	7	3364 (bc)
10	0.4	0.5	10	2167 (b)	0.6	0.6	15	3595 (abc)

Means in the same column followed by the same letter are not significantly different, $p<0.05$.

Table 3. GreenSeeker and Pocket Sensor NDVI, and topdress N rate, WTARC, WARC, and MARTIN, 2012.

Trt	WTARC			WARC			MARTIN		
	GS	PS	N	GS	PS	N	GS	PS	N
1	0.5	0.4	-	0.5	0.4	-	0.3	0.2	-
2	0.3	0.3	70	0.5	0.4	98	0.3	0.3	0
3	0.5	0.4	14	0.5	0.4	111	0.4	0.3	18
4	0.5	0.4	14	0.5	0.4	111	0.4	0.3	18
5	0.5	0.5	14	0.5	0.5	111	0.4	0.3	0
6	0.5	0.4	27	0.5	0.4	111	0.4	0.4	19
7	0.5	0.5	22	0.5	0.5	111	0.4	0.3	16
8	0.5	0.5	14	0.5	0.5	98	0.4	0.4	16
9	0.5	0.4	19	0.5	0.4	111	0.4	0.3	21
10	0.5	0.4	19	0.5	0.5	98	0.4	0.3	6

Table 4. Spring wheat grain yield, WTARC, WARC, and MARTIN, 2012.

Trt	WTARC	WARC	MARTIN
1	5861 (d)	4572 (e)	2910 (c)
2	6198 (d)	6500 (d)	3164 (bc)
3	6690 (c)	6713 (cd)	3386 (ab)
4	6988 (abc)	6914 (bcd)	3330 (abc)
5	7078 (abc)	7451 (ab)	3430 (abc)
6	7286 (a)	6849 (bcd)	3613 (a)
7	6664 (c)	7244 (abc)	3377 (abc)
8	6725 (bc)	7406 (abc)	3491 (abc)
9	6961 (abc)	7650 (a)	3283 (abc)
10	7162 (ab)	7654 (a)	3419 (abc)

Means in the same column followed by the same letter are not significantly different, $p<0.05$.

Table 5. GreenSeeker and Pocket Sensor NDVI, topdress N rate (kg ha^{-1}), and spring wheat grain yield (kg ha^{-1}), WTARC and MARTIN, 2013.

Trt	WTARC				MARTIN			
	GS	PS	N	GY	GS	PS	N	GY
1	0.6	0.6	-	4345 (ab)	0.4	0.4	-	3379 (a)
2	0.4	0.4	81	4093 (b)	0.4	0.4	0	3345 (a)
3	0.6	0.6	48	4234 (ab)	0.4	0.4	0	3548 (a)
4	0.6	0.6	48	4283 (ab)	0.4	0.4	0	3464 (a)
5	0.6	0.6	48	4554 (ab)	0.3	0.3	50	3526 (a)
6	0.6	0.6	48	4703 (ab)	0.3	0.3	50	3564 (a)
7	0.6	0.6	48	4427 (ab)	0.4	0.4	0	3318 (a)
8	0.6	0.6	48	4521 (ab)	0.4	0.4	0	3389 (a)
9	0.6	0.5	48	4871 (a)	0.4	0.4	0	3396 (a)
10	0.5	0.6	93	4563 (ab)	0.4	0.3	0	3504 (a)

Means in the same column followed by the same letter are not significantly different, $p<0.05$.

RESULTS

A strong linear relationship was observed between NDVI values obtained with GreenSeeker and with Pocket Sensor ($R^2=0.82$) (Figure 2). GreenSeeker and Pocket Sensor NDVI readings predicted % and 96% of variation in spring wheat grain yields respectively across site-years ($R^2 = 0.70$ and 0.81) (Figures 3 and 4). In both growing season, the rates generated by the USA/Canada/Mexico Algorithm were not appropriate for grain yield optimization. For example, much higher topdress N rates were prescribed for WARC (the irrigated site) compared to those for the dryland sites WTARC and Martin (Tables 2, 3, and 5). 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 (Tables 2, 4, and 5), indicating that the yield potential was either overestimated at WARC or underestimated at WTARC. This suggests that there is a need for two separate algorithms, one developed for dryland spring wheat, and another for irrigated spring wheat production systems.

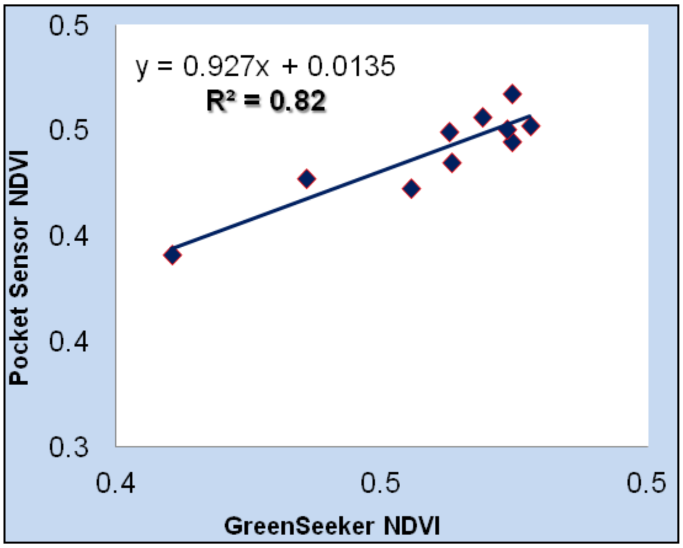

Figure 2. Relationship between GreenSeeker NDVI and Pocket Sensor NDVI, averaged over 7 site-years.

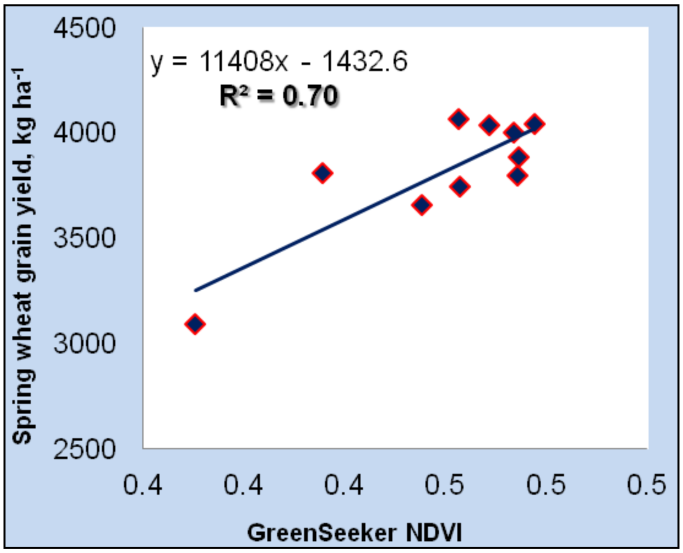

Figure 3. Relationship between GreenSeeker NDVI and spring wheat grain yield, averaged over 7 site-years.

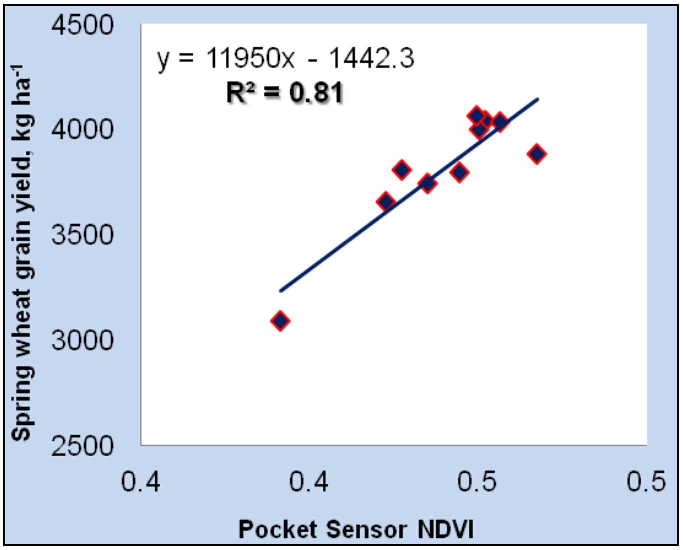

Figure 4. Relationship between Pocket Sensor NDVI and spring wheat grain yield, averaged over 7 site-years.

At Martin in 2012, a strong relationship between NDVI and grain yield was observed, indicating that the sensors performed well in terms of identifying the differences in yield potential among the treatments. Topdress N rates prescribed at this site-year did not optimize yields. A topdress rate of 18 kg N ha^{-1} was generated for Treatment 3 (Table 3) that received 22 kg N ha^{-1} preplant application, compared to a topdress rate of 19 kg N ha^{-1} for treatment 6 (Table 3) that received 80 kg N ha^{-1} preplant N application. Treatment 6 was one of the highest yielding treatments (Tables 4 and 5).

Consistently, there were no substantial differences in grain yields associated with topdress fertilizer N source (urea vs. UAN) at any of 7 site-years. 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.

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. Currently, state-wide collaborative research is being conducted in Montana to develop improved sensor-based N optimization algorithms for Montana spring wheat and winter wheat varieties and growing conditions.

ACKNOWLEDGEMENTS

We thank Montana Fertilizer Tax Advisory Committee for funding this study. We are grateful to our cooperating producer: Jack Patton and our student workers: Marliss Picard, Shauna Ellefsen, Stephanie Blockeel, Connie Miller, Blaine Berg, Cody Ward, Gabby Drishinski, Jeff William, Jeffrey Olson, Kayla Hershey, Matthew Arends, Michaela DeBoo, Morgan Koenig, Morgan Fowler, Nathan Gage, Rachel Bokma.

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