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University of Kentucky College of Agriculture, Food and Environment

Sensor Technology for Variable-Rate Nitrogen Applications on Wheat in Kentucky

Recommendations and Verification

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Nitrogen (N) applications on wheat using sensor-based technology can improve both N use efficiency and yields. The GreenSeeker® is an instrument that senses the N status of the crop as it moves over the field. If the sensor is combined with an N applicator, it can be used to apply the precise amount of N needed to each area of the field. The sensing and application technology in this system is accurate and reliable. The weak part of the process has been the algorithm (formula) that is placed in the software of the machine to tell it how much N to add based on the crop N status expressed as Normalized Difference Vegetation Index (NDVI). An algorithm developed for a particular geographical area of the U.S. is not always relevant in another area of the country. For example, the Oklahoma and Virginia algorithms for soft red winter wheat have consistently resulted in lower yields when applying variable-rate nitrogen (VRN) in Kentucky.

Several years of basic field research using the GreenSeeker has resulted in two reliable algorithms for Kentucky for soft red winter wheat. Both were developed using intensive management for high-yield wheat, one for soft red winter wheat on moderately well to well drained soils and another for moderately to somewhat poorly drained soils. The first one has been field tested with excellent results, and the other has not yet been fully field tested.

Algorithms

The algorithms were developed with small plot research using the experimental design shown in Table 1.

The first-split (February) N treatments (except for the 150 treatment) were designed to have enough plots to accommodate four replications of each of the March N treatments. This design resulted in 21 total treatments for each year. NDVI readings were made at Feekes 6 just before the second N split was applied. The grain yields allowed one to know the N rate needed at Feekes 6 for maximum yields at each of the Feekes 6 NDVI readings. Differential NDVI (DNDVI) was calculated by subtracting each NDVI reading from the NDVI reading made on the first split of the 150 lb/ac N treatment. This calculation was done in each of the four years. The final data obtained for the two different soil drainage groups presented in Tables 2 and 3, respectively, are an average of the four years. The equivalent graphical representations are shown in Figures 1 and 2.

Field Verification

Field trials were used to verify the validity of the algorithm for wheat growing on moderately well- to well-drained soils under farm conditions using the farmer's scale of equipment over a three-year period (Table 4).

At Feekes 3 (February) the first N-split was applied as a flat rate to each field using consultant/producer recommendations, as was the normal practice. An N-rich strip of 150 lb of N/ac was applied in each field at this time. At Feekes 6, the N-rich strip was read with the GreenSeeker to get an average NDVI, then VRN was applied to either four or six

Table 1. Experimental design

February (Feekes 3) N (lb/ac)	March (Feekes 6) N (lb/ac)
0	0, 30, 60, 90, 120, 150
30	0, 30, 60, 90, 120
60	0, 30, 60, 90
90	0, 30, 60
120	0, 30
150	0

Table 2. GreenSeeker differential NDVI algorithm for variable-rate N applications to wheat at Feekes 6 on moderately well- to well-drained soils in Kentucky

Differential NDVI	N Needed (lb/ac)
0.015	25
0.020	40
0.030	55
0.040	70
0.075	85
0.110	97.5
0.175	110
0.240	125

Table 3. GreenSeeker differential NDVI algorithm for variable-rate N applications to wheat at Feekes 6 on moderately to Somewhat poorly drained soils in Kentucky

Differential NDVI	N Needed (lb/ac)
0.025	20
0.040	33
0.055	45
0.080	60
0.105	75
0.135	90
0.180	105
0.210	120

different strips in each field. These strips were compared with farmer practice, flat rate (FP) strips. The FP N rate was set by experienced wheat consultants and the producer. Urea–ammonium nitrate (UAN) solution was the N source for all the applications.

The VRN yields and partial returns were greater than FP in every case. When treatments were replicated, the yields were statistically greater for VRN management in every case. The 2012 "after corn" trial and the four "after soybean" fields had only one replication per field. When each "after soybean" field was treated as a replication, the average yield comparison was significantly different. No equipment costs were included in the economic partial return analysis.

Wheat after soybean was tested for one year only. The yield increases and returns were much greater than expected and may not be representative of other seasons.

Verification Summary

- VRN on wheat using the Kentucky algorithm always resulted in higher yields and higher returns than observed with a flat N rate recommended by experienced professional wheat consultants to make the FP N application.
- The yield increases were due to both a better overall N recommendation for the field made by the sensor and the algorithm as well as better N distribution in the field.

How to Use VRN with GreenSeeker

The present recommendations are for four GreenSeeker sensor units equally spaced across the sprayer boom for a 60-foot boom, five for a 90-foot boom and six for a 120-foot boom. The readings are averaged across the boom to get one reading for the entire width; it is not making adjustments in small areas but changing N application rates as the soil drainage, topography or soil type changes across the field.

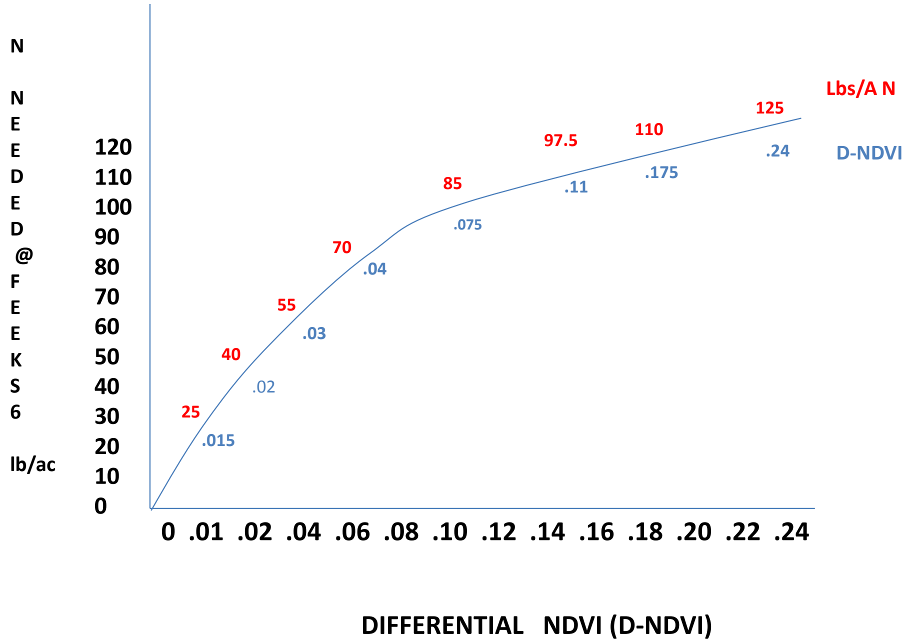


Figure 1. GreenSeeker differential NDVI algorithm for variable-rate N applications to wheat at Feekes 6 on moderately well- to well-drained soils in Kentucky

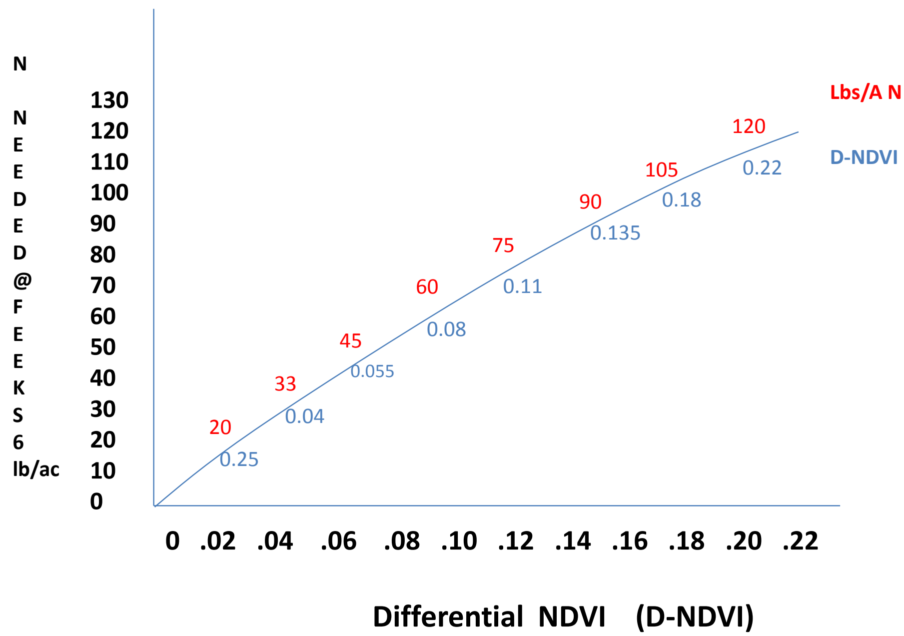


Figure 2. GreenSeeker differential NDVI algorithm for variable-rate N applications to wheat at Feekes 6 on moderately to somewhat poorly drained soils in Kentucky

Field Practices Prior to VRN Application

All other practices for intensive (high yielding) wheat management remain the same. The Feekes 3 N application should be a flat rate based on past practices and current observations such as tillering, visual color of the crop and amount of crop growth. At this time, a rate of 150 lb/ac of N should be applied to a strip (N-rich) in the field that fairly represents the field and is as wide or wider than the sprayer boom that will be used. Wheat varieties, amount of crop growth, stage of crop growth and field conditions all can affect the green color and the NDVI values. To maximize the GreenSeeker technology, an N-rich strip should be established in every wheat field.

Table 4. Three-year summary of field trials comparing VRN (GreenSeeker) with flat-rate farmer practice (FP)

Producer	Year	Yield[1] (bu/ac)		N Rate[2] (lb/ac)		Partial Returns[3] ($/ac)	
		VRN	FP	VRN	FP	VRN[3]	FP
	After Corn						
Hunt	2010	84.2a	79.3b	69.0	45.0	17.40	0
Hunt	2011	97.4a	92.5b	51.1	52.3	30.05	0
Hunt	2011	84.2a	82.2b	54.1	53.2	11.60	0
Halcomb	2012	74.8	72.2	86.1	64.0	4.55	0
Average		85.2a	81.6b	65.1	53.6	15.90	0
	After Soybean						
Halcomb	2012	91.0	81.2	88.5	64.0	46.55	0
Halcomb	2012	76.6	62.8	81.9	64.0	73.85	0
Halcomb	2012	88.8	81.1	88.5	64.0	33.95	0
Halcomb	2012	101.3	61.8	86.8	64.0	227.75	0
Average		89.4a	71.7b	86.4	64.0	95.52	0

[1] Yields in the same row with different letters were significantly different at the 0.1 level or less
[2] Average N rate for Feekes 6
[3] $6/bu wheat and $0.50/lb N

Selecting a Recommendation for Feekes 6

Two different algorithms have been developed for Kentucky. The moderately well- to well-drained algorithm was developed on soils well suited for wheat production. These soils drain well and normally are not saturated during rain events or for only short periods of time. The moderately to somewhat poorly drained algorithm was developed on soils that remain saturated for a few days after heavy rains. Wheat is grown on these soils, but they are not the best situation for wheat.

Using NDVI and D-NDVI to Make VRN Recommendations

For the GreenSeeker, the NDVI is an estimate of the green color and growth in an area. The D-NDVI is the difference between the NDVI of the N-rich strip and the NDVI at any other location in the field. Every place in the field has a D-NDVI. For example, if the N-rich strip reads 0.85 and another place in the field reads 0.81 the D-NDVI is 0.04. Another area of the field may have a D-NDVI of 0.01 and another may have a D-NDVI of 0.07.

There is a VRN recommendation for each D-NDVI (Figures 1 and 2) for the two different algorithms. This can be represented in a tabular form as shown in Table 5.

While the algorithm uses D-NDVI to calculate N rates, the GreenSeeker computer only calculates NDVI and uses NDVI to make N applications. The D-NDVI values in Table 5 must be converted to NDVI readings for each field. The highest NDVI reading in a field will be the NDVI reading for the N-rich strip. An example is given in Table 6 where the N-rich strip reads 0.85. All other NDVI readings must also be based off the highest reading. From there, you can develop the N rates needed for each NDVI value. The N-rich strip may have different NDVI values in different fields. A separate set of calculations will be needed for fields where the N-rich has different values. An N-rich strip should occur in every field to maximize the technology.

Setting a Minimum and Maximum Rate

Since the NDVI readings are averaged across the width of the boom, NDVI differences may well exist in areas smaller than the boom width. A minimum amount of nitrogen should always be applied to correct for these undetected differences. A minimum rate of 20 to 30 lb N/acre will be sufficient in most cases.

Table 5. Nitrogen rates needed at Feekes 6 for each D-NDVI

D-NDVI																								
0	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.11	.12	.13	.14	.15	.16	.17	.18	.19	.20	.21	.22	.23	.24
Moderately well to well-drained soil types (N rate/lb/ac)																								
0	20	40	55	70	75	80	83	87	90	94	97	100	102	104	106	108	110	112	115	117	120	122	124	125
Moderately to somewhat poorly drained soil types (N rate/lb/ac)																								
0	10	20	25	35	42	48	55	60	66	72	77	82	88	92	96	100	104	107	110	115	120	120	120	120

Table 6. Example of converting D-NDVI to NDVI

N-Rich Strip with 0.85 NDVI																								
.85	.84	.83	.82	.81	.80	.79	.78	.77	.76	.75	.74	.73	.72	.71	.70	.69	.68	.67	.66	.65	.64	.63	.62	.61
Moderately well to well-drained soil types (N rate/lb/ac)																								
0	20	40	55	70	75	80	83	87	90	94	97	100	102	104	106	108	110	112	115	117	120	122	124	125
Moderately to somewhat poorly drained soil types (N Rate/lb/ac)																								
0	10	20	25	35	42	48	55	60	66	72	77	82	88	92	96	100	104	107	110	115	120	120	120	120

A maximum rate of N will need to be set in many fields. Most sprayers do not have the capability to apply the full range of N rates that are built into the Kentucky algorithms (30 to 125 lb N/acre). Therefore, a maximum rate that corresponds to the capability of the sprayer is selected. The example shown in Table 7 is for a sprayer with a range of 50 lb N/acre. The N range on a particular sprayer can be changed by selecting a different liquid N concentration (28, 30 or 32% N).

Early Entry into On-Board Computer

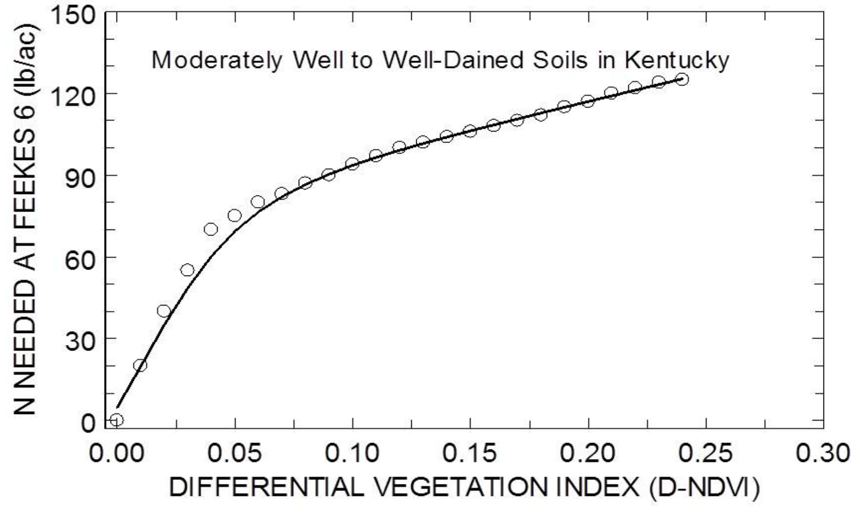
Once the recommendation is selected, the information can be entered into the on-board computer before going to the field. The GreenSeeker company does not have a Kentucky algorithm in their computer, therefore a custom entry must be made. The method is described in "Custom Algorithm" in Appendix B of the GreenSeeker RT200 *System Installation and Guide.* Table 8 shows examples of entries with a range of NDVIs for N-rich strips that can be entered into the computer prior to VRN applications. Each algorithm can be named separately using the N-rich NDVI for easy call-up. Once the N-rich NDVI for a field is read, then that entry can be called up and selected. This method requires no waiting for entries to be made before beginning the VRN application. An example in Table 8 is for the moderately well to well-drained algorithm with N-rich NDVIs beginning with 0.90 and going to 0.75.

Using Formulas instead of Tables

The algorithm information can be entered into the computer in a tabular form, as described in Tables 5 and 6, or as a formula as described below. Using a formula eliminates the need for early entries, as described in the previous section, but reduces the flexibility to make changes in the VRN algorithm when unusual conditions are encountered in any one year.

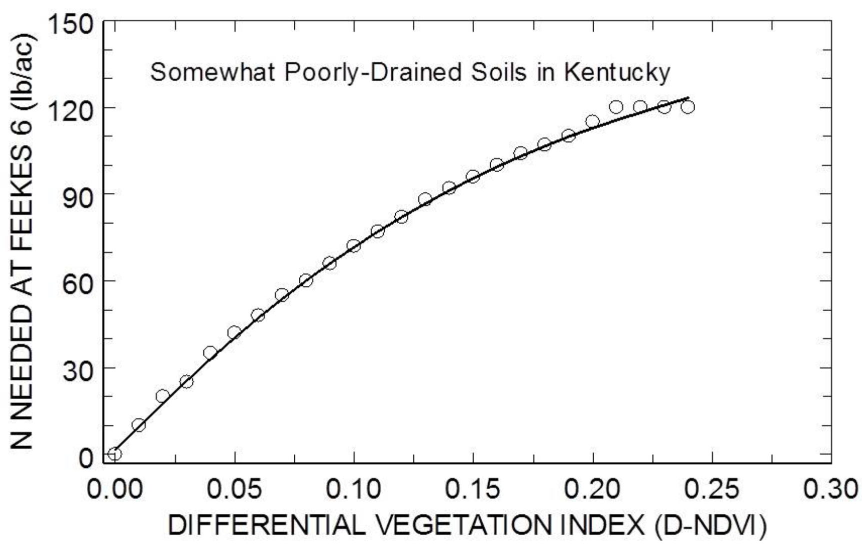
The information compiled in Table 5 is also illustrated in Figure 3 for moderately well to well-drained soils and in Figure 4 for somewhat poorly drained soils in Kentucky. In both figures, the symbols reflect the data displayed in Table 5 and the curves manifest the fitted relationship.

Due to the changing slope of the relationship, a nested model consisting of an exponential and a spherical component was chosen. The equations with the different parameters for the curves are provided below both figures. These equations can be used on the sprayer. If the D-NDVI value is monitored, the computer program uses these equations for calculating the N rate. If the user prefers the applied product rate instead of the N-rate, the resulting N-rate just needs to be divided by 2.988 in case of UAN 28 percent or divided by 3.546 in case of UAN 32 percent to arrive at a sprayer dose in gal/ac. The two factors 2.988 and 3.546, respectively, reflect the mass of N/gal of both products.



$$N-Rate=-2.259+77.8377\cdot\left[1-\exp\left(-\frac{3\cdot DNDVI}{0.08296}\right)\right]+938.819\left[1.5\frac{DNDVI}{6.7797}-0.5\left(\frac{DNDVI}{6.7797}\right)^3\right]$$

Figure 3. Nitrogen (N) needed at Feekes 6 for moderately well to well-drained soils in Kentucky as a function of differential vegetation index D-NDVI.



$$N-Rate=1.178+481.608\cdot\left[1-\exp\left(-\frac{3\cdot DNDVI}{1.0404}\right)\right]-4527.81\left[1.5\frac{DNDVI}{13.7339}-0.5\left(\frac{DNDVI}{13.7339}\right)^3\right]$$

Figure 4. Nitrogen (N) needed at Feekes 6 for somewhat poorly-drained soils in Kentucky as a function of differential vegetation index D-NDVI.

Table 7. Setting a Maximum and Minimum Rate

N-Rich Strip with 0.85 NDVI																								
.85	.84	.83	.82	.81	.80	.79	.78	.77	.76	.75	.74	.73	.72	.71	.70	.69	.68	.67	.66	.65	.64	.63	.62	.61
Moderately well to well-drained soil types (N Rate/lb/ac)																								
30	30	40	55	70	75	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Moderately to somewhat poorly drained soil types (N Rate/lb/ac)																								
30	30	30	30	35	42	48	55	60	66	72	77	80	80	80	80	80	80	80	80	80	80	80	80	80

Table 8. Examples for making early entries into on-board computer for the moderately well to well-drained soil types

N recommended (lb/ac)																								
30	30	40	55	70	75	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
N-rich strip with 0.90 NDVI																								
.90	.89	.88	.87	.86	.85	.84	.83	.82	.81	.80	.79	.78	.77	.76	.75	.74	.73	.72	.71	.70	.69	.68	.67	.66
N-rich strip with 0.89 NDVI																								
.89	.88	.87	.86	.85	.84	.83	.82	.81	.80	.79	.78	.77	.76	.75	.74	.73	.72	.71	.70	.69	.68	.67	.66	.65
N-rich strip with 0.75 NDVI																								
0.75	.74	.73	.72	.71	.70	.69	.68	.67	.66	.65	.64	.63	.62	.61	.60	.59	.58	.57	.56	.55	.54	.53	.52	.51

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