Original Article Journal of Biosystems Engineering

J. of Biosystems Eng. 42(2):98-103. (2017. 6)
https://doi.org/10.5307/JBE.2017.42.2.098

eISSN : 2234-1862
pISSN : 1738-1266

Development of a Nitrogen Application System for Nitrogen Deficiency in Corn

Hyun Kwon Noh*

Department of Biosystems Engineering, Chungbuk National University, Cheongju, Korea

Received: May 19th, 2017; Revised: May 30th, 2017; Accepted: May 30th, 2017

Abstract

Purpose: Precision agriculture includes determining the right amount of nitrogen for a specific location in the field. This work focused on developing and validating a model using variable rate nitrogen application based on the estimated SPAD value from the ground-based image sensor. **Methods:** A variable rate N application based on the decision making system was performed using a sensor-based variable rate nitrogen application system. To validate the nitrogen application decision making system based on the SPAD values, the developed N recommendation was compared with another conventional N recommendation. **Results:** Sensor-based variable rate nitrogen application was performed. The nitrogen deficiency level was measured using the image sensor system. Then, a variable rate application was run using the decision model and real-time control. **Conclusions:** These results would be useful for nitrogen management of corn in the field. The developed nitrogen application decision making system worked well, when considering the SPAD value estimation.

Keywords: Decision-making system, Nitrogen management, Precision agriculture, SPAD, Variable rate nitrogen application

Introduction

In precision agriculture, especially site-specific crop management, the major function of nitrogen management is to determine the right amount of nitrogen for a specific location in the field, based on the yield potential at that location. Nitrogen fertilizer is necessary for profitable corn production. However, excessive rates of nitrogen fertilizer application will have adverse effects on the environment (Schepers et al., 1991; van Es and Trautmann, 1990). Because of the spatial variability in soil properties, different locations in a field may require different amounts of nitrogen to achieve high yield.

Currently, soil sampling analyses, plant tissue analyses, soil plant analysis development (SPAD) meter readings, and aerial images are used to assess the crop nitrogen stress and estimate the yield potential (Waskom et al., 1996).

Researchers have studied the use of images for crop production management since the late 1970's. (McDonald and Hall, 1980; Noh et al., 2005; Tumbo, 2001; Janos et al., 2003; Mao, 2003).

In this study, a decision making system for variable rate N application in corn was developed, and variable rate N application based on the decision making system was performed by using a pulse width modulation (PWM) valve. To validate the nitrogen application decision making system based on the SPAD values, researchers compared the developed N recommendation with another conventional N recommendation. This paper reports the development and validation of a decision making system based on an estimated SPAD value, using a multi-spectral image sensor.

***Corresponding author:** Hyun Kwon Noh
Tel: +82-43-261-2581; **Fax:** +82-43-271-4413
E-mail: nhkisg@cbnu.ac.kr

Materials and Methods

Decision Making Model

For the variable rate nitrogen application, we must calculate the amount of nitrogen to apply, based on the estimated SPAD value from the image sensor. Figure 1 shows the flow chart of the sensor integrated variable rate application (VRA). In this chart, the N recommendation is determined by two SPAD values: one is an estimated SPAD value from the image sensor system and the other is a reference SPAD value for healthy corn.

Based on the SPAD value measurements, the average SPAD value from the visually identified healthy range was designated as the reference SPAD value (R_SPAD = 45). This value was also used as a reference value in the decision making model. In the case that the estimated SPAD is greater than this value, no additional nitrogen will be applied.

N application was determined by the decision making model that was based on the SPAD differences. Once the N recommendation was determined, the duty cycle was computed by the nozzle calibration equation and applied to the PWM driver. Then, variable rate N application was performed by operating the PWM valve.

Researchers conducted baseline tests (SPAD value changes according to nitrogen application) at the Agricultural Engineering Research Farm of the University of Illinois at Urbana-Champaign. A corn crop (Pioneer 33P27) was planted in a field on May 24, 2002.

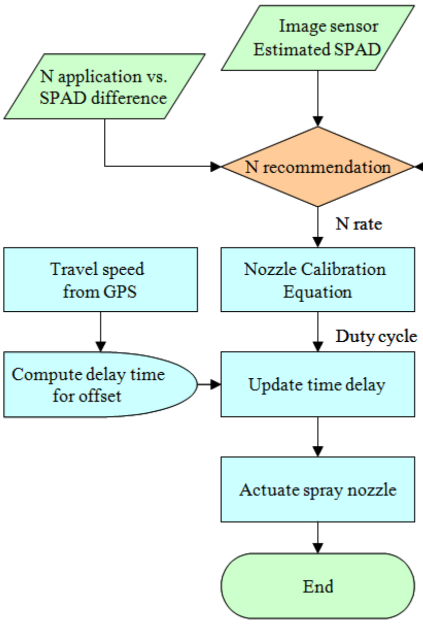

Figure 1. Flow chart of sensor integrated variable rate application (one cycle).

In the VRA test, nitrogen was applied to four passes (three passes with VRA and one pass without VRA). The SPAD values were measured weekly before and after the nitrogen application until the tassels appeared. After tasseling, the SPAD value was measured every alternate week. The yield was also measured during harvest, for each pass.

Figure 2 shows an example of the correlation between the yield and the SPAD value on different days during the growing season. The yield show proportional relation with the SPAD value after 7/31 (62). In the figure, the linear regression on August 21 was performed and plotted, and the correlation was 0.96. All the other regressions between yield and the SPAD value on different days were performed in the same way. Their correlations were computed.

The SPAD value at the reproductive stage R1 was used as a final SPAD value to determine the relationship between SPAD differences and the nitrogen application rate, because the correlation with yield at that stage was the best. The SPAD value at the vegetative growth stage V6 was used as an initial SPAD value.

Figure 3 shows the correlation between the nitrogen rate and the SPAD differences (SPAD value at the R1 stage on 8/21 - SPAD value before N application on 7/1). Each point represents an average of four replications. The polynomial regression was performed. The correlation was 0.89 for the polynomial regression; and in the case of linear regression the correlation was 0.83.

The decision making system that determines N recommendations used the above field test result, based on the relationship between the SPAD value difference and the nitrogen application as shown below.

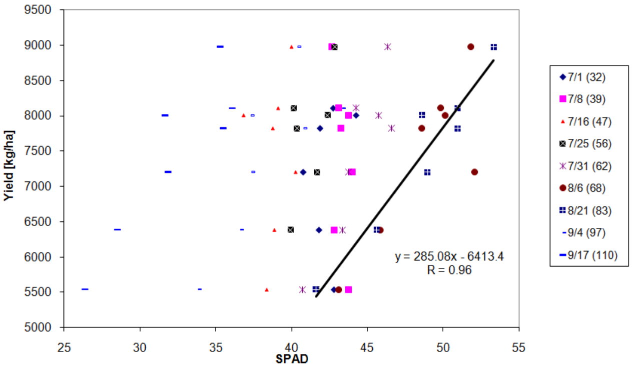

Figure 2. Correlation between yield and SPAD on different dates.

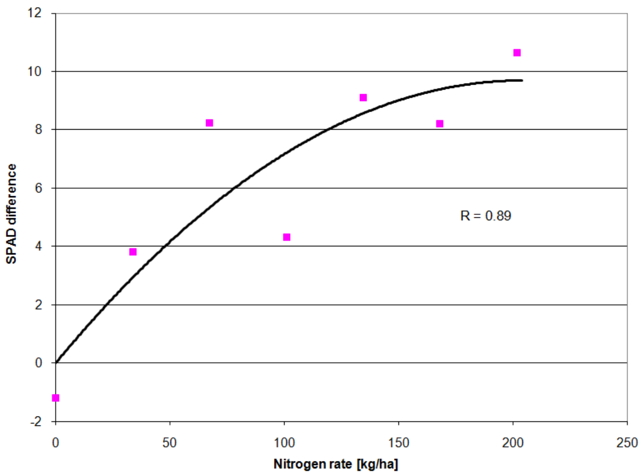

Figure 3. SPAD difference based on the applied nitrogen rate.

$$N[\mathrm{kg/ha}] = 0.6449 \times (d\_SPAD)^2 + 10.393 \times (d\_SPAD) \quad (1)$$

where d_SPAD is the difference between the SPAD value of healthy corn leaves and the Estimated SPAD value (E_SPAD) based on the image sensor system

After collecting data using the image sensor, we can calculate the desired N application rate using the above equation. The decision making model will then convert the desired N rate into a duty cycle to drive the PWM controller of each nozzle to implement the variable rate application based on the traveling speed of the sprayer.

To evaluate the N application based on the SPAD difference, sensor-based field tests were performed on three passes. Two different N recommendations were tested for validation of the nitrogen application decision making system based on the SPAD values.

Results and Discussion

Estimated SPAD Values and Applied N

Sensor-based variable rate nitrogen application was performed. The nitrogen deficiency level was measured using the image sensor system, and then variable rate application was performed using the decision model and real-time control. After the variable rate application, the E_SPAD and the real SPAD were compared along the travel distance for validation. The E_ SPAD values based on the image sensor system were recorded during the sensor-based variable rate application as shown in Figure 4.

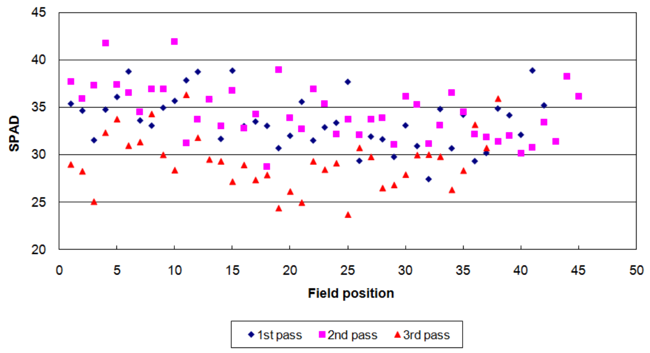

Figure 4. Estimated SPAD value based on the image sensor system.

Table 1. ANOVA analysis results of E_ SPAD on sensor-based VRA passes

Source of variation	SS	Df	MS	F	P-value	F crit
Between passes	620.27	2	310.13	37.25	0.000	3.078
Within passes	924.10	111	8.33			
Total	1544.37	113				

Table 2. Statistics of SPAD difference in VRA based on image sensor

		R_SPAD	E_SPAD	SPAD difference
1st Pass	Average	45.00	33.63	11.37
	Std			2.83
2nd Pass	Average	45.00	34.52	10.48
	Std			2.91
3rd Pass	Average	45.00	29.30	15.70
	Std			2.97

Table 1 shows the ANOVA analysis results of E_SPAD on sensor-based VRA passes. Those E_SPAD values on three passes over the same travel row were used in the decision-making model with the R_SPAD value.

The statistics of SPAD differences in VRA, based on the image sensor data from each pass are shown in Table 2.

From this table, the average values of the differences between E_SPAD and R_SPAD (45) were 11.37, 10.48, and 15.7 for the 1st, 2nd, and 3rd passes, respectively; with standard deviations as shown. From these results, it can be seen that the corn in these three passes was under nitrogen stress. The N deficiency was larger in the third pass than in the other two passes, and the N deficiency variation was similar among the passes. This investigation was also designed to evaluate the effectiveness of the nitrogen application decision making model developed in this research, based on the sensor estimated SPAD value instead of the conventional yield based model.

To validate the nitrogen application decision making system based on the SPAD values, the N recommendation (Equation **(1)**) was compared with another N recommendation (Francis & Piekielek, 1999), which is based on estimated yields, as follows:

$$N[\mathrm{kg/ha}] = \{280 + Yield \times 0.9 - 17 \times Mvalue \times RSPAD - 19 \times LSCrop \times RSPAD - 4 \times ARAMR\} \times 1.120851 \quad (2)$$

where, Yield = Yield goal [bu/acre], Mvalue = Manure value, RSPAD = Relative SPAD (ratio of field SPAD to R_SPAD), LSCrop = Leaf stage of crop, ARAMR = Average reference area meter reading.

In this study, the N application rates for the first and the second passes were determined using equation (**1**), and the rates for the third pass were calculated from equation (**2**). The values inserted into equation (**2**) were as follows:

Yield goal = 160 [bu/acre], Manure value = 0.75 (0.75 for manure value if no manure has been applied to the field since the previous crop's harvest and 3.50 if manure was applied), R_SPAD = 45 (use an average SPAD value of a healthy crop in the field), Leaf stage of crop = 11 (count and average the leaves of the crop in the field), and Average reference area meter reading = 45.

Figure 5 compares the recommended nitrogen application rates for all three passes. Based on these two equations, the average amounts of N application are shown in Table 3, and the statistics of increased SPAD on ten spots after VRA based on image sensor according to the pass are shown.

From Table 3, the average values of increased SPAD between SPAD after VRA and E_ SPAD before VRA, were 11.61, 12.64, and 17.01 for the 1st, 2nd, and 3rd passes, respectively; with standard deviations as shown.

Figure 6 shows the SPAD after VRA on ten points in each pass. The SPAD values were measured by the SPAD meter 14 days after sensor-based VRA. From these results, it can be seen that in all three passes the corn reached the reference nitrogen level which is R_SPAD value 45 in two weeks. The results also showed that the average applied N in the third pass was 30.08 kg/ha with standard deviation of 3.88 kg/ha, which was noticeably less than the other two passes. The average values of the applied N in the first and second passes were 57.83 and 51.83 kg/ha with standard deviations of 19.70 and 18.88 kg/ha, respectively.

Figure 7 shows the average of the SPAD value change after variable rate applications based on the image sensing system.

In Figure 7, the average SPAD values of the three passes reached the R_SPAD value (45) in two weeks. The average SPAD values on ten points obtained after 14 days of nitrogen application were 45.2 (std. dev. 3.81), 47.2 (std. dev. 2.78), and 46.3 (std. dev. 2.22).

Figure 8 shows the RSPAD (SPAD/R_SPAD) after two weeks. The average RSPAD values (standard deviation) of ten spots were 1.005 (0.085), 1.048 (0.062), and 1.029

Table 3. Statistics of SPAD difference and applied N in VRA based on image sensor

		R_SPAD	Increased SPAD	Applied N [kg/ha]
1st Pass	Average	45.24	11.61	57.83
	Std	3.81		19.70
2nd Pass	Average	47.16	12.64	51.83
	Std	2.78		18.88
3rd Pass	Average	46.31	17.01	30.08
	Std	2.22		3.88

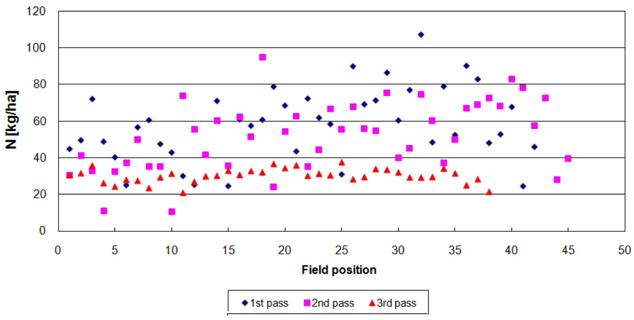

Figure 5. Nitrogen amount according to each pass.

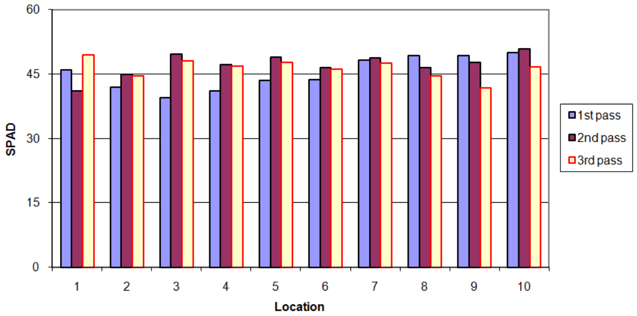

Figure 6. SPAD after VRA in 2 weeks.

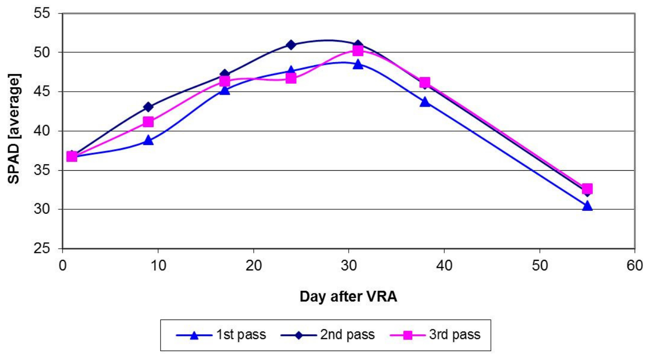

Figure 7. SPAD value after VRA based on NDS system.

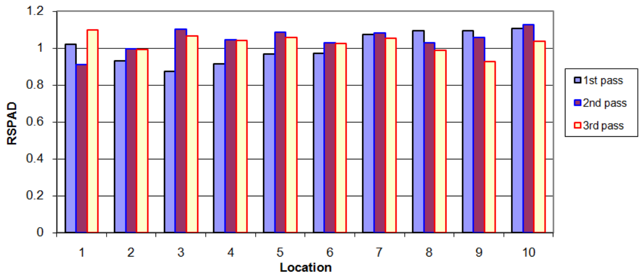

Figure 8. Relative SPAD of corn leaves after two weeks.

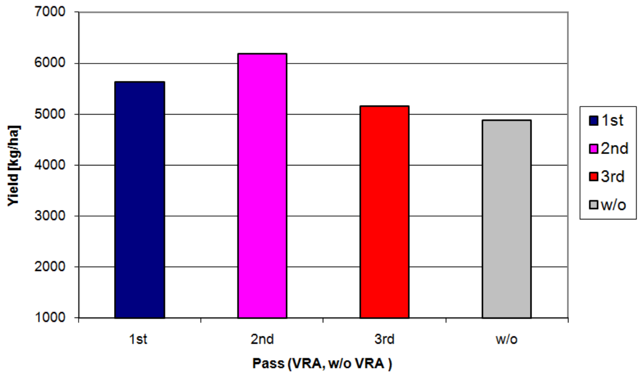

Figure 9. Yield of the image sensor-based nitrogen VRA.

Table 4. Yield and applied N on sensor-based VRA

		Yield [kg/ha]	*Increased yield*		*Added N* [kg/ha]	Increased yield / Added N [kg/kg]
			[kg/ha]	%		
1st pass	VRA	5637.9	753.5	3.1	57.8	13.0
2nd pass	VRA	6177.6	1293.2	5.3	51.8	25.0
3rd pass	VRA	5156.4	272.0	1.1	30.1	9.0
Other	w/o VRA	4884.4	Base	Base	Base	Base

(0.05) for the 1st, 2nd, and 3rd passes, respectively. The sensor-based variable rate application system worked and the RSPAD value was around 1.

Figure 9 shows the yield of the test field, in which sensor-based nitrogen variable rate application was performed. The 1st, 2nd, and 3rd passes include VRA treatment representing the field sensor-based nitrogen VRA. The other pass is performed without VRA treatment, and represents the field with uniform N application of 56 kg/ha.

In all passes, yield with nitrogen VRA increased more than without nitrogen VRA. However, the increased yields on the 1st and 2nd passes were higher than the 3rd pass. The 1st and 2nd pass VRA was applied using N recommendations based on SPAD differences, and the 3rd pass VRA was applied using conventional N recommendations based on yield.

The yield, increased yield and added N for sensor-based N VRA in the field are shown in Table 4.

The increased yields over applied N were 13.0, 25.0, and 9.0 for the 1st, 2nd, and 3rd passes, respectively. Considering these values, the resulting N recommendation for the 1st and 2nd passes were better than the 3rd pass. Thus, the nitrogen recommendation model based on SPAD differences developed in this study was more effective than the N recommendation based on yield.

Conclusions

Previous research (Noh et al., 2005) indicated that the multi-spectral imaging sensor can be used to estimate corn leaf SPAD values with reasonable accuracy during field operations. Based on the relationship between the SPAD value difference and the nitrogen application, a decision making system that determines N recommendations was developed and variable rate N application based on the decision making system was performed by operating a PWM valve.

The nitrogen application decision making system worked from the SPAD value estimation point of view. When we compared the E_SPAD values with the R_SPAD (target SPAD), the RSPAD (relative SPAD ratio) was around 1.

To validate the nitrogen application decision making system, the N recommendation was compared with another N recommendation, which was based on estimated yields. The results showed that the developed nitrogen recommendation model based on SPAD differences was more effective than the conventional N recommendation based on yield.

Integrating the image sensor with a variable-rate nitrogen application via the decision making system can provide the fundamental means for performing site-specific nitrogen management. Using the developed decision making N application system at the vegetative growth stage not only increased the yield compared with the reference field, but also reduced the total amount of N usually required by the conventional uniform N application method.

This result was based on a one-year field test. Additional field testing is recommended to validate the N application. The system could be both economically and environmentally advantageous.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgments

This work was supported by the intramural research grant of Chungbuk National University in 2015.

References

Francis, D. D. and W. P. Piekielek. 1999. Assessing crop nitrogen needs with chlorophyll meters. The Potash and Phosphate Institute Site-Specific Management Guide #SSMG-12.

Gitelson, A.A., Y.J. Kaufman and M.N. Merzlyak. 1997. Remote sensing of pigment content in higher plants: principles and techniques. In Proc. 3rd International Airborne Remote Sensing Conference and Exhibition, 657-664, Copenhagen, Denmark.

Janos, K.V., U.M. Mikio, M.Kumi and F. Antal. 2003. Leaf Water Potential Measurement Method Using Computer Image Analysis in Satsuma Mandarin. In Proc. Annual International meeting of ASAE, Paper Number: 031050, LasVegas, Nevada.

Mao, W., Y. Wang and Y. Wangl. 2003. Real-time Detection of Between-row Weeds Using Machine Vision. In Proc. Annual International meeting of ASAE, Paper Number: 031004, LasVegas, Nevada.

McDonald, R.B. and F.G. Hall, 1980. Global Crop Forecasting. Science 208(May, No 4445):670-679.

McWilliams, D.A., D.R. Berglund and G.J. Endres. 1999. Corn growth and management quick guide. NDSU Extension Service, A1173. North Dakota State University, Fargo, ND.

Noh, H., Q. Zhang, B. Shin, S. Han and D. Reum. 2005. Dynamic Calibration and Image Segmentation Methods for Multispectral Imaging Crop Nitrogen Deficiency Sensors. Transactions of the ASAE. Vol. 48(1):393-401.

Robert, P.C., R.H. Rust and W.E Larson. 1995. Preface, In Proc. Site-Specific Mgmt. for Agric. Sys., 27-30, Minneapolis, Minn.: ASA-CSSA-SSSA.

Schepers, J.S., M.G. Moravek, E.E. Alberts and K.D. Frank. 1991. Maize production impacts on groundwater quality. Journal of Environmental Quality 20:12-16.

Tumbo, S.D., D.G. Wagner and P. H. Heinemann. 2001. On-the-go sensing of chlorophyll status in corn. ASAE paper No. 01-1175. St. Joseph, Mich.: ASAE.

van Es, H.M, and N.M. Trautmann. 1990. Pesticide management for water quality: Principles and Practices. Cornell University Natural Resources Cooperative Extension Fact Sheet. http://www.pmep.cce.cornell.edu.

Waskom, R.M., D.G. Westfall, D.E. Spellman and P.N. Soltanpour, 1996. Monitoring nitrogen status of corn with a portable chlorophyll meter. Communications in Soil Science and Plant Analysis 27(3&4):54 560.