THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

CropSAT – A PUBLIC SATELLITE-BASED DECISION SUPPORT SYSTEM FOR VARIABLE-RATE NITROGEN FERTILIZATION IN SCANDINAVIA

Söderström M[1]., Stadig H[2]., Martinsson J[3]., Piikki K[1]., Stenberg M[4].

[1]Swedish University of Agricultural Sciences (SLU), Skara, Sweden

[2]Rural Economy and Agricultural Societies (Hushållningssällskapet), Skara, Sweden

[3]DataVäxt AB, Grästorp, Sweden

[4]Swedish Board of Agriculture (Jordbruksverket), Skara, Sweden

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract

CropSAT is a free-to-use web application for satellite-based production of variable-rate application (VRA) files of e.g. nitrogen (N) and fungicides currently available in Sweden and Denmark. Even in areas frequently covered by clouds, vegetation index maps from data derived from low-cost or freely available optical satellites can be used in practice as a cost-efficient tool in time-critical applications such as optimized nitrogen use. During the very cloudy year 2015, or more useable images were generated for 2/3 of all arable land in Sweden in the period end of April to the first part of June. By using the relative variation within fields, often images upto a few weeks old can be used as input for the VRA maps, reducing the need for entirely recently acquired images. CropSAT is an interactive decision support system in which the user decides upon the level of input in different index classes. The relationship between satellite data and data from ground-based sensors suggest that simple vegetation index maps can be calibrated by sensors on the ground to produce maps of N uptake. Thousands of users have tested CropSAT which has the potential to be developed further.

.

Keywords. *Vegetation index, nitrogen fertilization, decision support, public data, remote sensing.*

Introduction

Winter wheat (*Triticum aestivum* L.) is the most cultivated crop in Scandinavia. Split nitrogen (N) fertilization is commonly adopted to achieve desired crop quality and yield, while expected to reduce the risk for N leaching. Crop biomass, chlorophyll concentration and nitrogen uptake have been successfully described through the relationship with canopy reflectance in the red and near-infrared region of the electromagnetic spectrum (e.g. Jensen et al. 1990; Reusch 2003; Wiegand et al. 1991). Various crop canopy sensors that use canopy reflectance have been developed to assess the nitrogen status of crops (e.g. Link et al. 2002; Solie et al. 2002). In Europe the most commonly used system is the Yara N-Sensor (Yara Gmbh, Hanninghof, Germany), a tractor-mounted proximal sensing device that operates in the visible to near-infrared spectral range (Link et al. 2002), but also a handheld version of the instrument exists commonly used in field trials. In order to cover large areas and provide in-season support on crop growth to farmers, remote sensing from satellites has always been an option. The accessibility and temporal availability of remote sensing imagery improves continuously (Wang 2010; Mulla 2013). However, the use of support systems for crop production based on optical satellite remote sensing is a challenge in temperate regions frequently covered by clouds such as northern Europe.

In an effort to provide the farmers with a free, easy-to-use support system based on satellite data mainly for precision supplementary N fertilization, the web-based CropSAT service (CropSAT.se) was developed, starting in 2013 through collaboration between a range of actors. The project was initiated by the Swedish University of Agricultural Sciences (SLU, Skara, Sweden) in collaboration with the Rural Economy and Agricultural Societies (Hushållningssällskapet, Skara, Sweden) and the Lantmännen Farmers' Cooperative. The first web application was developed in 2014 with a simple wizard-like user interface, allowing the users to: locate and select fields using a combination of Google maps (Google Inc., Mountain View, CA, USA) and field boundaries from the Swedish Board of Agriculture (Jordbruksverket, Skara, Sweden); split fields if necessary; select satellite image; manually reclassify a vegetation index map into a N application map; and download a variable-rate application file. The system was improved in 2015 and was run with support from Agroväst Livsmedel AB (Skara, Sweden) and DataVäxt AB (Grästorp, Sweden) under the management of Focus-on-Nutrients, a national undertaking for improved nutrient-use-efficiency administered by the Swedish Board of Agriculture. The system was also introduced in Denmark in 2016 by SEGES (formerly Knowledge Centre for Agriculture, Aarhus, Denmark) and the Ministry of Environment and Food of Denmark (Copenhagen, Denmark).

This paper summarizes the Swedish experiences of the CropSAT system in terms of functionality and usage, image delivery, and comparisons with ground-based optical sensor measurements in 2015.

Materials and methods

CropSAT is based on low-cost or free satellite data: DMC (DMCii Ltd, Guildford, UK), Sentinel-2 (ESA, EU) and Landsat 8 (USGS/NASA, USA). Combined they offer good opportunities for spatial and temporal coverage at a reasonable cost. The different bands of these satellites in the visible to near-infrared (NIR) region are described in Figure 1.

The CropSAT system was primarily based on DMC low-cost data with 22-m spatial resolution, with 30-m Landsat 8 as backup. From 2016, the first of two Sentinel-2 satellites became available, with higher spatial resolution (10 m) and some additional spectral bands within the red edge region of the crop canopy spectra (with 20-m resolution; Figure 1) dedicated to vegetative studies. Our intent with CropSAT was to cover ~2.4 million ha of arable land, i.e. some 90 % of the arable land in Sweden, with a practically useful set of satellite images during the period for supplementary N fertilization – from mid-April to mid-June.

The vegetation index that we chose to use, after initial performance tests, was the modified soil adjusted vegetation index (MSAVI2; Qi et al. 1994). Other indices we considered but rejected because they reached saturation too early in the season were normalized difference vegetation index (NDVI; Rouse et al. 1973) and soil adjusted vegetation index (SAVI; Huete 1988). Pixels with clouds or cloud shadows, and pixels within 15 m of the field borders were removed. Removed pixels along field borders were subsequently recalculated (through averaging) by the remaining, neighboring pixels within the field.

To assess the satellite images we made comparisons with data collected on the ground with the Yara N-Sensor, both the handheld version which is mainly used for field trials, and the tractor mounted equipment which is used by farmers for variable-rate application of N. The Yara equipment has been used by farm service organizations for many years in field trials in Sweden to quickly measure N uptake, and it is generally accepted by farmers as providing useful recommendations of N fertilization levels. In this project we used the N uptake and biomass outputs for comparisons with the satellite data.

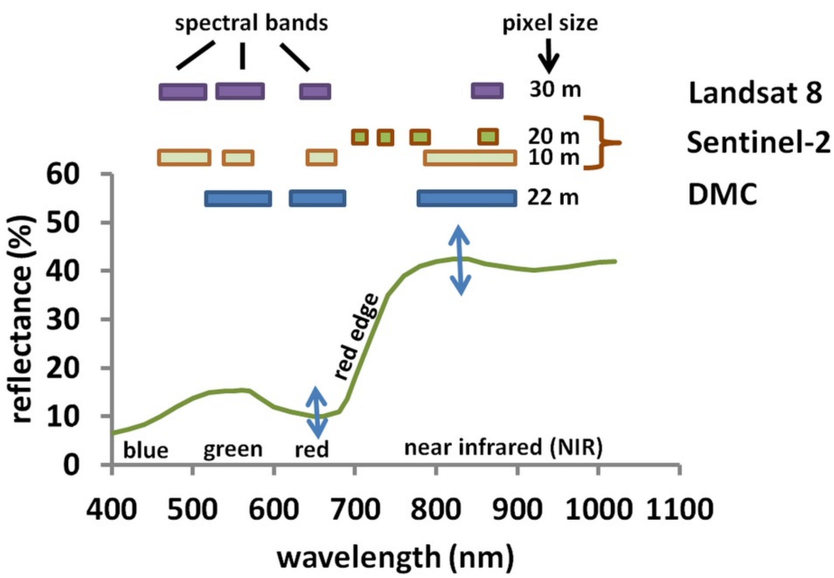

Fig 1. Spectral bands of the satellites used in CropSAT in the visible to the near-infrared region. Common vegetation indices are based on the reflectance differences in the NIR and the red region (indicated by the double arrows). In CropSAT, so far, the modified soil-adjusted vegetation index (MSAVI2) is used.

Weekly field measurements were conducted in each of 26 fields in southwest and south Sweden with the handheld Yara N-Sensor. These were paired with the average vegetation indices of the pixels within a distance of 15-30 m from the coordinate of the sensor measurement, if sensor measurement dates corresponded to the acquisition date of satellite imagery (± 2 days).

Linear regression models were parameterized successively during the season. Calibrations and validations were made through a leave-one-field-out approach. The mean absolute error (MAE), and the model efficiency (E; indicates how well a plot of observed and predicted values fit the 1:1-line; Nash and Sutcliffe, 1970) were calculated to assess the performance of the N uptake predictions.

Results and Discussion

According to statistics from the Swedish Meteorological and Hydrological Institute (SMHI, Norrköping, Sweden) it was an unusually cloudy and rainy spring in southern Sweden in 2015 and that limited the cloudless areas of the satellite scenes. Despite this, it was possible to acquire at least three cloud-free images for 2/3 of the agricultural area during the time window (Figure 2). In some areas, up to eight cloud-free images were acquired. Among the most intensively cultivated districts, it was only one region (Halland in the southwest) in which there were only two useful images. There were more than 4000 users of the CropSAT service and about 1500 variable-rate N application files were downloaded.

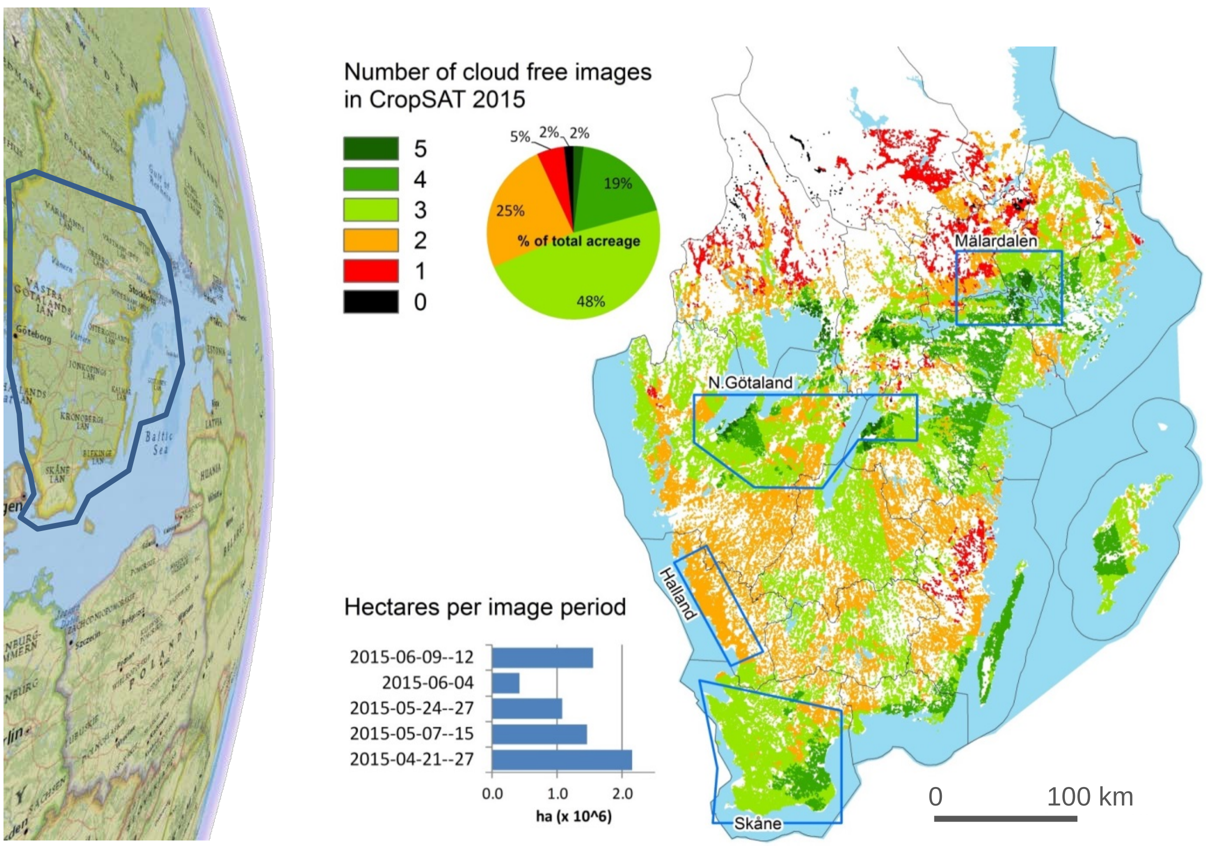

Fig 2. Map of southern Sweden displaying the number of cloud-free satellite images in CropSAT per agricultural field in 2015. The four areas marked are the initial focus areas of the CropSAT system which are intensively cultivated districts. The dates shown are written yyyy-mm-dd -- dd.

Comparisons between vegetation indices calculated in the satellite imagery from DMC and N uptake as estimated from measurements done by the handheld N-Sensor showed that SAVI and MSAVI2 performed best and was linearly correlated with N uptake (r^2 = 0.77 in both cases), whereas for NDVI, the proclivity to become saturated were obvious (index values stabilizes around 0.9) already at an uptake of 50 kg N ha^{-1}. In total there were five winter wheat varieties and there was a tendency that different varieties of winter wheat had different reflectance characteristics, even though the dataset used in this study was too limited to draw final conclusions.

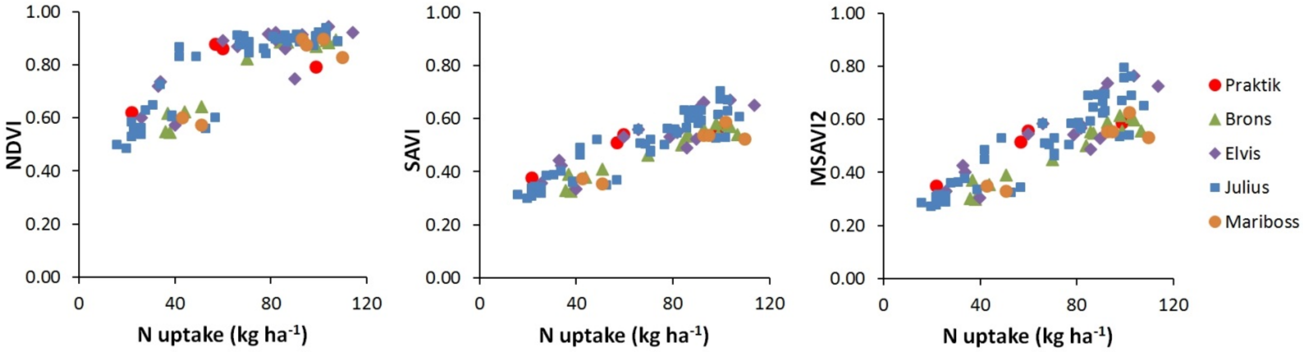

Fig 3. Nitrogen uptake in winter wheat (five varieties) in southwest Sweden, as estimated from the handheld N-sensor, plotted against different vegetation indices (NDVI, SAVI and MSAVI) derived from DMC satellite images. Measurements were done in 26 fields, April-June 2015.

CropSAT has an interactive user interface; it is the user who interprets the vegetation index maps and interactively creates maps of N fertilization. An issue for future developments of the concept is to better assist the farmer with the conversion from vegetation index to fertilization rate. One possible approach is to use ground-based sensors to estimate N uptake during the season for supplementary fertilization and translate vegetation indices to the amount of N in the crop canopy, using the ground-based reference measurements collected to date. A first attempt was made with the present dataset. By cross-validating (leave-one-field-out) regression models between DMC satellite MSAVI2 and the N uptake from handheld N-sensor measurements, we could asses the general performance of MSAVI2 for predictions of N uptake during the season 2015. Parameterized relationships were based on data up to the date of a satellite image, so the results simulated a possible practical application with a continuous data collection and calibration. In this test we used both fields with all varieties and, separately, those with one of the most common winter wheat varieties in our dataset (cv. Julius, SW Seed, Sweden). The validation statistics are shown in Table 1, and predicted versus observed values for the Julius variety are shown in Figure 4. Overall model efficiencies (E) and mean absolute errors (MAE) were as follows: Julius: 0.80, 9.6 kg N ha^{-1}; all varieties: 0.74, 12.7 kg N ha^{-1}.

Tab. 1. Validation statistics of nitrogen uptake predictions. Models were parameterized with observations collected up to each date and validated by leave-one-field-out cross-validation (n = number of field observations to the specified date; BBCH = crop development stage (Lancashire et al. 1991); MAE = mean absolute error; E = model efficiency).

Date	n	BBCH	MAE	E
All varieties				
21-April	26	22-31	9.8	-0.10
15-May	52	32-33	10.1	0.76
27-May	58	37	11.3	0.70
10-June	74	43-53	12.7	0.74
cv. Julius (SW Seed)				
21-April	14	22-31	8.6	0.18
15-May	28	32-33	9.0	0.77
27-May	31	37	9.9	0.74
10-June	38	43-53	9.6	0.80

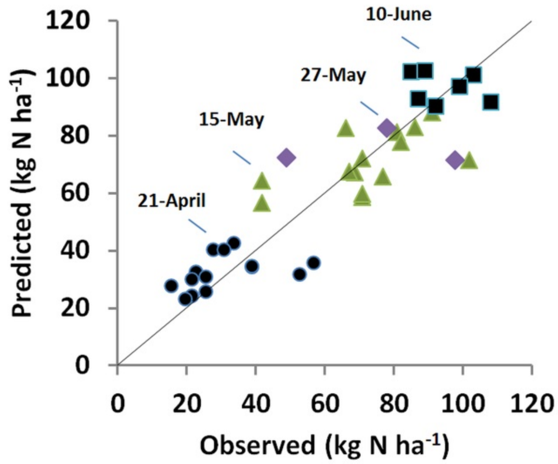

Fig 4. Nitrogen uptake, as measured by handheld Yara N-Sensors, predicted from the modified soil adjusted vegetation index (MSAVI2) estimated from DMC satellite imagery. Prediction models were successively parameterized during the season. The results are from a temporal leave-one-field-out cross-validation (see also Table 1). The 1:1 line indicates perfect correlation.

An important question that arises in this type of decision support system is if not entirely new images can be useful. In this system, it is only the relative, within-field variation that is presented, and the interpretation of the different index values are left to the user (Figure 5). In some cases, the spatial variation pattern is very stable and a map is more or less similar during a few weeks time. In other cases, changes in the pattern may occur quicker. Therefor, we recommend that users do field checks to investigate if the map seems to display the current pattern. The level of N need should preferably be decided at a few strategically selected locations in the field through the use of tools such as the Yara N-Tester (which is based on the Minolta SPAD-meter and measures light transmitted by the plant leaf at 650 and 940 nm [Uddling et al 2007]) that can assist in providing an N recommendation to the user. The successful combination of remote sensing data and chlorophyll meters has been reported e.g. by Miao et al. 2009. Obtained N values are inserted into CropSAT and a VRA file is generated and can be downloaded and used for controlling the spreader.

In 2016, publicly available data from the first of the two Sentinel-2 satellites were available in CropSAT. With a high spatial resolution, and additional bands in the red-edge region (Figure 1), we envisage that satellite based decision support systems such as CropSAT will be even more important tools in precision agriculture in the near future. CropSAT is a good example of a low-cost system that was made possible through collaboration between governmental agencies, university researchers, private companies and advisory organizations.

Summary

It is possible to use satellite data for applied N status assessment also in cloud-infested areas such as Scandinavia. The CropSAT vegetation index maps from satellites can be used for site-specific adjustment of N fertilizer in the fields. It is likely that there is a need for near daily revisit time of satellites in order to be able to acquire enough useful images for operational systems. Satellite images are very cost-effective in providing crop status data to farmers (for CropSAT in 2015 about 0.02 Euro ha^{-1}, estimated for the area covered by at least three images). Repeated ground-calibrations by handheld sensors during the season might be a viable approach to provide not only index maps but also N uptake maps. In a first test the prediction error was ~ 10 kg N ha^{-1}.

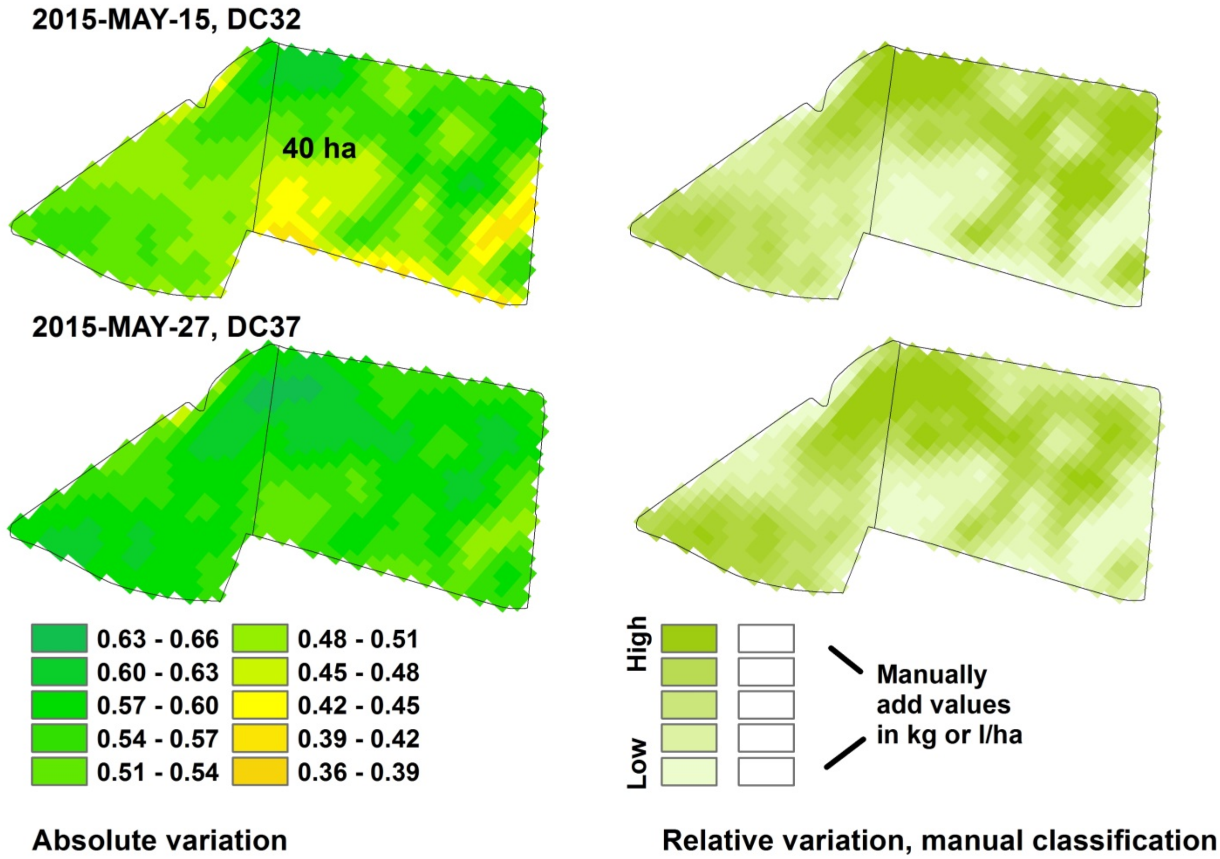

Fig 5. Example of absolute and relative within-field variation of MSAVI2 at one 40-ha winter wheat field at two dates. In CropSAT, the user classifies the relative map through inspection of the crop at a few locations with different index values.

Acknowledgements

CropSAT was developed in a project financed by the Swedish Foundation for Agricultural Research (SLF; project no. H1233115). Funding for 2015 and 2016 was provided by Focus-on-Nutrients (Swedish Board of Agriculture), and Agroväst Livsmedel AB.

References

Jensen, A., Lorenzen, B., Østergaard, H. S., & Hvelplund, E. K. (1990). Radiometric estimation of biomass and nitrogen content of barley grown at different nitrogen levels. International Journal of Remote Sensing, 11, 1809–1820.

Huete, A. (1988). A soil adjusted vegetation index (SAVI). Remote Sensing of Environment, 25, 295–309.

Lancashire, P. D., Bleiholder, H., van den Boom, T., Langeluddeke, P., Stauss, R., Weber, E., et al. (1991). A uniform decimal code for growth stages of crops and weeds. Annals of Applied Biology, 119, 561–601.

Link, A., Panitzki, M., & Reusch, S. (2002). Hydro N-Sensor: Tractor-mounted remote sensing for variable nitrogen fertilization. In P. C. Robert (Ed.), Proceedings of the 6th International Conference on Precision Agriculture (pp. 1012–1018). Madison, USA: ASA/CSSA/SSSA (published on CD).

Miao, Y., Mulla, D.J., Randall, G.W, Vetsch, J.A., & Vintila, R. (2009). Combining chlorophyll meter readings and high spatial resolution remote sensing images for in-season site-specific nitrogen management of corn. Precision Agriculture, 10, 45–62.

Mulla, D.J. (2013). Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering, 114(4), 358–371.

Nash, J.E., & Sutcliffe, J.V. (1970). River flow forecasting through conceptual models part I: a discussion of principles. Journal of Hydrology, 10, 282–290.

Qi, J., Chehbouni, A., Huete, A. R., Keer, Y. H., & Sorooshian, S. (1994). A modified soil vegetation adjusted index. Remote Sensing of Environment, 48, 119–126.

Reusch, S. (2003). Optimisation of oblique-view remote measurement of crop N-uptake under changing irradiance conditions. In J. V. Stafford & A. Werner (Eds.), Precision agriculture (pp. 573–578). Wageningen: Wageningen Academic Publishers.

Rouse, J. W., Jr., Hass, R. H., Schell, J. A., & Deering, D. W. (1973). Monitoring vegetation systems in the Great Plains with ERTS. In Proceedings Earth Resources Technology Satellite (ERTS) Symposium, 3rd., Greenbelt, MD, 10–14 Dec 1973 (Vol. I, pp. 309–317). Washington, DC: NASA SP-351, NASA.

Solie, J. B., Stone, M. L., Raun, W. R., Johnson, W. R., Freeman, K., Mullen, R., et al. (2002). Real-time sensing and N fertilization with a field scale GreenSeekerTM applicator. In P. C. Robert (Ed.), Proceedings of 6th international conference on precision agriculture (pp. 1466–1476). Madison, USA: ASA/CSSA/SSSA (published on CD).

Uddling, J., Gelang-Alfredsson, J., Piikki, K., & Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. Photosynthesis Research, 91, 37–46.

Wang, K., Franklin, S.E, & Guo, X. (2010). The applicability of a small satellite constellation in classification for large-area habitat mapping: a case study of DMC multispectral imagery in west-central Alberta. Canadian Journal of Remote Sensing, 36(6), 671–681.

Wiegand, C. L., Richardson, A. J., Escobar, D. E., & Gerbermann, A. H. (1991). Vegetation indices in crop assessments. Remote Sensing of Environment., 35, 105–119.