Training Program

on

Use of GreenSeekers® Optical Sensors for Studying the Crop Response Index, In-season Estimated Yields (INSEY), Fertilizer Response and in Other Applications

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With

Course Material Supplied by Bram Govaert and Ir. Nele Verhulst

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What is GreenSeeker®?

GreenSeeker® is an integrated optical sensing and application system that measures crop status and variably applies the crop's nitrogen requirements. Yield potential for a crop is identified using a vegetative index known as NDVI (normalized difference vegetative index) and an environmental factor. Nitrogen (N) is then recommended based on yield potential and the responsiveness of the crop to additional nitrogen.

The GreenSeeker® applies the right amount of N at the right place and at the right time thereby optimizing yield and N input expense.

How does the sensor work?

The sensor uses light emitting diodes (LED) to generate red and near infrared (NIR) light. The light generated is reflected off of the crop and measured by a photodiode located at the front of the sensor head.

What is NDVI?

Normalized Difference Vegetative Index (NDVI) is commonly used to measure plant health and vigor.

NDVI is calculated using the equation (NIRreflected - Redreflected)/(NIRreflected + Redreflected).

How does the sensor determine crop status?

GreenSeeker® calculates NDVI using red and NIR light. Red light is absorbed by plant chlorophyll as an energy source during photosynthesis. Therefore, healthy plants absorb more red light and reflect larger amounts of NIR than those that are unhealthy. NDVI is an excellent indicator of biomass (amount of living plant tissue), and is used in conjunction with growing degree days greater than zero (GDD>0) or days from planting to accurately project yield potential.

Why not use ambient light instead of an active LED light source?

Several problems exist when using the sun as a light source. The sun's intensity is affected by sun angle, cloudiness, haziness, etc., conditions which can cause inconsistent NDVI measurements. NTech developed an active sensor that generates its own illumination source to measure NDVI. In fact, the sensors function in nearly any condition including darkness, dramatically extending the application period.

Why is a nitrogen rich strip necessary?

Long-term research has determined that the amount of N required to achieve maximum yield varies significantly from year to year. Reducing pre-plant N application and using the N rich strip to establish a rich N environment allows a mid-season determination of additional N requirements. If the crop is capable of using additional N, the sensor will determine the magnitude and generate an N recommendation based on the predicted yield.

What is response index (RI) and how is it estimated?

RI is an in-season quantitative measure of the response to additional N for each field environment. Using the RT200 or a Handheld sensor, NDVI readings are collected from the nitrogen rich strip and the field rate to determine the benefit of additional N. To determine the response index we simply divide the NDVI from the N rich strip by the NDVI value of the field rate. This ratio provides an indication of how the crop will respond to additional N.

What N rate should be used in the N rich strip?

The rate for the nitrogen rich strip should be large enough to achieve the field's typical yield goal. This amount is crop and region dependent. For example, many winter wheat recommendations are based on an assumption that each bushel of grain produced requires 2 lbs. of N. Assuming a 40 bushel yield goal, an 80 lb. N recommendation is suggested. In this case, an N rich environment of 96 lbs (80 lbs x 1.2) of N should be applied.

What size strip should be used for the nitrogen rich strip?

The ideal strip would be an applicator boom width down the middle of the entire field. The N rich strip should be 300 to 500 feet long in a representative area of the field (not in a bottom, or an upland), or the N rich strip should run across several field "identifiable" management areas, such as different soil types or topography.

Does each field need an N rich strip?

Yes, to achieve optimal success, each field needs an N rich strip, just as conventional N management requires a soil sample from each field. The N rich strip integrates the effects of past field management, current field management (e.g. planting date, variety, etc.) and soil differences in the field on crop response to N. These factors often differ greatly from one field to another.

What other crops is NTech working on?

Algorithms have been developed for winter wheat, spring wheat and corn. . Researchers are also developing algorithms for potatoes, sugar beets, durum wheat, canola, barley, cotton, turf, and sunflowers.

What mapping capabilities does the system have?

GreenSeeker Application systems can produce a crop heath and vigor map with boom width resolution during fertilizer variable rate applications, or during any other farming operation. The pixel size determined by the boom width and ground speed. The system can produce "As Applied" maps (the amount of material applied) and "NDVI" maps. Using these maps, problem areas requiring other inputs and management decisions can be identified.

How are sensor readings taken of the N rich strip and the rest of the field?

The sensors on the RT200 boom can be used to take the N rich strip readings. This can be done with the three left or right sensors, or all sensors on the boom. The GreenSeeker Hand Held sensor can also be used to take the N rich strip readings.

What about leaf burn?

Top dress leaf burn can be an issue if a high rate of N is applied during periods of high temperature and humidity. NTech recommends using a streaming nozzle, or similar delivery system, to allow the solution to flow off of the plant, exposing only a small amount of plant tissue to possible burning. NTech recommends avoiding application when the plant tissue is wet and during the heat of the day. Remember, the system uses its own illumination source and can also function at night.

How is the N recommendation determined?

Sensor readings are used to measure both predicted crop yield potential, and crop response to additional N. These two factors, in addition to generally accepted N requirements per bushel, determine N recommendations and application rate.

Why do NDVI readings taken at different heights above the crop canopy remain constant? And, how does the sensor integrate a 24" wide area at different heights above the crop?

NDVI readings remain similar through the 32-48" range because the computation is actually a normalized ratio. Even though the intensity of the light source decreases as it moves farther away from the crop canopy, the sensor proportionally adjusts and therefore, NDVI readings are not affected by height variance. Also, optical masking and position of the sensor LEDs allows the sensor to view only a 24" wide strip regardless of the sensor height.

Does the sensor differentiate between weeds and the crop?

Today, the sensor does not differentiate between weed and crop species.

Can the OS technology be extended to crops with indeterminate plant growth habits, such as Cotton and Rapeseed?

The research is underway for in-season yield estimates for these crops. Preliminary results are encouraging but the technology is still immature. It requires more intensive research work .

Can fertilizer and crop protection chemicals be applied simultaneously?

Yes. NTech's RT Commander software has an injection system option designed to allow the use of a secondary boom for flat rate application of liquid fertilizer as a "carrier" for the chemical, and use the sprayer's existing wet boom for variably applying N with the GreenSeeker®. The N solution used as the carrier fluid in the existing wet boom and is set at a low rate in comparison to the range of rate the GreenSeeker® system uses. This may require addition of additional rate control equipment.

When is wheat spraying recommended?

NTech recommends N application at the 5 to 6 leaf stage (Feekes 5, GS 30) for wheat. Corn should be V-8 to V-12.

Does the sensor work on dormant wheat?

If the crop is brown (no green pigment) the sensor does not have the ability to recognize yield potential. The crop must be green for the sensor to function.

Does system operation require GPS or yield maps?

GreenSeeker® can apply with or without the use of a GPS signal, and does not rely on historical information or mapping to make an N recommendation. The sensor system determines the yield potential and uses the response index from the field to determine atop dress N rateŠ. in-season and on-the-go. However, the mapping system of GreenSeeker® does require the use of GPS for data logging.

Can distinct management zones within the field be identified and used to determine response indexes for each zone?

Potentially. NTech's research has treated the field as a single unit to determine responsiveness to additional N and adjust N inputs based on yield potential variability in that field. The GreenSeeker® system generates outstanding results but further management zone research may prove useful.

Does soil affect the NDVI value? How does GreenSeeker® address the impact of bare soil?

Soil NDVI values are much less than a living plant. This relative difference is what allows the sensor to determine biomass accurately. Current wheat and corn algorithms require at least 50% of the 24 inch field of view of each sensor is covered by vegetation. Typically, 5 to 6 leaf wheat has reached adequate coverage to get a reliable reading. Corn should be V8 to V-12.

Does dust affect the sensor reading?

Dust will not normally affect the NDVI readings because dust impacts the reflectance of red and NIR similarly. The RT200 system monitors the sensors for proper operation, if a sensor reports erroneous data, the data is not include in the calculation for fertilizer rate control. The GreenSeeker® diagnostics will also provide a warning if a sensor is "blinded". The operator should wipe the sensor's lenses clean each time he/she checks the nozzles.

What if it does not rain after fertilizer application? Is the crop able to take up the N?

Moisture availability is a concern in all top dress application. However, if the N source used is UAN, a portion of the solution (nitrate) can move readily into the surface soil after application and be plant available quickly.

Nitrogen is cheap and it is less costly to apply more N rather than investing in a variable rate application system. Why not continue to use pre-plant N?

Anhydrous ammonia is inexpensive, approximately $0.28/lb., and it is often considered appropriate to apply 100 lbs. of pre-plant N (wheat) and ignore the in season crop N needs. Pre-plant application of N is extremely inefficient (~33%). Prior to the 5 leaf stage, wheat's N needs are small and high rate pre-plant application of N is potentially wasted because the crop will not use it. The unused portion of the N that remains in the soil is often lost before the crop is able to use it. This may result in N stress later in the growing season and, ultimately, yield losses.

The amount of N supplied by the soil is not well understood and unpredictable. The organic fraction of soil is a huge reservoir of N. In fact, 1% organic matter contains about 2,000 lbs. of N per acre. If the organic fraction of N is mineralized and made plant available, the need for supplemental N is reduced or precluded. The GreenSeeker® saves unnecessary expense by applying the optimum amount of N for the soil conditions, thus eliminating excess expense and alleviating environmental effects.

The yield potential for any crop in a specific environment is not known until the season is underway. If N was applied to generate a 50 bushel wheat crop but only 27 bushels are harvested, what happens to the rest of the N? Will it be available for subsequent crops? Maybe, maybe not, depending on the environment. If the soil was able to support 24 of those 27 bushels, how much N is needed? If 20 lbs. of N would have generated the 27 bushel yield and 100 lbs. pre-plant was applied (hoping for a 50 bushel year), then the grower spent an unnecessary $12/acre by over-applying N. This example demonstrates how expensive excess application can be.

How durable is the GreenSeeker® system in a fertilizer and ag chemical application environment?

GreenSeeker's® electrical system consists of electronic control units (sensors and control boxes) and wiring harnesses. Both elements utilize components that have been proven in harsh environments. The sensor uses the same housing as does NTech's WeedSeeker®, which has been marketed for years. This housing undergoes an intensive sealing and testing procedure during assembly, including pressurization and leak tests to ensure the unit is air tight.

The system's control boxes are NEMA 4X rated (industry standard), which ensures liquid free sealing characteristics. All wiring harnesses utilize highest quality connectors that are fully sealed. These connectors are commonly used on agricultural equipment, HD off-road equipment, and in many industrial applications that operate in harsh and/or difficult environments. NTech engineers made electrical security one of the leading design requirements and have delivered a durable and very reliable system.

What happens when a sensor hits a tree, fence post, or the ground?

It is inevitable that the boom will strike something during the spray season. The ideal approach would be to carry a spare sensor in the cab for emergencies. The sensor can be replaced in 15 minutes by removing two bolts and one or two cable connections. The damaged sensor should be sent to the company/distributor for repair. Frequently, only the housing will need repair, a minimal expense. NTech offers an extended 5 year service program on the sensors. If a sensor is not covered by the initial warranty program, the company will replace it for $500 regardless of failure reason.

The RT200 system monitors the sensors for proper operation, if a sensor reports erroneous data, the data is not include in the data used for fertilizer rate control.

Why purchase this system?

The GreenSeeker® system maximizes your return on investment in nitrogen. If ideal growing conditions promise a high yield, enough N is applied to achieve that yield. If the environment will not support a large yield, nitrogen will not be wasted. Testing has proven that GreenSeeker® generates $8 to $10 average return per acre on winter or spring wheat, and an $18 per acre average for corn. This is based on higher yields and/or reduced N expense. Research and field data also indicates that some years the savings would be double these numbers.

Placing a dollar figure on the environmental savings is difficult, but the impact that GreenSeeker® technology will have is immense. Pre-plant application of N is extremely inefficient (~33%), GreenSeeker® data suggests that over 50% nitrogen use efficiency is possible. Applying the correct amount of N, at the right place and at the right time will decrease excess application and alleviate ground and surface water contamination without reducing yield. GreenSeeker® technology can help ensure a better quality of life for growers, their families and the general population.

Will the government help?

Government incentives help make the GreenSeeker® system even more attractive. The Environmental Quality Incentive Program (EQIP) and the Conservation Security Program (CSP) included in the Farm Bill are geared to systems like GreenSeeker®.

The amount of money available to adopt new nutrient management technologies varies by location. Contact the local NRCS office to determine the exact monies available.

A Stepwise Procedure for Predicting N requirements

(A Hypothetical Example)

Table 1 Layout of the experiment for calibration of Optical sensors for N response

No	**No**	**N30**	**N60**	**N90**	**N130**	**N160**	**N200**
R1							
R2							
R3							
R4							

Steps

1 Lay out an experiment with reps and N level as shown above Table 1.
2 Take NDVI observations at different dates after emergence (DAE), from each subplot with different Nitrogen application rates, at some regular interval Note the emergence date correctly or else use date of planting/ sowing date. Else use the planting date as reference.
3 Count the Number of vegetation period from the emergence date or planting date, taking into account only the vegetation period with the Growing Degree Days (GDD) higher > 0
4 GDD = [(Tmin + Tmax)/2] – 4.4°C >0

Table 2 **NDVI Measurements: Replication-I**

NDVI Readings Days after first emergence*	**No**	**N30**	**N60**	**N90**	**N130**	**N160**	**N200**
15							
30							
45							
60							
75							
90							
105							
120							

*Exclude the non-vegetation period (snow period) when GDD< 0 or count the period as vegetation period when GDD>0 as per equation below:

GDD = (Tmin + Tmax)/2 – 4.4°C>0)

Where, Tmin, T max are minimum and maximum air temperature expressed in ^{o}C.

1 **Fill the Table 2. (above) from actual field data on NDVI Measurements**
2 **Calculation of Response Index (RI) using equation:**

$$RI = (NDVI_{NRS}/NDVI_{i=0;\ n\ \text{and}\ d=0,\ n})$$

Where $NDVI_{NRS}$ refers to NDVI of the N- Rich strip or plot where N is maximum and there is no N deficiency (hidden or otherwise. $NDVI_{i=0;\ n\ \text{and}\ d=o,\ n}$ refers to NDVI of each N treatment and Replication on different dates from initial date of emergence.

Table 3 Response Index calculations:

Response Index at different days after emergence	**Replication -I**							**R-II**	**RIII**
	No	**N30**	**N60**	**N90**	**N130**	**N160**	**N200**		
15									
30									
45									
60									
75									
90									
105									
120									
Crop Yield Mg/ha									

Fill the above table with the calculated data and if possible plot all the data points on a graph and show the average trend line.

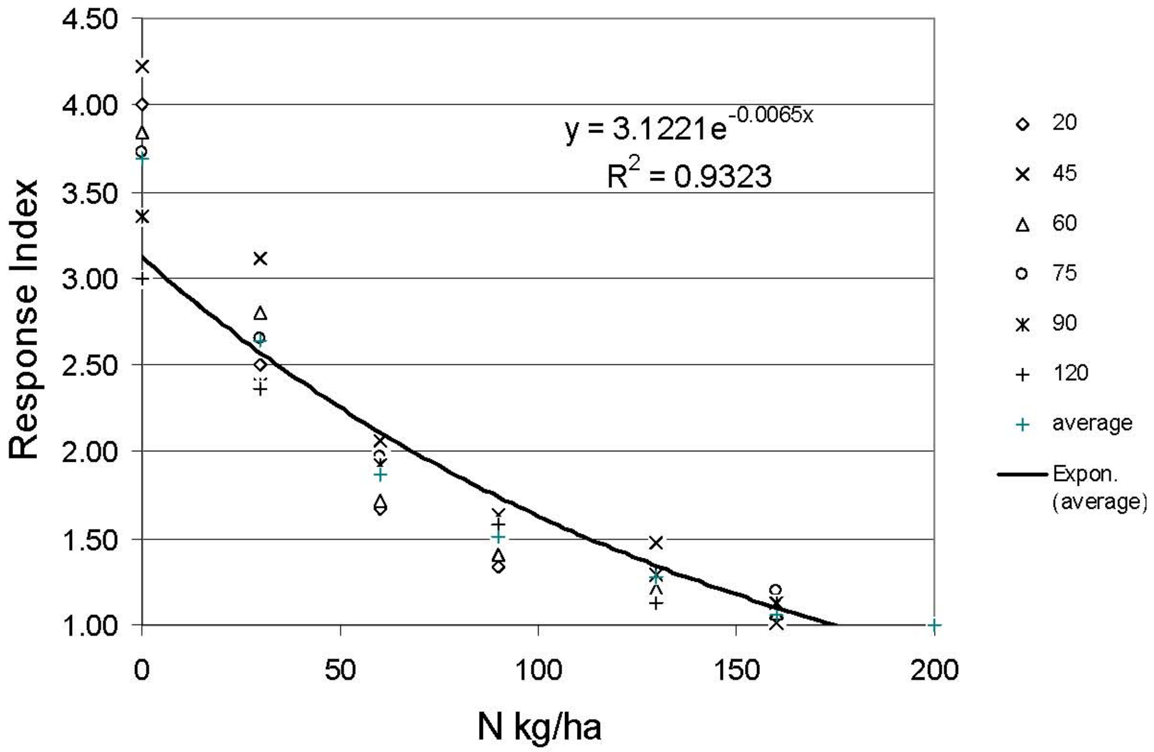
Figure Response Index as function of Nitrogen fertilizers application rate

6. Calculation of INSEY (In Season Estimated Yield) using following equation:

INSEY= NDVI$_{i=0;n;\ D=0,n}$ / DAS Where DAS or DAE = Days after **sowing** or **emergence** as the case may be) Calculate the INSEY Table 4 INSEY data calculations:

Note: If there is a non-vegetation period of (say of 40days where GDD <0) discount this 40days period from the total days from emergence to till time of taking the specific reading.

Nitrogen level	Days after sowing								Crop yield, Mg/ha
	15	30	45	60	75	90	105	120	
N0									
N30									
N60									
N90									
N130									
N160									
N200									



1. Collect crop yield data from all the N level plots and treatment replications.

Table 5 Crop yield data (Rep 1-Rep 4)

Crop yield, Mg /ha	**No**	**N30**	**N60**	**N90**	**N120**	**N150**	**N200**
R1							
R2							
R3							
R4							
Average							

1 **Plot all the INSEY at different dates against averaged crop yield data for different N levels on a graph describing yield as function of INSEY.**

6. Establish equation describing Yield as function of the INSEY.

30
▲ 60
◆ 20
× 40
✱ 50
80 95 110 average Expon. (average)

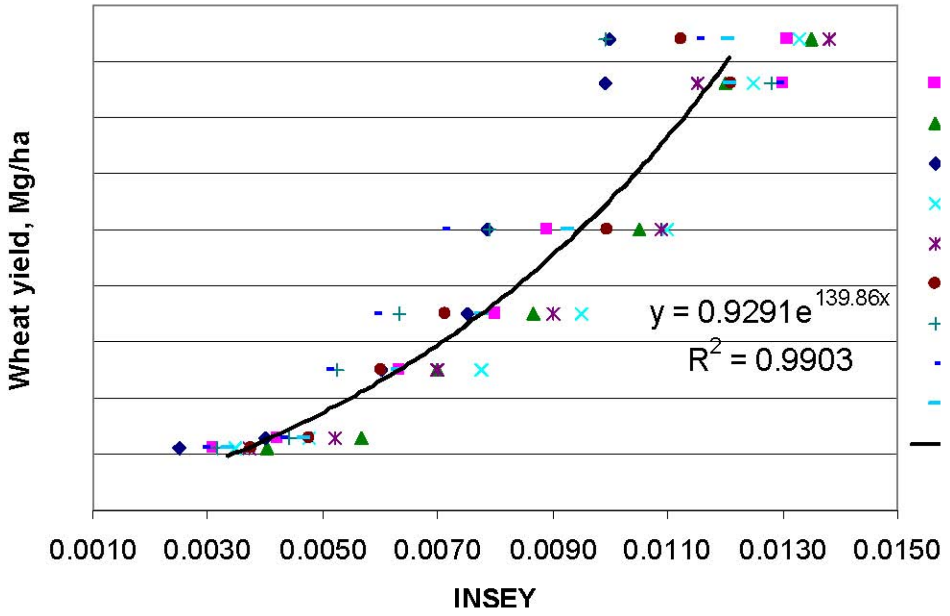


Figure. Yield as function of the INSEY

Important: For different days after planting run a correlation to find out the days after sowing when correlation between INSEY and grain yield or biomass is maximum.

Methods for prediction of Maximum crop yield based NDVI data
Explanation of the Terms commonly Used

1 Sense the N Rich Strip (NRS) or plot where N is maximum and there is no N deficiency
2 Sense a strip parallel to the NRS (Farmer Practice or FP)
3 Determine how many days from planting to sensing (days, GDD>0)
4 Compute INSEY (NDVI/days from planting to sensing where GDD>0)
5 Predicted yield YP0 = Predicted or potential yield based on growing conditions up to the time of sensing, that can be achieved with no additional (topdress) N fertilization (units: Mg/ha). For this purpose equation should be developed YP0= Function (INSEY) or use ready equations developed in Oklahoma University for winter wheat

YP0 = 0.5902*EXP(INSEY*258.2

6. YP_N = Predicted or potential yield that can be achieved with additional (topdress) N fertilization based on the in-season response index (RI_{NDVI}) (units: t/ha) = (YP0)*(RI_{NDVI})

Generating a Fertilizer N Rate Recommendation

- RINDVI= NDVI from plots receiving adequate but not excessive preplant N, divided by NDVI from plots where no preplant N was applied
- Computing Grain N Uptake at YP0 and YPN: The predicted amount of N that will be removed in the grain at harvest (using our equation generated from 1E) is computed as follows:

Grain N uptake, YP0 = Grain Yield (YP0) * expected % N in the Grain or Forage
GNUP_YP0 = YP0*0.0239 GNUP_YPN = YPN*0.0239

Where 0.0239 represents (0.0239 kg N uptake / kg grain 0r 2.39% N in the grain for winter wheat grown in Oklahoma.

For example, if YP0=3000 kg/ha, and desired yield is YPN=6000 kg/ha than GNUP_YP0 = YP0*0.0239=71.7 kg/ha GNUP_YPN = YPN*0.0239 =143.4 kg/ha. N= GNUP_YPN- GNUP_YP0=143.4-71.7=71.7 kg/ha

- Computing the Final Fertilizer N Rate: The fertilizer N rate to be applied is computed by subtracting the predicted amount of N to be removed in the grain at YP0 from the predicted amount of N to be removed in the grain at YPN, divided by Nitrogen use efficiency. This value can range anywhere from 50% to 70%.

-
- By dividing N to NUE or 71.7/0.6=113.6 kg/ha we get amount of fertilizer rate should be added into the soil in order to achieve potential crop yield of 6000 kg/ha.
- In excel sheet all steps and procedures to compute N requirements are demonstrated.

Vegetation Indices Available in the GreenSeeker® Sensor

There are several vegetation indices defined, evolving from more than thirty years of research in remote sensing and aerial imaging. In precision agriculture applications, two of the most commonly used indices are the Ratio and the Normalized Difference (NDVI), each comparing the relative reflectance of plant material and soils at two wavelengths. Additional modifications of the indices have been developed to compensate for various conditions of the plant canopy and background soil.

Five indices are available from the NTech Industries GreenSeeker® Sensors. The sensor always outputs NDVI, plus an additional index (default is IRVI), which makes it possible to *compare indices on the same data at the same time*. This can be changed by connecting the sensor directly to a computer. Once selected, the output options are stored in the sensor, and remain in effect until explicitly changed.

NDVI	Normalized Difference Vegetation Index
SA-NDVI	Soil Adjusted
WDR-NDVI	Wide Dynamic Range
RVI	Ratio
IRVI	Inverse Ratio

Index Equations

The wavelength bands are in the visible and infra-red (NIR) regions of the spectrum. Sensors output at ~660nm (Red) and ~770nm (NIR). Half-power bandwidths are approximately 25nm.

$ndvi = \frac{\rho_{NIR} - \rho_{VIS}}{\rho_{NIR} + \rho_{VIS}}$	Normalized Differential Vegetation Index
$sa\,ndvi = \left(\frac{\rho_{NIR} - \rho_{VIS}}{\rho_{NIR} + \rho_{VIS} + L}\right)(1 + L)$	Soil-Adjusted NDVI
$wdr\,ndvi = \frac{a\rho_{NIR} - \rho_{VIS}}{a\rho_{NIR} + \rho_{VIS}}$	Wide Dynamic Range NDVI
$rvi = \frac{\rho_{NIR}}{\rho_{VIS}}$	Ratio (NIR/RED)
$irvi = \frac{\rho_{VIS}}{\rho_{NIR}}$	Inverse Ratio (RED/NIR)

The 'a' and 'L' values for the SA and WDR indices, respectively, are entered and stored in the Sensor. SA-NDVI reverts to NDVI if L = 0, and WDR- NDVI reverts to NDVI if a = 1. Typical value for a is 0.1; typical value for L is 0.5.

References

University of Sheffield Remote Sensing: GEO6370 Vegetation Indices
http://www.shef.ac.uk/~bryant/6370/veg/vegsoil.htm

U.S. Water Conservation Laboratory: How a Vegetation Index Works
http://www.uswcl.ars.ag.gov/epd/remsen/Vi/VIworks.htm

Mark Servilla: The First Steps to Understanding Agriculture Remote Sensing
http://www.eomonline.com/modernagsite/archives/Servilla.html

USGS: Wide Dynamic Range VI application
http://www.gap.uidaho.edu/Bulletins/12/The Wide Dynamic Range Vegetation Index.htm

BGR: A Comparison of Slope-Based Vegetation Indices for Agricultural Applications
http://www.biogeorecon.com/vegindcs.htm

Other Applications Discussed some examples :

Some examples discussed:

1 Effect of precision laser assisted land leveling on crop yields and crop cover (NDVI) and water used.
2 Spatial variability due to salinity as measured by using Optical sensors (NDVI measurements).
3 Developing Growth curves for the dual purpose wheat.
4 Estimation of biomass in pasture lands
5 Effect of crop cover on runoff losses of soil (soil erosion)

For any additional information, participants can consult their lecture notes and the CD provided to them or visit the web site of the Okalahoma State University or of the NTech Inc.

GreenSeeker Optical Sensor Training Program

February 3-7, 2008 Hotel Shodlik, Tashkent

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The NDVI sensor, toward the integrated evaluation of crop management

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The NDVI sensor, toward the integrated evaluation of crop management

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Table of contents

Introduction

Presentation

- B. Govaerts, N. Verhulst, K. D. Sayre, W. Raun, J. Deckers. The NDVI sensor Introduction and in season nitrogen prediction. CD-ROM *Session 1 Introduction*

A. Plant reflectance and NDVI

Reflectance

Reflectance is the ratio of the amount of energy reflected from an object to the amount of energy incident on the object. Plants generally have low reflectance in the blue and red portion of the spectrum because of chlorophyll absorption, with a slightly higher reflectance in the green, so plants appear green to our eyes. Plants reflect almost half of the incident radiation in the NIR portion of the spectrum.

Vegetation Indices

The amount of energy reflected from a plant in the visible and near infrared (NIR) portion of the spectrum has been correlated to many crop characteristics. These characteristics include chlorophyll content, light use efficiency and canopy density. The most common application of reflectance data is the generation of vegetation indices (VIs), such as the normalized difference vegetation index (NDVI). The NDVI is calculated from reflectance measurements in the red and NIR portion of the spectrum:

$$NDVI = (NIR - Red) / (NIR + Red)$$

The NDVI has been correlated to many variables such as crop nutrient deficiency, final yield in small grains and long-term water stress. While in one sense these correlations are valid, it should be noted that it is very likely that the physical characteristic actually being detected by the index is related to some measure of canopy density (i.e. leaf area or percent cover) or total biomass. For example, in a field where nitrogen is the limiting factor to growth, the NDVI may show a strong correlation with plant nitrate content; however, in another field, where water is the limiting factor, NDVI may be just as strongly correlated with plant available soil-water. This does not mean such a relationship is not meaningful. It is, however, important to remember that the underlying factor for variability in a typical vegetation index cannot be blindly linked to a management input without some knowledge of the primary factor limiting growth. There are many versions of different vegetation indices; however, those that rely on NIR and red reflectance as the principal input will typically yield the same information as the NDVI. One of the reasons for the popularity of the NDVI is that many sensors (from hand-held to satellite) provide measurements in the NIR and red portion of the spectrum. NIR is also used in color infrared photographs. Most (if not all) of the new commercial satellites will have red and NIR bands, so the availability of these data will increase.

The following article gives a good overview of the physiological background of different vegetation indices.

- Araus, J.L., Casadesus, J., Bort, J. 2001. Recent tools for the screening of physiological traits determining yield. In: Reynolds, M. P., Ortiz-Monasterio, J. I., McNab, A. (Eds.). Application of physiology in wheat breeding. Mexico D.F. CIMMYT. Pp. 59-77 CD ROM *Reynolds et al., 2001*

Further reading

- Jackson, R.D., A.R. Huete. 1991. Interpreting vegetation indices. Preventive Veterinary Medicine 11:185-200.

B. NDVI and remote sensing: a small review

Satellite-based NDVI are influenced by a number of non-vegetation factors: atmospheric conditions (e.g. clouds and atmospheric path specific variables, aerosols, water vapour), satellite geometry and calibration (view and solar angles), soil backgrounds and crop canopy (Holben 1986; Soufflet et al. 1991; Justice et al. 1991). The angle of incidence of solar radiation also has a strong effect on vegetation indexes (Pinter 1993). When NDVI is measured with a hand-held sensor (GreenSeeker™ hand-held optical sensor unit designed at the Oklahoma State University, USA) held closely above the crops, the disturbing effects of atmospheric interference and satellite geometry are avoided. Moreover, the hand-held sensor contains its own light source, allowing measurements to be taken at any time, day or night independent and without interference of sun light and sun stand. This is a great advantage compared to the satellite-based measurements. The high resolution obtained with this hand-held sensor makes proper measurement possible at the plot level in contrast with the low resolution typical for air or space remote sensing material. The handheld sensor is non-destructive and the sensor samples at a very high rate (approximately 1,000 measurements per second) and can easily and time-efficiently measure a whole plot representative area. There are, however, still important scopes for research on the comparison of the NDVI hand-held sensor with satellite imagery, especially when scaling out of results and models becomes important.

References

Holben, B.N. 1986. Characteristics of maximum-value composite images from temporal AVHRR data. Int J Remote Sens 7:1395–1416.

Soufflet, V., Tanré, D., Begue, A., Podaire, A., Deschamps, P.Y. 1991. Atmospheric effects on NOAA AVHRR data over Sahelian regions. Int J Remote Sens 12:1189–1204.

Justice, C.O., Eck, T.F., Tanré, D., Holben, B.N. 1991. The effect of water vapour on the NDVI derived for the Sahelian region from NOAA AVHRR data. Int J Remote Sens 12:1165–1188.

Pinter, P.J. 1993. Solar angle independence in the relationship between absorbed PAR and remotely sensed data for alfalfa. Remote Sens Environ 46:19–25.

Within season nitrogen prediction

Presentation

- B. Govaerts, K. D. Sayre, W. Raun, N. Verhulst, J. Deckers. The NDVI sensor Concepts behind and in season nitrogen prediction. CD-ROM *Session 2 Nitrogen Prediction*

The following information comes from the of Website Oklahoma state University http://www.nue.okstate.edu/

Yield Prediction Equation (synthesis)

1 Mark 10, 4m^2 areas in 10 different fields
2 Record planting date
3 Collect mid-season sensor readings (F4 to F6 in wheat, V8 to V12 in corn) and record date
4 On these 100 plots, no N fertilizer can be applied mid-season, or anytime after sensor readings are collected
5 Collect grain yield from all 100 plots
6 Determine INSEY (NDVI divided by the days from planting to sensing)
7 Establish relationship between INSEY and collected grain yield.
8 Equation in 7 can be used within the Sensor Based N Rate Calculator (SBNRC) to make fertilizer N rates

Algorithm covered under the following patents

1 Raun, W.R., G.V. Johnson, J.B. Solie, and M.L. Stone. 2003. Process for in-season fertilizer nitrogen application based on predicted yield potential. US Patent No. 6601341 B2. Issued, August 5, 2003
2 Stone, M.L., D. Needham, J.B. Solie, W.R. Raun, and G.V. Johnson. 2003. Optical spectral reflectance sensor and controller. US Patent No. 6596996 B1, Issued July 22, 2003.
3 Raun, W.R., G.V. Johnson, J.B. Solie, M.L. Stone, K.W. Freeman. Use of within-field-element-size CV for improved nutrient fertilization in crop production. US Patent No. (Pending).
4 Solie, J.B., M.L. Stone, and S.D. Reed, 2004. Nozzle attitude controller for spot and variable rate application of agricultural chemicals and fertilizers. U.S. Patent 9,912,230.
5 Raun, W.R., G.V. Johnson, J.B. Solie, and M.L. Stone. 2004. A process for in-season fertilizer nitrogen application based on predicted yield potential. U.S. Patent. 10,195,138 (Allowed). CIP of 6,601,341.

1. Predicting Mid-Season Yield Potential (YP0)

A. N-Rate Field Experiments: At multiple locations, experiments must be set up in areas where a response to applied N is likely or at least probable. It is important to avoid those sites where N is known to have been applied liberally over the years. At each site, 3 to 5 N rates (all applied preplant) should be evaluated with the highest N rate being chosen in order to be “non-limiting” throughout the growing season, but not in excess.

In general 100 to 150 kg N/ha applied preplant will be adequate for maximum yields (e.g., expected in winter wheat, but these rates could be as high as 400 kg N uptake/NUE)/ha, depending on the crop. Plot size: large enough to accommodate taking several sensor readings throughout the season, and where actual yield (grain and/or forage) data can be collected. Individual plots should be no larger than 10x10 ft or 3x3m.
Replications: 4 or more

B. NDVI readings using the GreenSeeker handheld sensor: NDVI stands for "Normalized Difference Vegetation Index" and it is the "sensor" value displayed on your GreenSeeker handheld. NDVI is computed by the following formula where each represents reflectance in the following bands (near infrared-red)/(near infrared +red). Many researchers have shown that NDVI is an excellent measure of total biomass. Sensor readings from each of the plots delineated in 1A need to be taken at or near the physiological growth stage where mid-season N applications are made. In winter wheat this is roughly near Feekes 5 (post dormancy when leaf sheaths begin to lengthen), and Feekes 6 in spring wheat (prior to first hollow stem). For corn, sensor readings need to be collected by plant or for every 2 plants, somewhere between the 10 and 12 leaf stages.

C. Days from Emergence: In order to generate an equation that functions over sites and years (multiple sites, planted at different times and sensed on different dates), it is critical that planting date and emergence date are recorded. This date is then used to compute the number of days from planting to sensing or emergence to sensing (site and crop specific). In regions where winter conditions are prevalent for much of the growing season, it is important to compute days where GROWING DEGREE DAYS (GDD) were more than 0. GDD = (Tmin + Tmax)/2 – 4.4°C (The value "-4.4 °C will change as a function of the crop's minimum heat requirement for active growth, so this value works for many "cool season" crops, but will be somewhat higher for warm season crops) where Tmin and Tmax are minimum and maximum daily temperatures, respectively.

D. Estimating Yield Potential: By dividing NDVI (estimate of total biomass) by the number of days from planting to sensing (or emergence to sensing), we basically end up with an estimate of biomass produced per day (note that to count a day, GDD must be >0 as noted above in 1C). This index (NDVI/days from planting to sensing or emergence to sensing) which is called INSEY (In Season Estimated Yield) is an excellent predictor of yield potential or the yield (grain or forage depending on the system) that is likely to result with no added inputs. This estimate of yield or yield potential is essentially the YIELD GOAL with no added fertilizer N.

E. Generating the Yield Prediction Equation: Once actual harvest data has been collected from each of the plots in 1A, and placed in the same data file and for the same corresponding plots where NDVI, planting date, sensing date, and INSEY (computed in D), an X-Y plot of yield versus INSEY needs to be made (see example data sheet below).

F. Recording the Response Index (RI) at each Site: At each location where the N-rate experiments defined in 1A are conducted, it is critical that mid-season RI's are recorded. To do this, average NDVI readings from the high N plots are divided by the average NDVI readings in the check plots (0-N preplant). Depending on the year, location and crop, RI's can be expected to range fom 1.0 to 3.0. This information will be used to later document 'responsiveness' to fertilizer N by site.

G. Determination of % N in the Grain or Forage of the Crop Investigated: In general the percent N removed in each grain or forage crop for specific regions is well known. However, if it is not, determining %N (using dry combustion or wet-acid-digest) is possible at any commercial laboratory. All you have to do is compile enough grain or forage samples (50-100), and submit them to the commercial lab, and compute the average. For winter wheat in Oklahoma, the percent N in the grain averages 2.39%, 1.18% for corn grain in Nebraska, and 2.45% for spring wheat in North Dakota. For the crop in question, just take enough samples, and that are representative of the varieties used in the region.

2. Predicting the Potential Response to Applied N

A. Nitrogen Rich Strips: A critical component of the algorithm is being able to precisely predict whether or not there will be an in-season response to applied fertilizer N and the magnitude of that response. The only way to do this is to place “PRE-PLANT” Nitrogen-Rich Strips (NRS) in each and every farmer field where FERTILIZER N RATE RECOMMENDATIONS are to be made. Preferably, the NRS should be placed from one end of the field to the other (somewhere in the middle and not on the outer edges where fertilizer applicator error can be problematic…. turning, double planting, etc). The width of the NRS will vary from one location to another, depending on how wide the fertilizer spreader is that is used. One pass through the center of each field is sufficient.

Application rate for the NRS should be high enough to ensure that nitrogen availability will not limit grain production. Once the NRS’s are established in farmer fields, researchers are encouraged to visit these sites to ‘observe’ the differences between the NRS and the farmer practice. The farmer practice does not need to conform to anything specific, except that the rate should be somewhat N-limiting (50% or less than the NRS) and, it would be useful to know how much N was applied preplant using his conventional methods, and that amount applied in the NRS. Depending on the location, NDVI readings (100-200 feet in length) will be collected sometime in the middle of the growing season (from both the NRS and the Farmer Practice (FP)) when “N Fertilizer Adjustments” can be made. In winter wheat this is generally 90 to 120 days after planting (Feekes growth stage 5), and in corn it is at the 8 to 12 leaf stage (40 to 50 days after planting). This will be highly dependent upon the crop in question and the region where it is grown.

B. Computing the Response Index (RI): The Response Index (RI) or the potential responsiveness to added fertilizer N expected is calculated by dividing the average NDVI in the Nitrogen Rich Strip (NRS) by the average NDVI in the Farmer Practice (FP). This will generally range somewhere between 1.0 and 3.0. If for example the Response Index were 1.5, it would mean that we can likely achieve a 50% increase in yield if added fertilizer N is applied. It says nothing about how much N should be applied, but it does indicate the likelihood of obtaining a response and how much of a response can be expected. What we are doing here is “Predicting the Potential Responsiveness of the Crop to Applied N” for that year, that field, that crop, under those growing conditions, planted on x-date and sensed on x-date. This information is also highly tailored to the response expected to N and only N. Because the Nitrogen Rich Strip compared to the Farmer Practice only evaluates the difference between “N non-limiting” or the NRS and the Farmer Practice “N possibly limiting”, the only thing that this RI can be used for is N fertilization. In theory, the same approach could be used for other elements such as sulfur, whereby we could have a Sulfur Rich Strip (SRS) where S was non-limiting, compared to the farmer practice where no S had been applied. If there were a large difference between the two, it is possible that S as ammonium sulfate could be applied to correct for the deficiency.

3. Yield Potential Achievable with Added N Fertilization (YPN)

A. Predicting YPN: The predicted attainable yield with added nitrogen is calculated as: $YP_N = YP_0 * RI$ where the response index was calculated as previously described. As was noted earlier, this could be for different nutrients, but as specified here it is for nitrogen. It should be noted that two limits are preferably imposed on this calculation, namely: (1) RI generally cannot exceed 3.0; and (2) YP_N cannot exceed YP_{MAX} where YP_{MAX} is the biological maximum for a specific crop, grown within a specific region, and under defined management practices. The value of 3.0 for maximum RI, is arbitrary and may vary for a specific crop, grown in a specific region under different conditions.

B. Keeping YP_0 and RI Separate: It is important to understand that the Yield Potential Achievable with no added N fertilization (YP_0) needs to be understood independent of the Response Index (RI). The responsiveness to applied fertilizer N has nothing to do with the "expected yield" unless of course it was tied into how much fertilizer N was applied. For this reason, you must be very careful to keep these two components as independent inputs. Many researchers have used the sufficiency concept whereby N fertilizer is applied whenever the "Check" plot shows up as "lighter green" (lower NDVI or chlorophyll meter reading) than the Nitrogen Rich Strip. While useful, this approach still says nothing about exactly "how much" fertilizer N should be applied, but rather that "some" needs to be applied. The approach delineated here keeps RI and YP_0 apart, simply because we apply N based on responsiveness, but with the specific yield potential in mind.

C. Yield Potential and Response Index Change from Year to Year: Whether it is due to planting date, timely or untimely rainfall, etc., yield potential in the same field will vary from one year to the next even when "managed" the same. The Response Index (RI) changes in the same field from one year to the next simply because of the marked influence of "environment" on N availability. N mineralized from soil organic matter can be quite high one year (warm and wet) and quite low the next (cool, and dry). The environmental conditions conducive to the mineralization of soil organic matter are quite variable and as such the demands for fertilizer N should be expected to be variable from one year to the next as well. In others words the ability of the environment to supply N (via mineralization of soil organic matter and/or deposited in rainfall) are quite variable and we need to take this amount of N supplied by the environment into consideration when making mid-season fertilizer N recommendations. We do this by carefully evaluating the Nitrogen Rich Strip and the Farmer Practice where an 'estimate' of how much N was supplied by the environment is available. Our research has shown that even in long-term plots where NO NITROGEN has been applied for over 30 years, we can in some years produce NEAR MAXIMUM yields with no applied N. How? This has been recorded in warm, wet years where enough N was mineralized from the soil organic matter and N supplied in the rainfall was sufficient to provide for all of the N needs for maximum yields.

4. Generating a Fertilizer N Rate Recommendation

A. Computing Grain N Uptake at YP_0 and YP_N: The predicted amount of N that will be removed in the grain at harvest (using our equation generated from 1E) is computed as follows:

> Grain N uptake, YP_0 = Grain Yield (YP_0) * expected % N in the Grain or Forage $GNUP\_YP_0 = YP_0*0.0239$ $GNUP\_YP_N = YP_N*0.0239$ where 0.0239 represents 2.39%N in the grain for winter wheat grown in Oklahoma.

B. Computing the Final Fertilizer N Rate: The fertilizer N rate to be applied is computed by subtracting the predicted amount of N to be removed in the grain at YP0 from the predicted amount of N to be removed in the grain at YPN, divided by some level of expected use efficiency. In the example below, we use 70% or 0.70 as the divisor, but this value can range anywhere from 50% to 80%. Why do we subtract GNUP_YP0 from GNUP_YPN? The best estimate of projected N removed in the grain (with and without fertilizer) come from GNUP_YP0 and GNUP_YPN, respectively. Because of this, N requirement (based on projected N removed in the grain with and without N fertilizer) should theoretically be the difference between the two divided by an efficiency factor.

	A	B	C	D	E	F	G	H	I	J
1	**STEP 1 STEP 2**		**STEP 3 STEP 4**		**STEP 5**	**STEP 6**	**STEP 7**	**STEP 8 STEP 9**		**STEP 10**
2	Enter Plot NDVI	Enter number of days from planting where GDD>0	Compute INSEY	Compute **YP0**	**Determine RI**	Compute **YPN**	YPMAX determined by agronomists (YPN cannot exceed YPMAX)	Determine Grain N uptake at **YP0**	Determine Grain N uptake at **YPN**	Determine Fertilizer N requirement
3			= NDVI/Days , GDD>0	**YP0 =** 992.26 * exp(142.67 * INSEY)	= NDVI (Nitrogen Rich Strip)/ NDVI (farmer check)	**YPN =** YP0 * RI	**YPN(cap)** <= 7000 kg/ha	GNUP_YP0 = **YP0** in kg/ha * 0.0239%	GNUP_YPN = **YPN** in kg/ha * 0.0239%	FNR=(GNUP_YPN GNUP_YP0)/0.70
4										
5	**GreenSeeker NDVI**	**Days, GDD>0**	**INSEY**	**YP0 in kg/ha**	**RI**	**YPN (kg/ha)**	**YPN(cap) kg/ha**	**GNUP_YP0**	**GNUP_YPN**	**FNR, kgN/ha**
6	0.55	68	0.00809	3146	1.5	4719	4719	75	113	63
7	0.65	84	0.00774	2993	1.5	4489	4489	72	107	60
8	0.75	84	0.00893	3547	1.5	5320	5320	85	127	71
9	0.85	84	0.01012	4203	1.5	6305	6305	100	151	84
10										
11	*average of **2.39%**N in OK winter wheat									
12	Grain yield MAX of 7000 kg/ha is used in this example for winter wheat									

5. Added Information Needed

Forage N uptake versus NDVI: Although not necessarily required for the development of the algorithm, it is advisable for the researchers to collect NDVI readings from small scale plots and where they can determine the relationship between this reading and forage biomass, and forage N uptake. In order to do so, this analysis is destructive. In other words, in these plots where NDVI readings are taken mid season, the forage will be physically harvested, dried, ground and analyzed for total N. By multiplying dry weight by the percent N in the forage, forage N uptake can be obtained and correlated with the NDVI readings that were collected before the forage was harvested.

Further Readings Nitrogen Prediction

Website Oklahoma state University http://www.nue.okstate.edu/

Johnson, G.V., Raun, W.R., 2003. Nitrogen response index as a guide to fertilizer management. Journal of Plant Nutrition 26, 249-262.

Lukina, E.V., Freeman, K.W., Wynn, K.J., Thomason, W.E., Mullen, R.W., Stone, M.L., Solie, J.B., Klatt, A.R., Johnson, G.V., Elliott, R.L., Raun, W.R., 2001. Nitrogen fertilization optimization algorithm based on in-season estimates of yield and plant nitrogen uptake. Journal of Plant Nutrition 24, 885-898.

Moges, S.M., Raun, W.R., Mullen, R.W., Freeman, K.W., Johnson, G.V., Solie, J.B., 2004.

Evaluation of green, red, and near infrared bands for predicting winter wheat biomass, nitrogen uptake, and final grain yield. Journal of Plant Nutrition 27, 1431-1441.

Use of the NDVI sensor to understand, characterize and monitor crop management practices

A. Soil quality, concept and case study

Presentation

- B. Govaerts, K. D. Sayre, J. Deckers, M. Mezzalama, J. Nicol, P. Decorte, K. Lichter, A. Limon-Ortega, N. Verhulst, L. Dendooven. Soil quality, concept and case study. CD-ROM *Session 3 Soil Quality*

Soil quality framework

Among the authors defining soil quality are Larson and Pierce (1991), Doran and Parkin (1994), Gregorich et al. (1994) and Karlen et al. (1997) (Etchevers, 2002). Larson and Pierce (1991) define soil quality as: “The capacity of a soil to function, both within its ecosystem boundaries (for example soil map unit boundaries) and with the environment external to that ecosystem. Soil quality relates specifically to the ability of soil to function as a medium for plant growth (productivity), in the partitioning and regulation of water flow in the environment, and as an environmental buffer.” As a simple operational definition, soil quality means: ‘fitness for use’ (Larson and Pierce, 1994). Karlen et al. (1997) define soil quality for the Soil Science Society of American Ad Hoc Committee on Soil Health as: “the capacity of a specific kind of soil to function, within natural managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation”. Doran and Parkin (1994) summarize the different definition they found as: “Soil quality is the capacity of soil to function effectively at present and in the future or as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.” At last, Gregorich et al. (1994) define soil quality as: “The degree of fitness of a soil for a specific use”. No soil is likely to successfully provide all these functions, some of which occur in natural ecosystems and some of which are the result of human modification. Soil quality depends on the extent to which a soil fulfils the role it is destined for (Singer and Ewing, 2000). Therefore, within the framework of agricultural production, high soil quality equates to maintenance of high productivity without significant soil or environmental degradation.

A minimum set of soil characteristics that represents soil quality must be selected and quantified, to be able to apply any evaluation assessment and as such to proceed from a theoretical definition to a measurement of soil quality. Different authors proposed several minimum data sets We propose that instead of working with predefined lists of indicators, a selection of the indicators is based on the agro-ecological site-specific conditions by comparing optimal conditions for the specific land use with the real conditions. This comparison will reveal the limiting factors of the system. All parameters related with these limiting factors should be measured in a first overall evaluation. Based on the obtained results, we can thereafter refine the list of relevant parameters and come up with a minimum dataset.

An approach frequently used in the evaluation of sustainable management systems is a comparative assessment. A comparative approach is one in which the performance of the system is determined in relation to alternatives. The characteristics and outputs of alternative systems are compared at some time, with respect to biotic and abiotic soil system attributes. A decision about the relative sustainability of each system, based on the difference in magnitude of the measured parameters, is being made. In contrast to the comparative assessment approach, there is a dynamic assessment approach, in which the dynamics of the system form a metre for its sustainability.

The following paper summarizes very accurately the soil quality concept

- Barrios, E., Delve, R.J., Bekunda, M., Mowo, J., Agunda, J., Ramisch, J., Trejo, M.T., Thomas, R.J., 2006. Indicators of soil quality: A south-south development of a methodological guide for linking local and technical knowledge. CD-ROM
  Barrios et al., 2006

Further readings

Doran, J.W., Parkin, T.B., 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C.,

Bezdicek, D.F., Stewart, B.A. (Eds.) Defining soil quality for a sustainable environment. ASA and SSSA, Madison, WI, USA. pp. 3-21.

Karlen, D.L., Stott, D.E., 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.) Defining soil quality for a sustainable environment. ASA and SSSA, Madison, WI, USA. pp. 53-72.

Larson, W.E., Pierce, F.J., 1994. The dynamics of soil quality as a measurement of sustainable management. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.) Defining soil quality for a sustainable environment. ASA and SSSA, Madison, Wisconsin. pp. 37-51.

Case study from Mexico

Applying the concept of soil quality requires the definition of a set of indicator parameters to be measured. As discussed, several minimum lists of indicators can be found in literature. The approach used for this case study, however, is different. There was no longer worked with the so-called generally predefined minimum data sets (Larson and Pierce, 1994), but with an agro-ecological specific site selection of the indicators. This led to a two-step-approach. The first step was the set up of a limiting factor parameter list, based on a comparison of the optimal conditions for the land-use and the actual agro-ecological characteristics. Parameters connected with the limiting factors form the limiting factor parameter list and indicators for them are being measured. Afterwards, from the set of measured indicators, the most explicative indicators were selected to form the real strict minimum data set. The table below shows the result of the comparison of the optimal conditions with the actual situation at the CIMMYT station. Indicators related with the limiting factors will possibly be relevant for the evaluation of the system and form the limiting factor parameter.

More details on the case study are available in

- Govaerts, B., Sayre, K. D., Deckers, J., 2005. Stable high yields with zero tillage and permanent bed planting? Field Crops Research 94, 33-42. CD-ROM
- *Govaerts et al., 2005a*
- Govaerts, B., Sayre, K. D., Deckers, J., 2006. A minimum data set for soil quality assessment wheat and maize cropping in the highlands of Mexico. Soil & Tillage Research 87, 163-174. CD-ROM
  Govaerts et al., 2006a

Govaerts, B., Mezzalama, M., Sayre, K.D., Crossa, J., Nicol, J.M., Deckers, J., 2006. Long-term consequences of tillage, residue management, and crop rotation on maize/wheat root rot and nematode populations in subtropical highlands. Applied Soil Ecology 32, 305-315. CD-ROM Govaerts et al., 2006b

Some examples from research on permanent beds in irrigated situations are presented below

Limon-Ortega, A., Sayre, K.D., Drijber, R.A., Francis, C.A., 2002. Soil attributes in a furrow-irrigated bed planting system in northwest Mexico. Soil & Tillage Research 63, 123-132. CD-ROM *Limon-Ortega et al., 2002*

- Govaerts, B., Sayre, K.D., Ceballos-Ramirez, J.M., Luna-Guido, M.L., Limon-Ortega, A., Deckers, J., Dendooven, L., 2006. Conventionally Tilled and Permanent Raised Beds with Different Crop Residue Management: Effects on

Soil C and N Dynamics. Plant and Soil 280, 143-155. CD-ROM *Govaerts et al., 2006c*

Limon-Ortega, A., Govaerts, B., Deckers, J., Sayre, K.D., 2006. Soil aggregate distribution/stability and microbial biomass in a permanent bed wheat-maize planting system after 12 years. Field Crops Research 97, 302-309. CD-ROM

Limon-Ortega et al., 2006

Comparison of optimal conditions for crop growth versus El Batán agro-ecological conditions (Govaerts et al., 2006)

Parameter Wheat optimal Conditions El Batán Maize optimal Conditions El Possible conditions conditions Batán limitation?

Climate

Soiltemp. 15-22°C 16-18°C* 15-22°C NO

Optimumday 20–25°C# 20-25°C 25-30°C* 20-25°C NO temp. Mean night temp. >13 °C * NO Mean day temp. <45 °C * NO Rainfall 400 -600 mm # 600 mm 400 mm * 600 mm YES

Periods of drought Periods of drought Periods of excessive Periods of rainfall excessive rainfall

Soil

Structure Fine # Clay Fine * Clay NO

Water content Avoid water Periods of drought Avoid water Periods of drought YES logging and logging logging and logging Avoid run off Avoid run off Avoid starvation Avoid starvation

Aeration Well # Low Well * Low YES Compaction Compaction High bulk density High bulk density Slaking Slaking

Organic matter High # High High * High NO Field capacity High * High NO pH >5.0# 5.9 5.0–7.0* 5.9 NO Al-content Low # 0 Low * 0 NO Nutrient condition High # Tend to decline High * Tend to decline YES Micronutrients Commonly Tend to decline Commonly Tend to decline YES

deficient Cu, B, deficient Fe, Zn Mn,Zn** **

Pathogen Pathogen free Yellow Rust, Leaf Pathogen free Nematode YES Rust and Sepatoria sensible tritici

Tanner and Raemaeker, 2002; * Ristanovic, 2002; ** Sayre, K. D. personal communication YES= possible limiting factor; NO= not limiting; temp.= Temperature

Limiting factor parameter set for the El Batán area (Govaerts et al., 2006)

Parameters	
Agronomical	Grain Yield
	Dry biomass
	Weed growth
Soil	Compaction
	Infiltration
	Moisture content
	Aggregate stability
	Bulk density

Micronutrients
Organic Carbon
Nematode scores
Root scores
Nutrient status

B. Use of the NDVI handheld sensor to monitor crop development throughout the season

Presentation

- B. Govaerts, N. Verhulst, K. D. Sayre, J. Deckers, P. Decorte, B. Goudeseune. Use of the NDVI sensor to understand, characterize and monitor crop management practices. CD-ROM *Session 4 Understand crop management*

Crop growth curves

Crop and crop growth are the integrated evaluators of the efficiency of the chosen agricultural management system within the boundaries of the agro-ecological environment. Given a crop cultivar (that has been selected for the given agro-ecological zone), the crop forms the integrated evaluator of all environmental factors, including the influence of management and how it determines resource use efficiency. Yields can be measured as an end of season static result of seasonal crop performance, but these results do not reflect the dynamics of the within season crop performance. End-of-season yield results do not permit the evaluation of within season management interactions with the production environment and will not allow full understanding of the management practice. In order to understand and evaluate cropping systems, and to fine-tune resource management, crop performance over time is a crucial factor. The effect of management factors, such as tillage systems and crop residue management on crop development during the crop cycle has not been studied intensively. Until now most of the knowledge on plant growth has been developed for conventional management practices, including heavy tillage and common crop residue removal. The NDVI handheld sensor can be used to follow crop growth throughout the season, increasing as such our understanding of the different management practices.

Following papers summarize the results obtained in Mexico.

Govaerts, B., Sayre, K.D., Martinez, A., Deckers, J., 2005. Using optical sensor readings to evaluate crop growth and spatial variability within contrasting tillage systems. Poster presented at the third world congress on conservation agriculture. Linking productivity, livelihoods and conservation. Papers and Posters. 3th to 7th October 2005. Nairobi, Kenya. CD-ROM *Govaerts et al., 2005b*

Govaerts, B., Verhulst, N., Sayre, K.D., De Corte, P., Crossa, J.,Deckers, J., Dendooven, L., 2008. Crop growth evaluation with an optical sensor: influence of management on crop growth and soil moisture dynamics. CD-ROM *Govaerts et al., 2008*

Further readings crop growth under different management practices

Raimbault, B.A., Vyn, T.J., 1991. Crop-Rotation and Tillage Effects on Corn Growth and Soil Structural Stability. Agronomy Journal 83, 979-985.

Riley, H.C.F., 1998. Soil mineral-N and N-fertilizer requirements of spring cereals in two long-term tillage trials on loam soil in southeast Norway. Soil & Tillage Research 48, 265-274.

Vyn, T.J., Raimbault, B.A., 1993. Long-Term Effect of 5 Tillage Systems on Corn Response and

Soil-Structure. Agronomy Journal 85, 1074-1079.

C. Spatial variability in crop performance as an indicator of sustainability

Presentation

- B. Govaerts, N. Verhulst, K. D. Sayre, J. Deckers, P. Decorte, B. Goudeseune. Use of the NDVI sensor to understand, characterize and monitor crop management practices. CD-ROM *Session 4 Understand crop management*

The spatial structure of ecosystems often reflects how these systems function. Spatial ecosystem structure reflects the spatial distribution of the key production-related processes. A change in spatial variability in plant performance on any scale indicates that the distribution of limiting resources has changed or that another resource has become limiting. This may reflect a change in the processes that both control and are affected by the availability of resources on that scale. When all plant-growth elements are abundantly available, a uniform pattern of plant growth must be seen. However, when one or more plant critical plant elements are limiting, plant-to-plant competition effects will increase plant-to-plant performance variability, increasing CV, compared with optimally growing plants. We proposed, as general principle, that competition for resources results in greater within plot plant-to-plant variability. Within-plot spatial variability can be the result of inherent variation in plot conditions. However, agronomical practices also influence spatial within-plot plant variability. Increased within plot plant spatial variability throughout the season can therefore be considered a reaction to inefficient use of critical plant growth resources provoked by an unsustainable management of these resources. The sensor is a tool to follow the spatial variability in crop performance throughout the season.

The following papers summarize the newly introduced concept that uses the spatial variability as an indicator of crop management sustainability.

Govaerts, B., Sayre, K. D., Deckers, J., Limon-Ortega, A., Barrera-Franco, M. G., and Martinez, A. Spatial variability related to plant performance under different tillage and residue management systems: an expression of the sustainability of plant production? 2003. Morelia, Mexico. Integrated Research on Coupled Human Environmental Systems; Land Open Science Conference. 12-2-2003. CDROM *Govaerts et al., 2003*

Govaerts, B., Sayre, K.D., Deckers, J., Decorte, P., Goudeseune, B., Lichter, K., Crossa, J., Dendooven, L., 2007. Evaluating spatial within plot crop variability for different management practices with an optical sensor? Plant and Soil 299, 29-42. CD-ROM *Govaerts et al., 2007*

Using the CV as crop growth evaluation parameter was also done for maize by Raun et al. (2005). The concept used is different, but can be of interest for the reader.

- Raun, W.R., Solie, J.B., Martin, K.L., Freeman, K.W., Stone, M.L., Johnson, G.V., Mullen, R.W., 2005. Growth stage, development, and spatial variability in corn evaluated using optical sensor readings. Journal of Plant Nutrition 28, 173
  182. CD-ROM *Raun et al., 2005*

Further readings on spatial variability crop spatial variability

Martin, K.L., Hodgen, P.J., Freeman, K.W., Melchiori, R., Arnall, D.B., Teal, R.K., Mullen, R.W., Desta, K., Phillips, S.B., Solie, J.B., Stone, M.L., Caviglia, O., Solari, F., Bianchini, A., Francis, D.I., Schepers, J.S., Hatfield, J., Raun, W.R., 2005. Plant-to-plant variability in corn production. Agronomy

Journal 97, 16031611.
Scotford, I.M., Miller, P.C.H., 2004a. Combination of spectral reflectance and ultrasonic sensing to monitor the growth of winter wheat. Biosystems Engineering 87, 27-38.
Scotford, I.M., Miller, P.C.H., 2004b. Estimating tiller density and leaf area index of winter wheat using spectral reflectance and ultrasonic sensing techniques. Biosystems Engineering 89, 395-408.
Washmon, C.N., Solie, J.B., Raun, W.R., Itenfisu, D.D., 2002. Within field variability in wheat grain yields over nine years in Oklahoma. Journal of Plant Nutrition 25, 2655-2662.

D. Using spatial variability in crop performance (NDVI) to evaluate soil processes determining the system sustainability

Presentation

- B. Govaerts, N. Verhulst, K. D. Sayre, J. Deckers, P. Decorte, B. Goudeseune Using spatial crop performance variability (NDVI) to evaluate soil processes determining the system sustainability CD-ROM *Session 5 Spatial variability*

Spatial structure to identify the limiting factors of the system

Spatial variability in crop development integrates the effects of spatial variability in soil, above ground environment and plant characteristics. Differences in resources only results in spatial variability in crop development when the resource is limiting crop performance. Linking spatial variability in crop performance to differences in soil attributes could identify the limiting factors driving the system. Patterns of crop performance will follow the spatial variability of the underlying limiting soil attributes. The sensor detects ‘cold and hot zones’ of plant performance, which can be correlated to field spots of differing soil quality. This allows a detailed investigation of underlying soil processes and how they might be affected by different management practices.
The following articles apply this concept in central Mexico:

Govaerts, B., Sayre, K.D., Martinez, M., Martinez, A., Deckers, J., 2004. NDVI measured plant growth variability with conservation tillage, relation with limiting resources. Comm. Appl. Biol. Sci., 69/2, 139-142. CD-ROM *Govaerts et al., 2004*
Verhulst, N., Govaerts, B., Sayre, K.D. , Deckers, J., Dendooven, L., 2008. Spatial within-plot variability and production limiting factors as influenced by cropping systems management. Submitted to Plant and Soil. CD-ROM *Verhulst et al., 2008*

Further readings on spatial variability

Kravchenko, A.N., Robertson, G.P., Thelen, K.D., Harwood; R.R., 2005. Management, Topographical en Weather Effects on Spatial Variability of Crop Grain Yields. Agronomy Journal 97, 514-523. CD-ROM *Kravchenko et al., 2005*
Kravchenko, A.N., Bullock, D.G., 2000. Correlation of corn and soybean grain yield with topography and soil properties. Agronomy Journal 92,75–83.
Robertson, G.P. and Gross, K.L., 1994. Assessing the heterogeneity of below-ground resources: Quantifying pattern and scale. In: Plant Exploitation of Environmental Heterogeneity. Caldwell, M. M., Pearcy, R.W. (eds.). Academic Press, New York, New York, USA: 237-253.