SENSOR FOR ONLINE CONTROL OF SITE SPECIFIC NITROGEN APPLICATION

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INTRODUCTION

There seems to be general agreement, that site specific application of fertilizers can improve the efficiency of use. However, how should the site specific need for nutrients be found out? Our approach is getting site specific signals for nitrogen top dressing from the color of the plants, taking into consideration that with increasing nitrogen supply the color changes from yellow-green to blue-green. It should be mentioned that winter-cereals in Central-Europe quite often get nitrogen fertilizer two or three times during the season. So our approach is aiming at the second or third nitrogen application.

METHOD

The natural light reflected from plants was recorded by a field-spectrometer in the spectral range from 450 to 850 nm, which is the visible plus the near infrared range. The resolution was 2 nm and the height of the spectrometer above the soil was 2 m. The reflected radiation depends on the incident solar radiation (irradiance). Therefore, the incident solar radiation was recorded as well. The reflectance -which is the relation between the reflected and the incident solar radiation - was used as signal. The question was, which wavelengths give the best indication of the plant nitrogen supply.

REFLECTANCE CURVES

Fig. 1 shows the reflectance of a winter-rye crop in the first days of May, when usually the second nitrogen dose is applied. The first dose of nitrogen was given with five different rates ranging from 0 to 80 kg N per ha about six weeks earlier. As might be expected the green cereal plants reflect much less in the visible range than in the infrared range. Yet the reaction on increasing nitrogen supply is different in the visible and in the infrared range. In the visible range the reflectance decreases with increasing nitrogen supply. This results from the increase of chlorophyll per unit leaf area as well as per unit field area, since chlorophyll absorbs the visible light. Yet on the other hand the growth in biomass production resulting from the improved nitrogen supply brings about an increase in the near infrared reflectance. All curves show a rather steep slope between the red and the near infrared reflectance. This slope moves to longer wavelengths when the supply of nitrogen is improved.

INTERPRETATION

The question is, how the spectral data should be evaluated or interpreted in order to get a reliable signal for the nitrogen supply of plants (Table 1). Simple methods would be to relate the reflectance either in the green , in the red, or in the near infrared range to the nitrogen supply. Instead of this the relation between wavelengths in two different spectral ranges could be used such as the relation of near infrared to red or near infrared to green. Still another approach would be the use of indices like the "Normalized Difference Vegetation Index" or the "Soil Adjusted Vegetation Index" by Huete (7). Both indices can easily be calculated from the reflectance in the red and near infrared range.

Finally the signal needed as indicator of the nitrogen supply can be derived from the point of inflection of the S shaped curve of the reflectance in the red and near infrared range. This point of inflection can be calculated in different ways:

1) by numerically differentiating the reflectance curve twice and setting it equal to zero,
2) by using an empirical approximating formula.

This disadvantage of the first method is, that the reflectance data must be recorded in a high resolution with a span of about 2 nm. This makes this method very expensive, since many bands are needed.

The second method for calculating the point of inflection using an empirical approximating formula has been proposed by Guyot, Baret and Major (5). Only four different reflectance bands are needed.

RESULTS

Table 2 shows the relation between the spectral indices and the nitrogen supply represented by the coefficients of determination (= r^2). All indices depend on the nitrogen fertilization. However, there are differences. The 800 nm near infrared reflectance shows the weakest relation, and the red edge inflection point indices on the other hand are rather closely related to the nitrogen supply. The red edge inflection point calculated by the approximating formula has the best coefficient of determination.

The relation between this index and the nitrogen supply is linear (Fig. 2) and indicates, that 1 nm difference of the index represents approximately a difference of 15 kg N per ha.

INTERFERING FACTORS

There are interfering factors. Changes in the zenith angle of the sun, in the cloudiness, or in the color of the soil can influence the reflectance and its indices. In order to evaluate the influence of the solar zenith angle, records were taken on a sunny day in mid-May with a fixed spectrometer in winter barley. Similarly, records were taken on a day with varying cumulus clouds. Finally the soil color was altered by watering a dry, bright soil and thus creating a dark, wet soil. The effect of the interfering factors was calculated by using a fraction or coefficient, in which the numerator is the index-difference belonging to the change of the nitrogen applied and in which the denominator is the index-difference pertaining to the change of the interfering factor such as the solar zenith angle, the cloudiness, or the color of the soil (Table 3).

In Table 4 the coefficients are listed. There are quite distinct differences in the influence of the interfering factors on the indices. Generally, the least interfering occurs with indices representing the point of inflection. This can especially be seen, when the geometric mean of the three coefficients is calculated. Thus the point of inflection can be regarded as an index, which on the one hand depends very clearly on the nitrogen supply of the plants and on the other hand is not altered much by the interfering factors. The question however is, how it should be calculated. The numerical method gives the best results, but it requires recording of the reflectance with a high resolution and thus is expensive. The empirical approximating method by Guyot, Baret, and Major (5) needs only four channels and therefore is less expensive, and its geometric mean of the coefficients is almost as good. Therefore we decided to use this index.

RED EDGE INFLECTION POINT SENSOR

Fig. 3 shows some technical details of the sensor. In addition to the respective channels of the four wavelengths, a channel for dark current calibration is used. At least two radiometers are necessary to obtain reflectances, one pointing downward and the other one pointing upwards. However, one sensor pointed upwards for recording the incident solar radiation may serve several sensors pointed downwards. The sensors can be connected directly to a parallel port of the process-controller.

RECORDING TIME WITHIN THE GROWING SEASON

Since the reflectance depends on the chlorophyll-concentration per unit of leaf area as well as per unit of field area, changes might be expected in the spectrometric data during the growing season. In the first part of the growing season the plants might still get some nitrogen from the seeds, so that the relation between the nitrogen applied as fertilizer and the reflectance might be somewhat uncertain. In addition during this stage reflectance of leaf area as well as of not covered soil is recorded. And it is well known that the reflectance of soil is quite different from that of leaves (4). So how reliable is the point of inflection as an indicator of the nitrogen supply of plants at different stages during the growing season?

Fig. 4 shows the situation again for winter rye, to which the first dose of nitrogen was given in Mid-March with applications ranging from 0 to 80 kg N/ha. The differences between the points of inflection with respect to the nitrogen supply clearly increase during the early part of the growing season. The second nitrogen dressing usually is applied when EC stage 31 is attained. At this stage of the crop the differences between the points of inflection are well developed. In case a third nitrogen dressing is given, it is applied approximately at EC stage 50. In this period of development the differences of the points of inflection still are quite distinct. So from this point of view the method seems to be useful for the second and third application of nitrogen.

ONLINE CONTROL OR MAPPING

The point of inflection reflectance method can be used for site specific nitrogen application either online for on the go control (Fig. 5) or in a two step way via a field map. On the go control is facilitated by the high speed, with which the sensor can deliver the signals. About 150 signals can be supplied per second. But the two step way via a field map makes it possible to consider additional factors as for example site specific soil properties.

Fig. 6 shows the point of inflection reflectance for a wheat field in Northern Germany at the time of the second nitrogen application. The field is a loamy soil located in a rolling landscape near the Baltic sea. In this case the first application of fertilizer was distributed uniformly over the whole field. Despite this there are differences across the field ranging from 720 nm to 728 nm for the point of inflection. From our previous experience 1 nm represents approximately 15 kg/ha difference in the nitrogen supply; so 8 nm difference would correspond to 120 kg/ha difference in nitrogen available. This is about half the total amount of nitrogen applied to a good cereal crop.

CALIBRATION

A direct absolute conclusion from the reflectance data to the nitrogen needed is hardly possible, since many factors should be considered. Yet a relative calibration seems possible. Within the field two points are selected which differ distinctly in the nitrogen supply. At these two points the nitrogen requirement is estimated by conventional methods. In addition for these two points the reflectance is recorded in order to get a relation between the sensors record and the nitrogen needed. This relation then can be used for controlling the site specific application by the sensor data.

LIMITS

It should be pointed out, that the nitrogen supply is not analysed directly and that in the first instance the inflection point reflectance only is an indicator of the chlorophyll-concentration per unit field area. The method described presumes a close correlation between the chlorophyll-concentration and the nitrogen supply. But the chlorophyll-concentration and thus the color of plants can also depend on diseases or on a deficiency of other nutrients. A presupposition of the inflection point reflectance method therefore is a healthy crop, which is well supplied with other nutrients.

CONCLUSIONS

The colour of plants is an indicator of the nitrogen supply. Therefore the reflected radiation is used as basis for sensing the nitrogen status.
Reflectance data depending on wavelengths and nitrogen supply of crops are presented. These data are used in numerous ways and mathematical combinations in correlation to the nitrogen supply. A very good indicator of the nitrogen supply is the inflection point of the S shaped curve for red and infrared reflectance. An opitcal sensor providing these control signals is presented.

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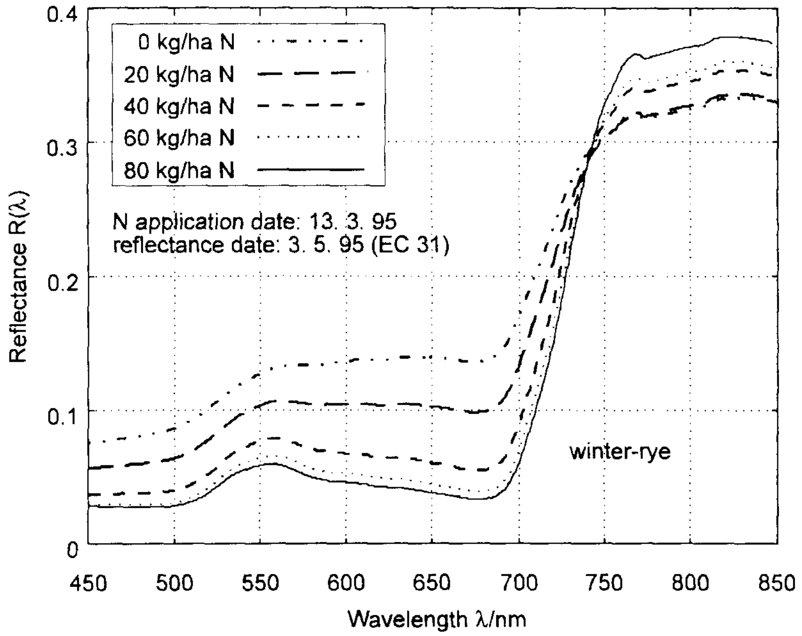

Reusch	Fig.1: Reflectance Spectra and Nitrogen Supply at Time of Second Top Dressing
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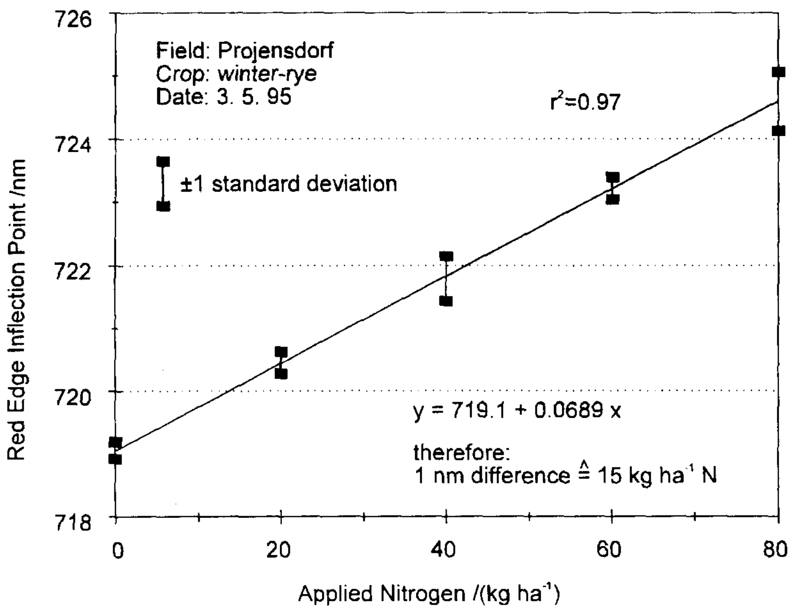

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DEFINITION	Number of bands	ABBRE-VIATION
1. Reflectance at 550 nm (green)	1	R 550
2. Reflectance at 670 nm (red)	1	R 670
3. Reflectance at 800 nm (near infrared)	1	R 800
4. Relation of near infrared to red reflectance	2	IR/R
5. Relation of near infrared to green reflectance	2	IR/G
6. Normalized Difference Vegetation Index = $\frac{R_{800} - R_{670}}{R_{800} + R_{670}}$	2	NDVI
7. Soil Adjusted Vegetation Index = $\frac{1.5(R_{800} - R_{670})}{R_{800} + R_{670} + 0.5}$	2	SAVI
8. Red edge inflection point, numerical differentiation $\frac{d^2R}{R\lambda^2} = 0$	50 - 80	REIP
9. Red edge inflection point, approximating formula $= 700 + 40 \frac{(R_{670} + R_{780})/2 - R_{700}}{R_{740} - R_{700}}$	4	REIP

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TABLE 1: SPECTRAL INDICES OF THE NITROGEN SUPPLY

DEFINITION	COEFFICIENTS OF DETERMINATION (r^2)
1. Reflectance at 550 nm (green)	0, 910
2. Reflectance at 670 nm (red)	0, 884
3. Reflectance at 800 nm (near infrared)	0, 569
4. Relation of near infrared to red reflectance	0, 911
5. Relation of near infrared to green reflectance	0, 943
6. Normalized Difference Vegetation Index = $\frac{R_{800} - R_{670}}{R_{800} + R_{670}}$	0, 914
7. Soil Adjusted Vegetation Index = $\frac{1.5(R_{800} - R_{670})}{R_{800} + R_{670} + 0.5}$	0, 907
8. Red edge inflection point, numerical differentiation $\frac{d^2R}{R\lambda^2} = 0$	0, 932
9. Red edge inflection point, approximating formula $= 700 + 40 \frac{(R_{670} + R_{780})/2 - R_{700}}{R_{740} - R_{700}}$	0, 970

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TABLE 2: RELATION BETWEEN SPECTRAL INDICES AND NITROGEN SUPPLY REPRESENTED BY THE COEFFICIENTS OF DETERMINATION

Factor 1 : Zenith - angle of the sun

$$\text{coefficient } \zeta = \frac{\text{index - difference resulting from altering the N dose}}{\text{index - standard deviation resulting from the changing zenith angle}}$$

Factor 2 : Cloudiness

$$\text{coefficient } \zeta = \frac{\text{index - difference resulting from altering the N dose}}{\text{index - standard deviation resulting from the changes in cloudiness}}$$

Factor 3 : Soil - brightness

$$\text{coefficient } \zeta = \frac{\text{index - difference resulting from altering the N dose}}{\text{index - difference resulting from wetting the dry soil}}$$

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TABLE 3: DEFINITION OF COEFFICIENTS FOR INTERFERING FACTORS

SPECTRAL INDICES	Sun ζ_r	Clouds ζ_c	Soil ζ_s	Total $\sqrt[3]{\zeta_r \zeta_c \zeta_s}$
1. Reflectance at 550 nm (green)	4,5	0,2	6,6	**1,9**
2. Reflectance at 670 nm (red)	7,2	0,8	8,4	**3,6**
3. Reflectance at 800 nm (near infrared)	5,1	5,7	1,2	**3,2**
4. Relation of near infrared to red reflectance	7,4	4,9	7,9	**6,6**
5. Relation of near infrared to green reflectance	12,9	4,2	19,0	**10,8**
6. Normalized Difference Vegetation Index	11,9	2,7	12,6	**7,4**
7. Soil Adjusted Vegetation Index	11,5	7,4	32,4	**14,1**
8. Red edge inflection point, numerical differentiation	45,9	10,7	21,8	**22,0**
9. Red edge inflection point, approximating formula	61,1	12,7	10,1	**19,8**

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TABLE 4: EVALUATING THE EFFECT OF INTERFERING FACTORS

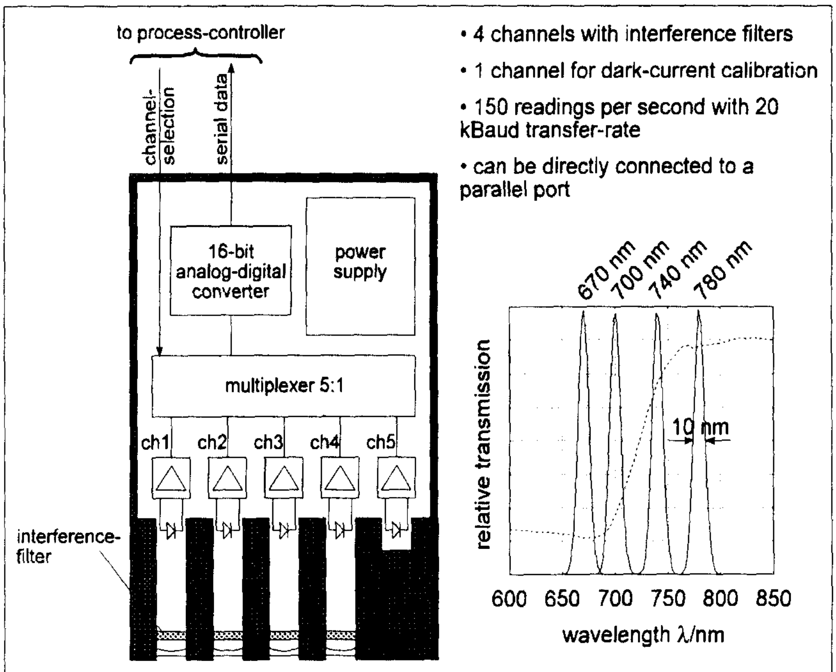

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Fig. 3: Red Edge Inflection Point Sensor (left) and Transmission of its Filters (right)

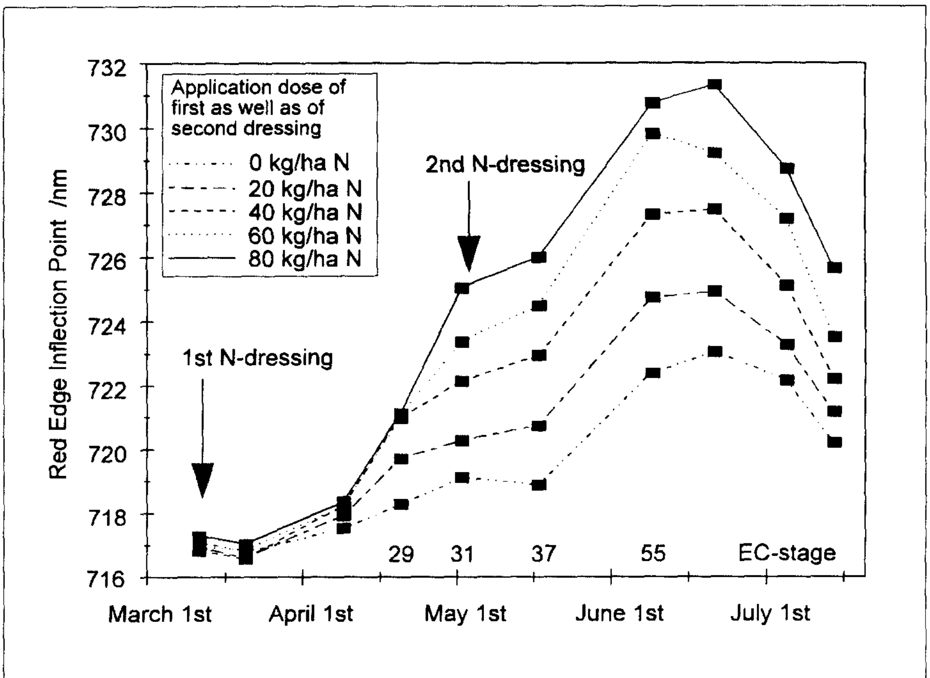

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Fig.4: Red Edge Inflection Point in the Growing Season

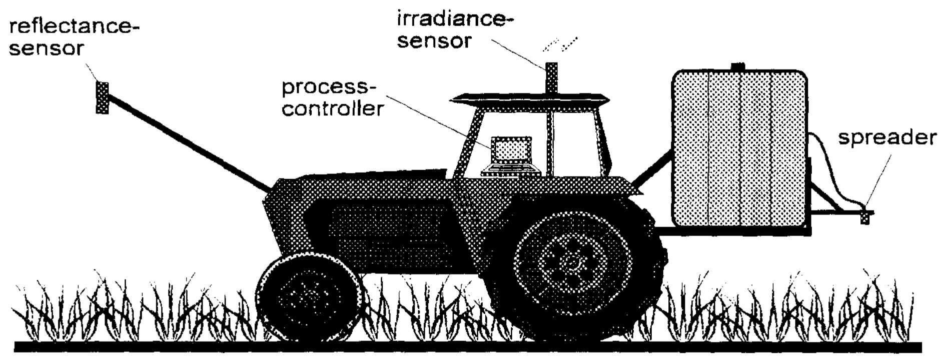

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Fig. 5: Concept for Sensor-Controlled Fertilizing

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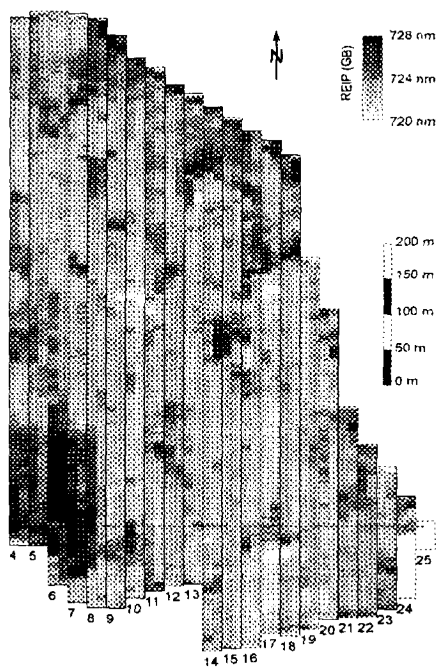

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Fig.6: Mapping of Red Edge Inflection Points in Winter Wheat (29. 4. 96)

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