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On the Optical Recording of Nitrogen Supply in Plants

Optically recording the nitrogen supply in plants is much less expensive and faster than chemical analyses. It is therefore used for site-specific nitrogen application. In farming practice it is misleadingly denoted as "green-sensing." Yet the optics do not directly record the intensity of the greenness. The signals from the N supply originate from the range of red and near infrared radiation. They register the chlorophyll-concentration in the leaves and/or the crop biomass and in this way indicate the N supply. An important factor is whether the chlorophyll concentration in the leaves or the biomass is better suited to indicate the N supply. Present day systems are dealt with under this aspect.

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Keywords

Reflectance, fluorescence, chlorophyll, leaf-area-index

The irradiation hitting the crop is either absorbed for the photosynthesis, or transmitted through the leaves, or reflected. All three items depend on the irradiation, which can change. Therefore it is general practice to relate the absorbed, the transmitted and the reflected light to the irradiation. This ratio is the absorptance, the transmittance, or the reflectance.

In theory, the signals for the N-supply could be obtained from every one of these three items. But only the reflectance is thrown back from the crop-canopy upwards and thus can easily be recorded by a sensor on the tractor (*Fig. 1, top*).

In addition to the reflectance, the leaves emit fluorescent light (*Fig.1, bottom*). The fluorescence is a byproduct of the photosynthesis and is consequently fed from the absorptance. It is an indicator of the energetic inefficiency of the photosynthesis. Intensive fluorescence can result from crop-stress. A healthy crop might just loose about 2 % of the absorbed light- energy via fluorescence. Yet if the plants are stressed, this loss of light-energy can rise to the six-fold.

Within the range of the red radiation, the fluorescence exhibits two maxima, i.e. at 680 nm and at 735 nm wavelength. The ratio of these maxima is an indicator of the chlorophyll-concentration in the leaves, because the fluorescent light with 680 nm wavelength is partly reabsorbed for the photosynthesis. On the other hand, the fluorescence with 735 nm is beyond the range for photosynthetic absorption. This explains, why by the ratio of the intensities of these wavelengths and thus via the chlorophyll-concentration of the leaves the N-supply can be indicated [1].

The reflectance of the visible light

decreases when the N-supply increases, since simultaneously the chlorophyll-concentration in the leaves, the photosynthesis, and thus also the absorptance rises. Contrary to this, the reflectance of infrared light increases with the N-supply, because of more biomass. The result is that the ascendance of the reflectance-curve in the transition from the red- to the near infrared light, commonly known as the "red-edge" range, is getting steeper (*Fig. 2*).

Indicating the N-supply via wide bands of wavelengths, such as the complete range of red-, green-, or blue light, has not been successful up till now. Instead of this with the Kiel system [2] the signals are obtained either via the point of inflection within the red edge range or via the relation of two very narrow bands of wavelengths, located also within this range (Fig. 2).

Nitrogen-effects on the crop

The main effects on the chlorophyll-concentration in the leaves and on the biomass of the crop are well known. But which of these two effects is more important? According to *Figure 3*, the N-effect on the biomass, represented by the leaf- area-index, is much more important than the effect on the chlorophyll-concentration in the leaves [3]. Yet both criteria can be combined by using their product. This product, i.e. the leaf-area-index multiplied by the chlorophyll concentration per m^2 of leaf-area, is the chlorophyll-concentration per m^2 of ground-area. The N-effect on this product shows up very clearly (*Fig. 3, right*).

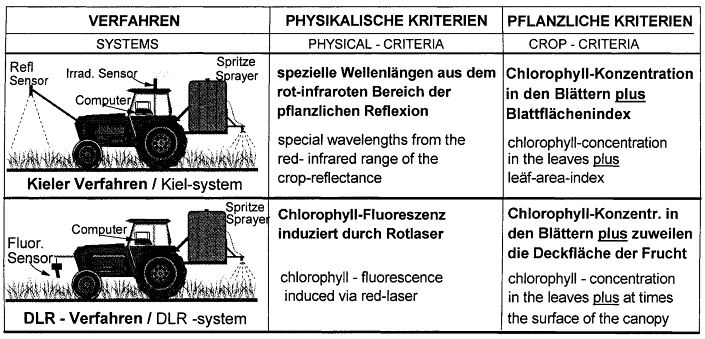

Fig. 1: Systems

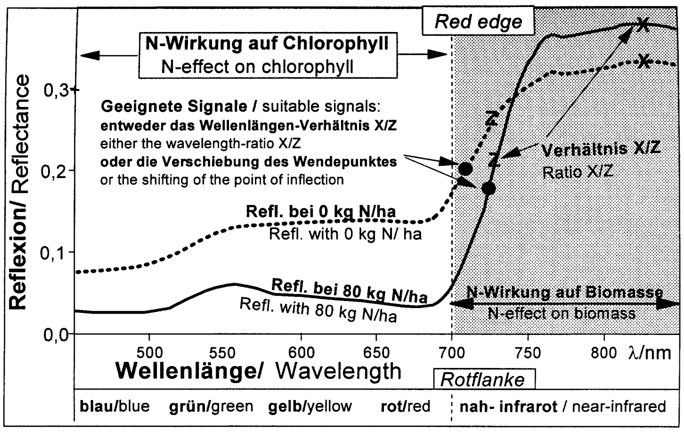

Fig. 2: Reflectance-curves of winter-rye at time of second top-dressing, depending on nitrogen spread seven weeks earlier

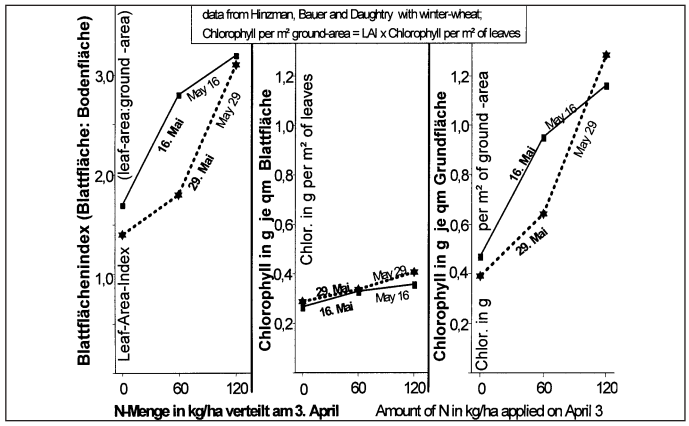

Fig. 3: Effect of nitrogen on the leaf-area-index and on chlorophyll

Gaps in the canopy

Certainly both systems (*Fig. 1*) need green plants within the view-area of the sensor. Yet the reaction on gaps in the canopy is completely different.

In this respect it is necessary to distinguish between small gaps within the view-area of the sensor and large gaps, which extend beyond the view-area. Small gaps occur typically in a crop, whose canopy is not yet closed, whereas with autumn sown crops, large gaps often can result from winter-killing within depressions in the field.

The results of reflectance-sensing are also influenced by light-signals emitted from the bare soil. These signals are completely false as far as the N-supply of plants is concerned. Therefore, the canopy should be largely closed within the view-area of the sensor. Thus the use of reflectance-sensing for closely spaced crops such as small grains or rape usually starts with the second top-dressing and in most cases not earlier. However, to some extent bare soil in the view-area of the sensor can be removed by using an oblique- instead of a vertical direction of view. For widely spaced crops- such as maize, potatoes or beets- it might make sense to use an adequately narrowed view-angle of the sensor.

With fluorescence-sensing the result of gaps is only, that fewer signals are received. No false signals are created, since the soil does not emit fluorescence. Therefore, small gaps within the area of view in the not yet closed canopy do not limit its use. The system is suitable for the first top-dressing in early spring- as far as the recording technique is concerned.

Yet in addition to the recording technique it is important, whether especially with small grains and rape the very young plants already indicate the N-supply by the soil via their reflectance. The seedlings get the initial nitrogen from the seeds, and it is only after this stage, that the supply via the soil can influence the look of the canopy. This limit, of course, applies to all optical systems.

For larger gaps in the canopy the application of fertilizer should be suspended. The respective automatic control of the spreader is activated via the "false" signals with reflectance–sensing, and via the completely absent signals with fluorescence-sensing.

Recording the volume or the top-surface?

The fluorescence-ratio is not influenced by the leaf-area-index, contrary to the reflectance signals (*Fig. 1*). But the leaf-area-index is a more important indicator of the N-supply than the chlorophyll concentration in the leaves (*Fig. 2*). Recent attempts are to combine recording of the fluorescence-ratio and of the crop-biomass. This is achieved by scanning the canopy via the red laser-irradiance, which induces the fluorescence. The frequency, by which the inducing radiation is creating fluorescence, is an indicator of the biomass.

However, there exist fundamental differences in the ability of near infrared- and red irradiation to record the biomass. The near infrared irradiation is not absorbed, but mostly transmitted through the leaves. Contrary to this the red radiation mainly is absorbed, yet hardly transmitted. Consequently the near infrared irradiation causes predominantly volume-reflectance. And the red irradiation mainly results in top-surface-reflectance or in correspondingly induced top-surface-fluorescence (*Fig. 4*).

This explains why the near infrared irradiation provides for a definitely better indication of the biomass or of the leaf-area-index of small cereal crops (*Fig. 4, right*). The aim should be to combine this important advantage of the reflectance- system with the gap-advantage of the fluorescence- system.

Literature

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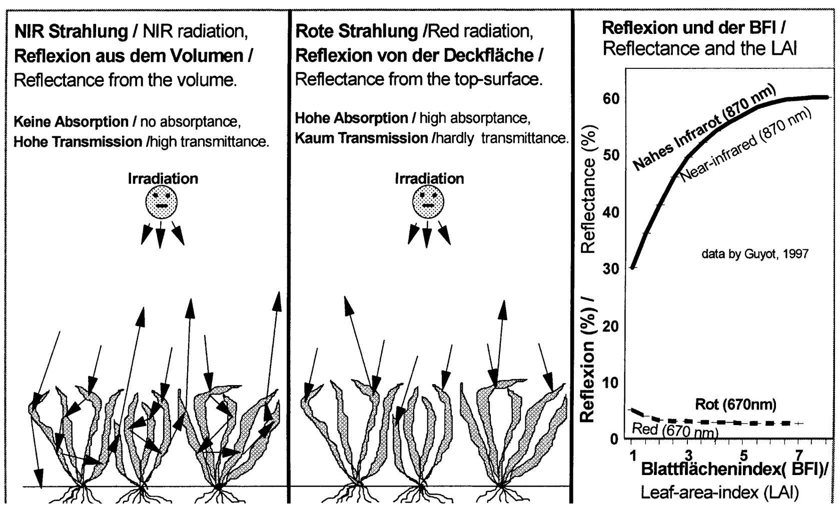

Fig. 4: Reflectance from the volume or from the top-surface