APPLICATION AND TESTING OF A CROP SCANNING INSTRUMENT – FIELD EXPERIMENTS WITH REDUCED CROP WIDTH, TALL MAIZE PLANTS AND MONITORING OF CEREAL YIELD

U. SCHMIDHALTER, J. GLAS, R. HEIGL, R. MANHART, S. WIESENT, R. GUTSER, E. NEUDECKER

Chair of Plant Nutrition, Department of Plant Sciences, Technical University of Munich
Am Hochanger 2, 85350 Freising
E-mail: schmidhalter@weihenstephan.de

ABSTRACT

A crop scanner was tested in wheat, maize and potato crops during the year 2000. The crop scanner allows to detect the nitrogen and/or biomass status of plants. The application was extended to narrow crop widths for smaller plot studies, as frequently present in detailed experimentation studies, and to tall plants as maize crops. The crop scanner was further tested for detecting the final grain yield of cereals. A device was constructed which allowed to scan the nitrogen or biomass status in stripes with crop width of 7.5 m with a scanned area of about 2 m^2. Further reductions in crop width are possible. For tall plants as maize crops the scanner was mounted on a modified grape harvester. Field testing of the crop scanner showed that modifications of the implemented fertilising algorithm by including soil-borne information improved significantly the performance. Using the crop scanner as a yield monitor showed promising results.

INTRODUCTION

A tractor-mounted crop scanning instrument, the so-called Hydro N-sensor (Hydro-agri®, Dülmen, Germany) (Reusch, 1999) allows to detect the nitrogen status and biomass status of plants. The on-the-go obtained spectral information has been combined with a fertilising algorithm which allows site-specific nitrogen fertilisation of plants. The fertilising algorithm consisted in the year 2000 of a trapezoidal function with decreasing nitrogen dressings given at either low or high biomass. However, there is most likely no universal function applicable to all sites, soil conditions and varieties. This would call for an interactive algorithm which allows user-specific modifications. At present the user can only marginally influence the shape of this algorithm. However, the existing algorithm can be combined with information e.g. from long-term yield maps or site-specific soil information and calibration performed on-site allows to include varietal information.
The N-sensor has not yet been tested in independent studies. Some information is available from the developer (Wollring et al., 1998; Reusch, 1999) and personal communications from practitioners. These results indicated an interesting potential of the N-sensor to perform on-the-go site-specific fertilisation of wheat crops. The N-sensor can not be used for the first nitrogen application at the beginning of the vegetation period in early spring. Results obtained with site-specific nitrogen fertilisation in later growth stages showed potential yield increases up to 5 decitons ha^{-1}, averaging about 2 decitons ha^{-1}, and further advantages as more uniform stands and increases in protein contents and N-use efficiency (Wollring et al. 1998; Wollring and Reusch, 2000). It is reasonable to assume that improvements in the existing fertilisation algorithm could contribute to further increases in yield and quality. The application in other crops than cereals should be investigated as well.

Most desirable a rigorous testing should be conducted under well controlled conditions. However, the tractor mounted crop scanning instrument can not be used on small plots or stripes smaller than 12-15 m in width. The sensor has four optical inputs with 90° azimutal angle between them and an average view zenith angle of 64° each. Light is collected from four inputs and optically averaged through a four-split light fibre. This arrangement allows to take an average measurement from four spots located around the tractor practically independent of solar azimuth direction. For detailed field experimentation the N-sensor should allow to sense smaller plot sizes. Yield increases of 2 decitons ha^{-1} can not be proved with conventional yield monitors mounted on combine harvesters. Destructive harvests in randomised field experiments are frequently limited to fairly small areas which are much smaller than the area sensed by the sensor.

Conventional tractors do not allow to use the sensor in tall maize crops. For maize, there is a lesser interest to use the sensor as nitrogen sensor, because normally nitrogen fertilisation is conducted in early development stages. However, there is a strong interest to document biomass development in various studies.

There are a number of problems encountered when yield data are obtained with yield monitors mounted on combines (Blackmore and Marshall, 1996). As the yield maps highly influence the decision making process the maps should represent the variation in yield and not other systemic errors. Although yield monitors have become quite popular for cereals, their spread is probably limited to less than 1% of the area cultivated with cereals. Therefore it seemed attractive not only to use the N-sensor for site-specific fertilisation but also to test its potential to monitor cereal yield.

This study aimed to achieve four goals, (i) to develop a device which allowed to scan crops at reduced crop width representing smaller plot sizes typical for detailed experimentation work, (ii) to allow crop scanning in tall maize plants, (iii) to obtain first experiences with the N-sensor in wheat, maize and potato crops, partly by including additional soil information in the N-fertiliser dressing, (iv) and to test the applicability of the N-sensor as a crop scanner for yield mapping of cereals.

MATERIAL AND METHODS

In the year 2000 the N-sensor was tested in wheat, maize and potato crops. In most of the experiments it was only used to obtain site-specific information on the variability of biomass or the nitrogen status. In one field experiment with wheat, the second and third application of nitrogen were varied in three different treatments consisting of a fully randomised design with stripes, each 7.5 m in width and 200 m in length. The treatments included a uniform application of nitrogen, a sensor treatment by varying single nitrogen doses between 0-80 kg N ha^{-1}, and the combination of the previously obtained sensor information with site-specific soil information. The latter did not yet, however, fully combine on-line biomass-/N-sensor information with the map overlay of soil information, because only average soil values were used for the individual stripes.

Beside testing the reliability of the N-sensor in wheat, maize and potato crops there was a need to develop applications for the special needs of detailed field experimentation. To better match experimental requirements, which frequently require smaller plot sizes, a device was developed which allowed to measure on stripes with reduced crop width. In maize, the sensor can normally only be used as long as the plants are not taller than 40 cm due to height restrictions of the tractor. We sought therefore for an alternative which allowed to scan maize crops in later development stages.

Plant biomass at tillering or shooting of cereals must not necessarily correlate with the final yield, however it may be similar. If biomass could be scanned at plant ripeness the crop scanner could eventually be used for yield mapping. To overcome problems of conventional yield monitors we compared an alternative technique based on the crop scan to detect cereal yields. Additionally point-samplings of destructive harvests were included. First results of this new technique to monitor cereal yields are described.

RESULTS AND DISCUSSION

Crop scanning at reduced crop width

We constructed a frame which allowed to mount the Hydro N-sensor lateral on the backside of the tractor (FIGURE 1).

FIGURE 1. Crop scan sensor for measurements of biomass-/N-status at reduced crop width mounted lateral onto a frame fixed to the tractor. The GPS is positioned on the frame to the right of the sensor.

The sensor was positioned parallel to the working direction, 5.4 m from the mid of the tramline at a height of 1.0 m above plant canopy. Measurements could be conducted either on the left or the right side of the tramline having different treatments. The experimental width was 7.5 m from the mid of the tramline. Precautions were taken that the sensing area was not influenced by shadow. To exclude this, a program was written (F. Ruthenkolk, 2000, unpublished) which allowed calculating sensing areas as function of sensor height, solar azimuth and solar zenith angle. Daytime hours during the vegetation period were predicted when measurements could safely be conducted. The N-sensor is normally mounted on the top of the 3 m high tractor and integrates four ellipsoidal areas of about 45 m^2, the sensed areas lie between 4.5-7 m on either side from the mid of the tramline. Lowering the height of the sensor reduces the sensed area, at 1 m height above plant canopy to about 2 m^2. Lower heights for smaller crop width can be achieved at the expense of decreased sensed areas. The system constructed proved to be advantageous for detailed field experimentation as a higher number of replications could be tested on a smaller area. This becomes especially important when several treatment factors or different management strategies are tested. Compared to the conventional positioning of the sensor half of the crop width and a significantly smaller area was required. In detailed field experimentation the area which can be worked on is frequently limited by the available machine or manpower. Additionally, a smaller area represents better destructively harvested areas sampled during the vegetative period. Frequently fairly small areas, e.g. about 1 m^2, are destructively harvested at one site for each treatment. Other measurements can necessarily only describe point measurements, e.g. soil water content or nutrient level measurements. A smaller sensed area will most likely better represent such measurements.

Crop scanning in maize before and after flowering

With conventional vehicles measurements of the nitrogen status of maize plants can only be realised at early stages of development due to the height of the plants. The N-sensor was therefore mounted on a modified grape harvester and tested successfully throughout the development of maize plants (FIGURE 2).

FIGURE 2. Crop scan sensor for measurements of biomass-/N-status mounted on a modified grape harvester for measurements in maize.

Testing the Hydro N-Sensor

Previous experience showed that the N-sensor can reliably indicate the nitrogen status of plants, especially of cereals starting from the second fertiliser dressing (EC 29-32) (Reusch, 1997). This could be confirmed in our study (data not shown). The differentiation in potato crops becomes apparent only in later stages of growth. The nitrogen status of maize plants can be documented as well. The algorithm implemented for fertiliser dressing, however, still can be improved. Especially at low biomass a too high fertilisation was recommended. This became evident in the experiment where three approaches were tested for site-specific fertilising. Yield did not differ among the three treatments which compared a uniform application of nitrogen according to good agricultural practice, a nitrogen fertilisation treatment based on average crop scan information, and a third treatment which included crop scan information and soil mapping information. Within the stripes the amount given was not varied. A further optimisation might have resulted by varying the nitrogen applications along the stripes. With respect to N-fertiliser use efficiency the third treatment representing the combined information including soil and plant information was slightly better than the uniform treatment. Both treatments, however, were better than the second treatment, based on crop scan information alone. This was mainly due to a non-optimum fertilising algorithm implemented in the N-sensor. As previously demonstrated the sensor has a good potential to detect differences in biomass or in the nitrogen status (Reusch, 1997). A detailed analysis showed that at low biomass over-fertilisation was recommended. Improvements in the fertilising algorithm have now been implemented in a new software which is available since 2001. We conclude from our own results that especially for the third fertiliser dressing it is advantageous to include soil-borne information, e.g. the soil water status, in site-specific soil nitrogen management decisions.

Use of the crop scan sensor for yield mapping

Measurements performed during the ripening of wheat plants showed that the N-sensor can predict site-specific yields. Comparing this information to the data obtained by a yield monitor on a combine showed that the yield patterns are similarly reflected in both maps (FIGURE 3). Yield data obtained by the N sensor and yield monitor correlated with r^2=0.50.

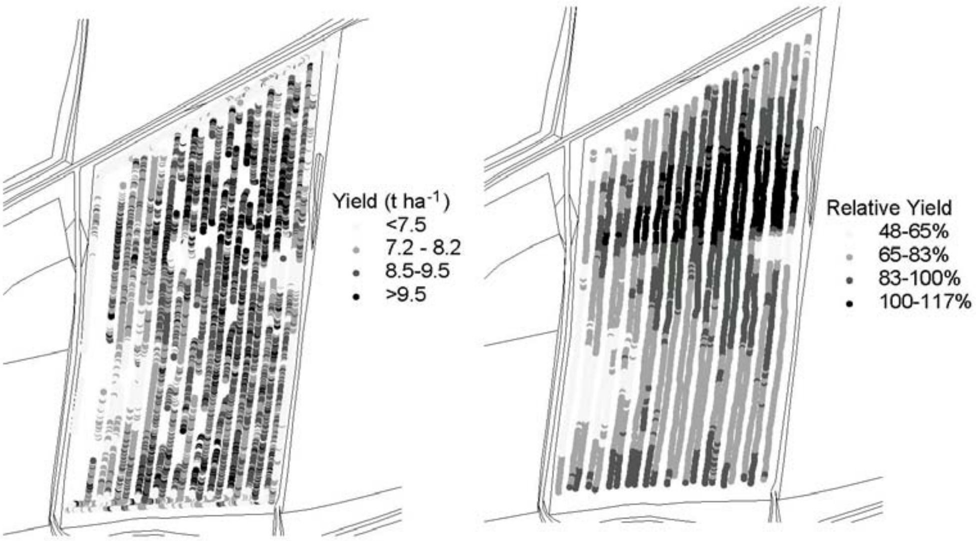

FIGURE 3. Yield data obtained by yield monitor on a combine (t ha^{-1}) (left figure) and estimated at plant ripeness with a crop scan sensor (relative yield) (right figure). Yield was significantly correlated to each other at r^2=0.50.

Clearly, both systems could indicate high- and low-yielding sites. The observation of the yield monitor map points to specific problems of the yield monitor system mounted on a combine harvester. Whereas the crop scan sensor indicates continuous trends in relative yield, strong small scale variations become apparent in the absolute data obtained from the yield monitor. Yield monitor data are not reliable at the beginning and end of a field. Missing data are not infrequently observed with yield monitors. In the literature several classes of errors associated with yield monitors on harvesters have been identified. For our analysis extreme values obtained from the yield monitor were excluded. Additionally, smoothing averages of 20 data values were used for the yield monitor data and five data values for the crop scan data. Thereafter a buffer algorithm was applied including all data within 3 m. No extreme values were obtained with the crop scanner. Data obtained by destructive harvest seemed to compare better to the crop scan data than to the yield monitor data. This evaluation, however, has to be treated with care, because the destructive harvests represented a small area. Our data at the present do not allow to finally compare the two yield mapping systems. However, the high plausibility of the data found with the crop scan suggests a very interesting potential to be further investigated. This might offer a very attractive tool for farmers or service providers having this equipment. Similar results to the ground based crop scan system can also be obtained by remote sensing imagery which principally delivers the same information. Although the latter shows a much better spatial performance, there are several restricting factors. Scanning by remote sensing is very much limited to sunny cloudless days. Ripening of cereals may vary from field to field and sensing has to be performed at a defined plant stage. In general, a more precise scanning is possible with the crop scan system. Relative differentiation of yield classes may be appropriate for most management decisions.

CONCLUSIONS

Previous results demonstrated yield advantages in cereals obtained with the N-sensor which allows sensing the nitrogen status and on-the-go site-specific fertilisation under farming conditions. However, these results could not be tested in detailed experimentation studies due to the sensors scanning area requirements of 12-15 m in width. Whereas this is suitable for practical applications, a rigorous testing of the N-sensor could not be performed. Applications were therefore developed which allow to use the N-sensor in small experimental plots and additionally in tall maize crop stands. Our first investigations point to a reliable detection of the nitrogen/biomass status especially in cereals. We achieved promising results in using the N-sensor as yield monitor in cereals. Further detailed evaluation studies are required and are on-going.

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