FungiPrecise - a German project for precise real-time fungicide application in winter wheat

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Abstract

A joint research project funded by the German Federal Office for Agriculture and Food (support code: 2814704511) was started in fall 2012 to develop real-time application technologies using non-contact sensors for precise fungicide spraying in winter wheat.
The joint research project consists of three subprojects:

1. Precision Farming Module “Fungicide” (proPlant Co.)
2. Ultrasonic-controlled field sprayer (Agri Con Co.)
3. Camera-controlled field sprayer and coordination of the project (ATB).

The decision support system proPlant expert.classic or the internet-version proPlant expert.com (proPlant Co.) resp. suggest the appropriate fungicides and their dosages for a certain infection scenario of eight important leaf and ear diseases of winter wheat. The Precision Farming Module “Fungicide”, which will run on the onboard terminal in the tractor`s cabin, controls the spraying process. The module defines the local target application amount while spraying by using the local sensor value as input parameter.

First results from regression analyses, performed on the data from one year experiments in 2013, showed that there is a dependency between the parameters Leave Area Index (LAI) as well as plant biomass and the sensor value which is important for the dosage algorithm in precise real-time fungicide application.

Keywords: biomass, fungicide, leaf area index, sensors, winter wheat

INTRODUCTION

Regarding to real-time or online technologies in recent years, new technologies have been introduced into practical farming especially in the field of nitrogen application. At least seven sensors were commercially available at that time (Reckleben, 2010, Ehlert, 2011). These technologies are based on sensors mainly detecting the canopy reflectance. In the field of plant protection, although few sensor-based real-time technologies in weed control and growth regulator application are commercially available, solutions for fungicide application are mostly missing currently.

Common practice in crop protection is the uniform application of fungicides over an entire field. At the beginning of fungal epidemics the pathogens usually develop in patches (Campbell and Madden, 1990, Hughes and Madden, 1995), which means that in disease free subareas an application would not be necessary.

The estimation of disease incidence within the field by walking is very time consuming. Therefore, reports of site-specific fungicide application based on visual assessment of diseases and the generation of disease maps afterwards came from experimental sites only (Secher, 1997; Bjerre, 1999). If weather conditions are favourable, diseases spread quickly over the entire field. Under practical conditions, this visible assessment method causes problems, because disease maps are not instantly available to make decisions on disease control.

Automatic disease detection, before their incidence reaches thresholds, would help to provide information about parts of the fields in which diseases occur. Sensor technologies have to replace visual disease assessment. Those sensors must detect diseased plant parts reliably and in early stages of disease development while driving the agricultural machines through the field. The sensors must recognize the disease symptoms efficiently and quickly. There are various approaches which are used in research to detect plant disease symptoms. Bock et al. (2010) wrote a review paper about useful methods.

Since there are no sensor-based technologies on the market for automatic detection before the pathogens reach critical thresholds, an alternative method for optimizing fungicide application in real-time was developed in recent years. The application rate is adopted according to local plant surface (Leaf Area Index, LAI) or biomass, respectively. When soil and relief conditions are heterogeneous within a field it is likely that crop growth is also heterogeneous. This is because of differences in water and nutrient availability (Fig. 1).

Fig. 1. Heterogenic cereal field with different plant growth (winter barley, May 22th 2012, flowering growth stage)

The strategy is to reduce the application amount in areas with low LAI/biomass by letting the concentration of the liquid in the sprayer tank constant. While in sparse canopies a certain amount is lost on the soil; in dense canopies only the upper leaf layers are reached. The plant surface has to be wetted equally by the spray liquid which is especially important in the case of protective fungicides. In the case of systemic fungicides a certain concentration has to be built up in the plant body to kill the pathogen tissue in that. Therefore LAI and aboveground biomass are important parameters in precise variable rate fungicide application. To control a field sprayer by a sensor the sensor signal must correlate with LAI or plant biomass, respectively.

Beside the heterogeneity in plant surface and biomass the economics of fungicide use is another aspect that needs consideration. A well established crop produces higher yield than a crop suffering from malnutrition or water stress. This results in largely differing subarea yield. Consequently, crop losses prevented by fungicide applications and final marginal income can vary significantly within one field. Marginal income is higher in high yield subareas compared to low yield areas. Therefore, variable rate fungicide spraying according to LAI or biomass optimizes the use of production inputs and reduces the operation costs and energy input. In addition, the impact of biocides on the environment is reduced.

The CROP-Meter, developed at the Leibniz Institute for Agricultural Engineering (ATB), was a first mechanical sensor for precise fungicide application in cereals that was commercially available. The sensor was operated in front of the tractor. The horizontally pivoted metal rod was deflected by the bending moment of stem resistance (Ehlert and Dammer, 2006). The sensor signal was correlated with plant surface (Dammer et al., 2008) and biomass (Ehlert and Dammer, 2006) which served as parameters to vary the application amount. In long term field trials average fungicide savings of 22 % were achieved (Dammer and Ehlert, 2006). With one filling of the sprayer tank more area was sprayed. The spraying equipment was operated at more capacity. Therefore, also machine costs were saved. No yield reduction and no higher occurrence of plant diseases have been found in comparison to a common uniform treatment (Dammer, 2005 a).

Within a former research project the information from the CROP-Meter (sensor) and from the decision support system proPlant expert.precise (map) was combined to provide a real-time spraying system with map overlay (Dammer et al., 2009). The prototype of the system proPlant expert.precise estimated infection risks from fungal diseases using weather and field-specific data for up to three management areas with different yield expectations. The system generated a spraying map with different fungicide dosages. The system was tested in 2007 in three winter wheat fields. Compared to a conventional uniform spraying the CROP-Meter with map overlay treatment resulted in up to 32.6 % fungicide savings (CROP-Meter versus uniform: up to 20.3 %).

The operation of sensors, which works contactless, is more easily compared to sensors like the CROP-Meter which was in contact with the crop while spraying. Therefore within the project FungiPrecise spraying technologies will be developed based on ultrasonic and camera technology.

MATERIAL AND METHODS

The sensors used in this project would be able to deliver two-dimensional (camera) and three-dimensional (ultrasonic) signals from the scanned area. In contrast spectrometric canopy reflectance sensors, which are used in practice for nitrogen application, are mixed signals of soil and plant (one dimensional). Also the deflection angle from the CROP-Meter was a one dimensional measurement from the scanned area. Camera and ultrasonic sensors have a small design and can be easy attached to agricultural machines.

Decision support system and dosage algorithm

The most important factor for fungal infections on plants is weather. Decision support systems as proPlant expert.classic can provide the farmer with information about disease infection probabilities (days with high, low and no infection risks), advise the application time, the suitable fungicide products, and also application rates (Volk et al., 2010). The system is especially useful to find the time to start spraying, in case of latent pathogen infestation. This is when fungal infection just begins but symptoms are not visible yet. The system helps to carry out fungicide application according to demand. This avoids useless application measures and possible yield reductions, which were also obtained after a fungicide application (Böttger, 1984; Martin, 1986). Besides weather data, other parameters influencing pathogen infections are incorporated in the system like cultivar, sowing date, plant density, growth stage, nutrition, and soil dryness. In Germany this system is widely used by farmers and consultants for field-specific decisions, not only in cereals but also in other field crops. Therefore, it is used in the project to deliver the above mentioned basic information for a fungicide application in winter wheat.

Beside the information coming from the decision support system the actual LAI and biomass information come from the sensors. According to the correlation between the sensor values and the LAI and biomass a simple, universal and usable dosage algorithm (under practical farm condition) had to be developed. The programming will be done by the company proPlant. The Precision Farming Module "Fungicide" has to be ISOBUS conform to control different commercially available field sprayers.

Ultrasonic sensor controlled field sprayer

Ultrasonic sensors send out short pulses. In sugar cane (Portz et al., 2013), cotton and soybean (Sui et al., 1989), corn (Shrestha et al., 2002) and cereal (Reusch, 2009) ultrasonic sensors deliver promising results to determine various plant parameters as height, biomass, and N-uptake. The research work in this subproject is carried out by the company Agri Con. The time-of-flight of the different echoes is measured and afterwards an "ultrasonic height" is calculated. The aim of this subproject is to investigate the correlation of the sensor signal with biomass and LAI of the crop. A calibration function has to be found for different growth stages and varieties of winter wheat. One sensor (Fig. 2) shall be attached to each section of the spray boom so that it can be controlled separately.

Fig. 2. Test prototype of the ultrasonic sensor (Agri Con)

Camera controlled field sprayer

The 3-chip CCD multispectral camera-sensor (MS2100) takes red, infrared and green images simultaneously. The red and infrared images are used to calculate a grey scale image of the NDVI = (IR-R)/(IR+R) vegetation index. In a calibration step a threshold was determined to separate green crop from background in a binarization step. All image pixels are set to white if a particular NDVI exceeds the threshold. The percentage of pixels representing "green" gives the coverage of the green crop and represents the sensor value.

The background can also be mature or dead plant tissue. This occurs especially in field areas with a sparse crop growth. These areas can mature up to one month earlier compared to well growing areas with dense crop canopies (Dammer, 2005 a). There is no need to protect mature crop tissue with fungicides against pathogen infections.

The camera sensor system (Fig. 3) was used recently for detecting plant parameters in canola (Dammer, 2005 b), for detecting head blight (*Fusarium* spp.) in winter wheat (Dammer et al., 2011), and for herbicide application in cereal crops (Dammer et al., 2012).

As a result of field trials the correlation between plant parameters and the sensor signal is analyzed. In this subproject performed by the ATB a dosage algorithm between the sensor value and the application rate has to be found. With a field sprayer-tractor-camera sensor machinery field strip trials will be performed in the last year 2015 to evaluate the impact of camera sensor controlled fungicide application on crop yield and disease occurrence.

Fig. 3. Test prototype of the camera sensor (ATB)

RESULTS AND DISCUSSION

Collaboration of the subprojects and first year field experiments

The collaboration plan between the three subprojects was compiled and can be defined as illustrated in Fig. 4.

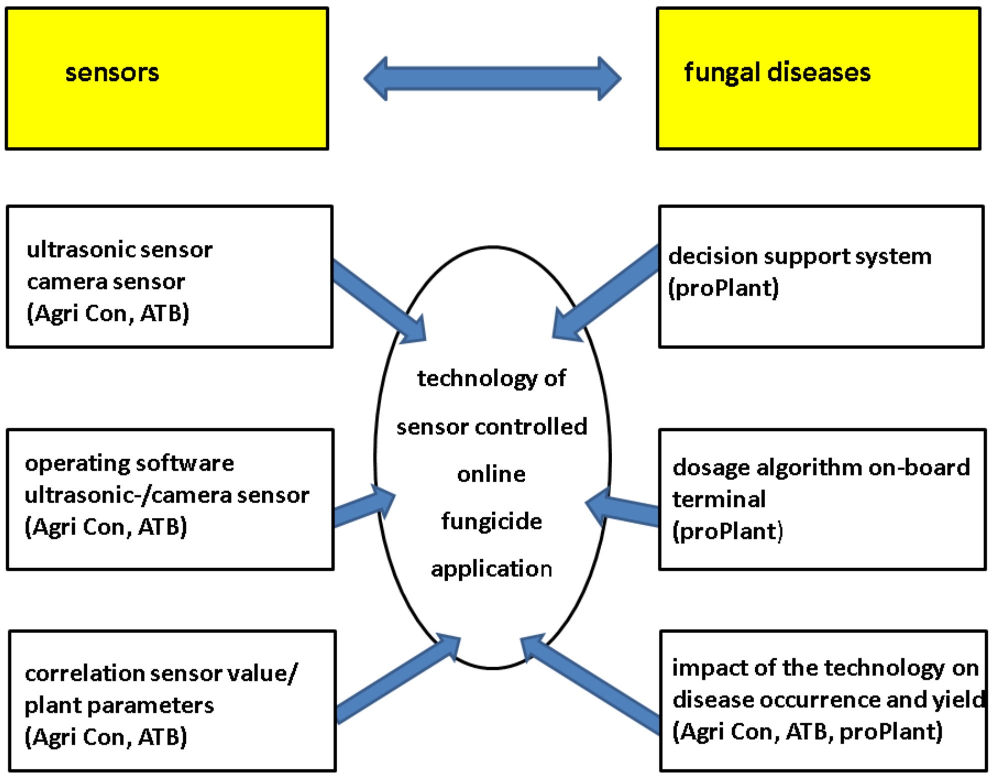

Fig. 4. Structure plan of the mode of collaboration between the 3 subprojects

In the first year 2013 special field experiments were conducted in winter wheat fields of local agricultural farms in responsibility of Agri Con and ATB respectively to analyze the relationship of crop parameters and the sensor signal. The experiments which are the basis of the results presented in this paper were conducted on the following two fields:

Agri Con Ostrau I (longitude E13.11, latitude N51.23)
ATB Dabrun I (longitude E12.71, latitude N51.82.

In total 15 sampling points with different crop growth were selected manually at each measuring time. At these sampling transects the following parameters were determined amongst others:

- Sensor signal (ultrasonic sensor, camera sensor)
- LAI by using the SunScan® device
- Biomass at the detecting area of the sensor.

For characterization the occurring variability of the sensor values and the crop parameters, the minimum and maximum values are shown in Tab. 1 and Tab. 2.

Table 1. Minimum and maximum values of the determined crop parameters of the field Ostrau I (Agri Con) at a sensor detecting area of 1.0 m x 0.5 m (0.5 m)

Date	Ultrasonic height [cm]		LAI		Biomass [kg per 0.5 m]		Growth stage [BBCH]	
	min	max	min	max	min	max	min	max
06.05.	23	57	1.9	5.3	0.28	0.48	33	33
21.05.	37	64	1.6	7.7	0.39	1.28	37	37
11.06.	-	-	3.1	10.0	1.57	4.18	49	55

Table 2. Minimum and maximum values of the determined crop parameters of the field Dabrun I (ATB) at a sensor detecting area of 2.2 m x 1.4 m (3.08 m)

Date	Coverage level [%]		LAI		Biomass [kg per 3.08 m]		Growth stage [BBCH]	
	min	max	min	max	min	max	min	max
15.05.	68	98	2.25	5.23	3.68	6.72	33	34
05.06.	46	99	2.5	6.0	4.9	11.62	51	61
19.06.	40	99	0.4	3.8	4.38	10.86	69	71
04.07.	19	94	1.8	4.7	-	-	57	87

In the field Ostrau I, the camera sensor could not operated because of logistics problems. Due to a bug in the recording software the ultrasonic sensor values were erroneous at the field Dabrun I, as well as the third measurement in Ostrau I on June 11th. Therefore, the respective values of the coverage level and ultrasonic value in table 1 and 2 are missing.

There is a high variability of all sensor values and crop parameters in both of the fields. Regarding to the growth stage according to the BBCH code (Lancashire et al., 1991) there were distinctive growth differences especially in the field

Dabrun I. Even at the first measuring date the crop were in the BBCH 34 in the sparse canopy areas compared to BBCH 33 in the dense canopy areas.

Relationship between the ultrasonic sensor value and biomass as well as LAI

In Fig. 5 and 6 the relationship between the ultrasonic sensor values and the crop parameters LAI and biomass is shown. The first results showed a positive relationship between the ultrasonic value and both parameters biomass and LAI.

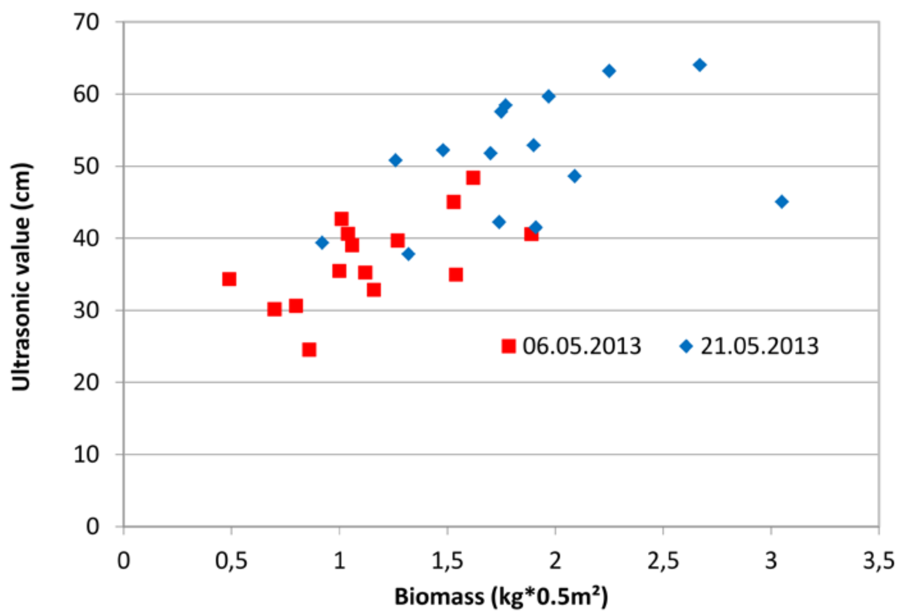

Fig. 5. Relationship between the ultrasonic value and the biomass at the field Ostrau I

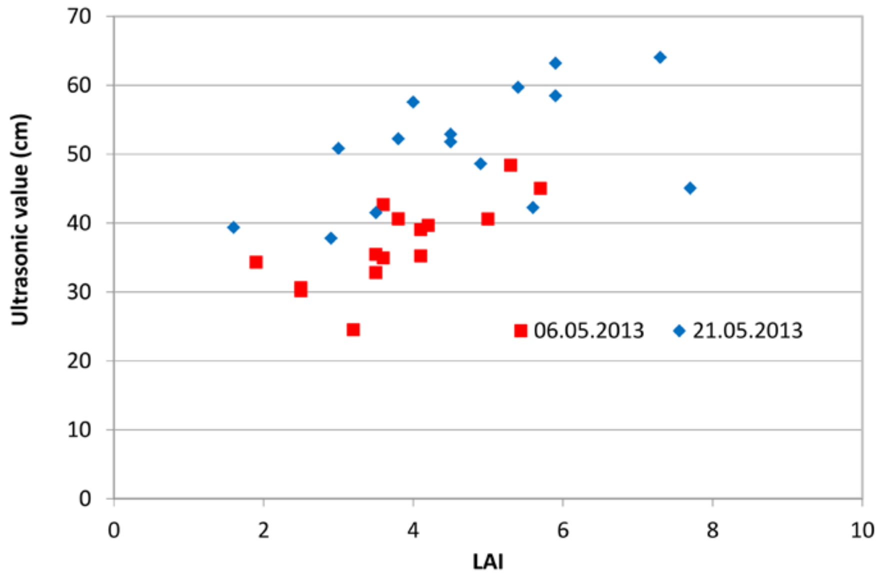

Fig. 6. Relationship between the ultrasonic value and the LAI at the field Os-trau I

Relationship between the camera sensor value and biomass as well as LAI

In Fig. 7 and 8 the relationship between the camera sensor values and the crop parameters LAI and biomass are shown.

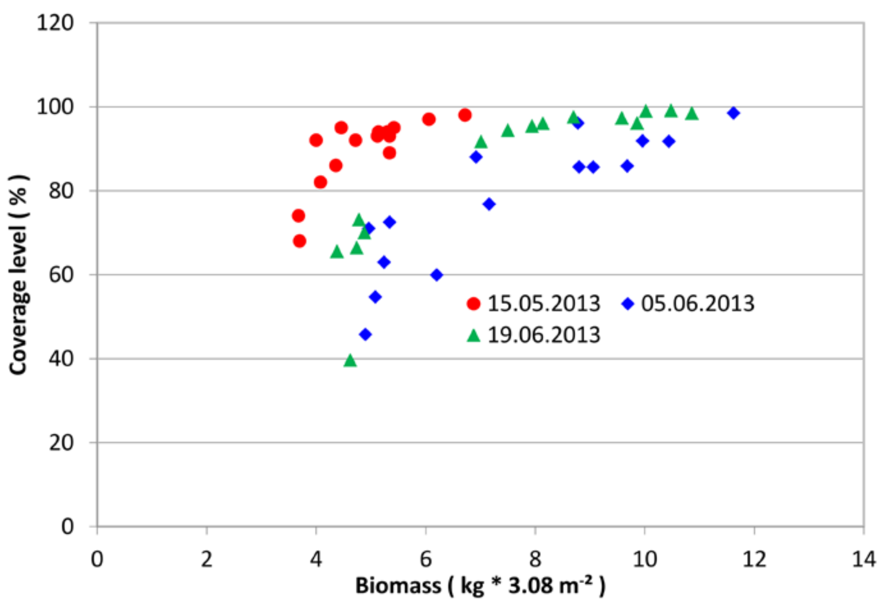

Fig. 7. Relationship between the camera value and the biomass at the field Dabrun I

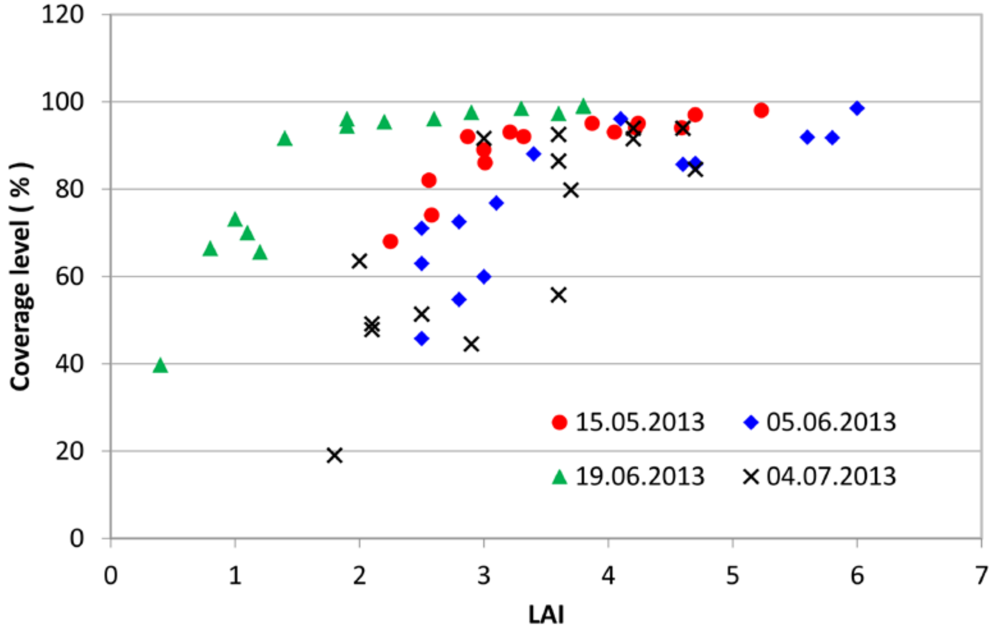

Fig. 8. Relationship between the camera value and the LAI at the field Dabrun I

At the sampling points with a sparse crop canopy, the coverage level increased proportionally at first. In denser crop canopies beginning from a certain biomass (around 6 kg) and LAI (around 3) value on the coverage level remained constant scattering from around 90 % to 100 %. That means from those values on the biomass as well as the LAI was not precisely estimated by the camera measured coverage level anymore.

At the last sampling time, 4th of July the crop at the 15 sampling points was in a wide range of growth stages from BBCH 57 to BBCH 87 and therefore in different colors from green to yellow and grey. A maturing crop can have a high biomass and LAI value but a low coverage level of the green biomass. Therefore at the last sampling time there was also a relationship between the coverage level and the LAI but with more scattering of the data. The relationship between coverage level and biomass could not be investigated because at the last sampling time the measuring area was not harvested. Nevertheless, at this time of milk ripeness no fungicide applications are allowed anymore.

Conclusions

There was a relationship between the sensor values and the two plant parameters LAI and biomass. That indicates the possibility that the sensor values can be used as input signal for the sprayer system to adapt the local spraying amount to the two plant parameters in a variable rate application. These primarily findings have also to be further checked in 2014 when the field trials will be repeated.

The reason why the coverage level measured by the camera sensor remained constant (near a maximum value of 90 to 100 %) from a certain LAI and biomass value on is probably related to the fact that the camera measurement is a two-dimensional projection of the three dimensional cereal crop architecture (several leaf layers). In dense crop canopies the sensor can only "see" the upper leaves. A further reason might be the camera measurements itself. The objective lens was a SIGMA fisheye 8 mm (F3.5 EX DG) to get the measured area as large as possible at a fixed distance. The characteristic of those images is the deformation of the pixels at the margins. Therefore in 2014 an aspherical SIGMA 14 mm (HSM 1:2.8 D) objective with a smaller measuring area will be used in the field trials.

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