Application According to Plant Biomass

Sensor Based Distribution of Nitrogen Fertilizer, Growth Regulators, and Fungicides

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Recently a mechanical sensor pendulum-meter was developed for measuring the crop biomass density in cereal fields. It has a working width of 1 m and is central mounted in front of a tractor. The sensor has finished the stage of research and development and is now market available under the name "Crop-meter". To investigate the agronomic potential of the Crop-meter, the sensor was combined with a centrifugal spreader and a field sprayer for the variable rate application of nitrogen fertilizer, growth regulators and fungicides in real time. Based on farm scale strip trials, the effects regarding savings and yield response the new sensor was positive assessed.

Keywords
Crop-meter, crop biomass, agro-chemicals, variable rate application

Introduction

Information about the distribution of the density of crop biomass growing in a field is necessary for some precision agriculture operations. For time-efficient, non-destructive and labour-saving measurements, sensors are needed which can determine and predict - preferably on-line - the crop biomass and yields of crops. Determination of spatially variable crop biomass can be used for optimising inputs of agro-chemicals, improving crop management, and environmental protection.

Surveying crop biomass distribution is possible by manual methods [1, 2], aerial photography [3, 4], and vehicle based methods [5, 6]. Under practical farming conditions, surveying of heterogeneity is possible by yield mapping in harvesters [7]. In addition to the known methods, site-specific plant mass can be estimated continuously by a mechanical sensor based on a physical pendulum [8].

In the literature a lot of methods for site specific fertilising have been presented [9, 10, 11, 12]. Grid soil sampling can provide an accurate basis for variable rate fertiliser application maps, however research indicates the cost and labour associated with sampling at the intensity required for accurate mapping may be prohibitive [13]. To reduce the expense for grid soil sampling, Fleming *et al.* [13] or Lamp et al. [14] determined management zones of equal soil quality.

Under practical conditions, there are a lot of unanswered questions as how to define these management zones and how to take the samples in the fields. The soil sample-based nitrogen application is more a solution for precision agriculture under research conditions.

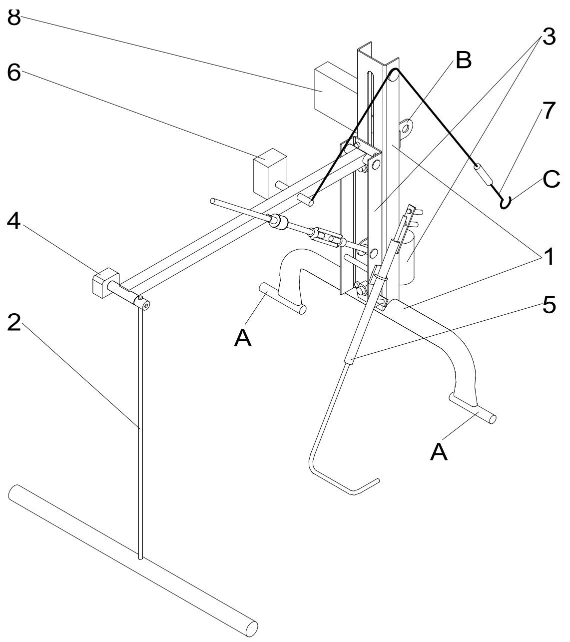
To reduce the expense of grid soil sampling, the real-time Soil Doctor® system was developed [15]. The system features both contacting and non-invasive sensor techniques embodying scientific principles drawn from electrochemistry, soil complex resistivity, and soil conductivity. The system includes equipment and methods for transient fertiliser and seeding rate control as well as data management, visualisation, and interpretation.

The company Hydro Agri offers a nitrogen sensor using spectral analysis of reflectance in plant populations for estimating the required amount of nitrogen-fertiliser [16]. Another method is based on laser-induced-fluorescence for estimating the chlorophyll content in the leaves of grain plants for site specific nitrogen application [17].

The objective of this study was the technological realisation of Crop-meter based variable rate application of nitrogen fertiliser, growth regulators and fungicides including the assessment of agronomic effects.

Material and methods

The sensor has the basic arrangement of a three point mounted device in front of a tractor (**Figure 1**). To change the sensor from working status to transport position and vice versa, the operator does not need



1 - Frame
2 - Pendulum body
3 - Depth compensation
4 - Potentiometer
5 - Surface sensor rod
6 - Inclination sensor
7 - Drawing cable
8 - Electronic box
A,A,B,(C) - Linkage points

Main parameters:
- Complete mass - 40 kg
- Working width - 1.0 m
- Voltage - 12 V -
- Energy consumption - max. 50W

Figure 1: Diagram of sensor Crop-meter

to leave the tractor cab. The procedure is actuated by the movement of the tractor three point front power lift.

The sensor was modified to work with on-board computer (agrocom. ACT) and job calculators (Mueller-Electronic) on a centrifugal spreader (**Figure 2**) and in a field sprayer (**Figure 3**) using the agricultural bus system (LBS), based on the international standard ISO 11783.

To indicate the effects of site-specific applications of nitrogen fertiliser, growth regulators and fungicides, farm scale strip trials were set up with 3 or 4 replications. The basic arrangement of investigations is shown for a example in **Figure 4**.

Figure 2: Sensor in combination with a centrifugal spreader for nitrogen fertilising

Figure 3: Sensor in combination with a field sprayer for plant protection

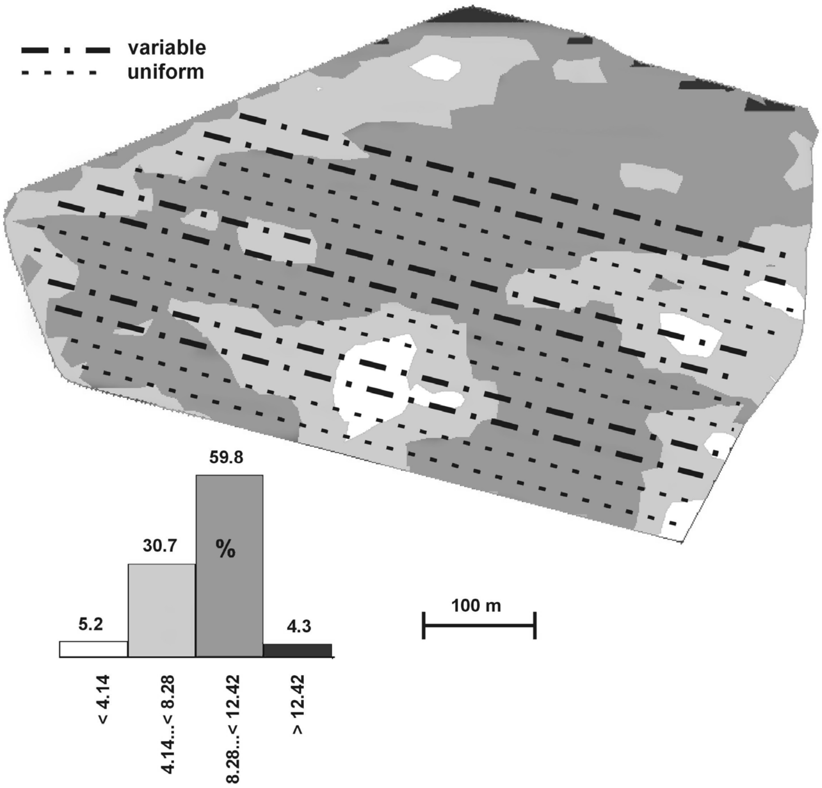


Figure 4: Example for relative plant dry mass distribution and strip arrangement

A requirement for sensor based variable rate application of agrochemicals in real time was the development of a suitable and universal dosage algorithm. Taking into account regulations for agro chemicals, the farmer defines an upper application rate $\dot{m}_{max}$. The defined minimum application rate $\dot{m}_{min}$ depends on the management strategy; it might be zero. Based on a test measurement in a typical tramline of a field, the edge points for area related crop mass m_{C1} and m_{C2} were defined (**Figure 5**). In the interval between the points AP_1 and AP_2, the application rate was adjusted directly in proportion to the measured crop biomass.

To perform the site-specific fertilisation trials in real time, the Crop-meter was combined with a tractor and a fertiliser spreader (Amazone ZAM MAX-tronic) (Figure 2). The Crop-meter was tested in four years 2000 - 2003 for the 2nd and the 3rd application of nitrogen in winter wheat. The total area was 328 ha on 9 fields in different eastern regions of Germany. The application rate for nitrogen fertiliser was based on the rule that, in the parts of field with dry stress (small plant growth) the fertiliser can not be absorbed by the roots of the plants. Therefore the application rate in these parts was reduced. Each strip consists of two working widths of the centrifugal spreader. For yield measurements, a weigh-bridge as well as the yield monitors in combine harvesters (Claas; New Holland) were used. The references were three passes of full working width of a combine harvester in the centre of each strip. This was done to minimise the problem of imprecisely distributed fertiliser and considering the triangular distribution pattern of a centrifugal spreader.

The variable-rate application of growth regulator and fungicides was performed using a commercial 4000 l sprayer (trials in 2000 and 2001: Air Matic® system, 18 m boom width; trails in 2002 and 2003: VarioSelect® system, 24 m boom width) (Figure 3). The rule was to reduce drastically the application rate for growth regulator in parts of fields with sparse vegetation resulting in a lower risk of lodging. Because of reduced surface of leafs and stalks has to be covered by the fungicide

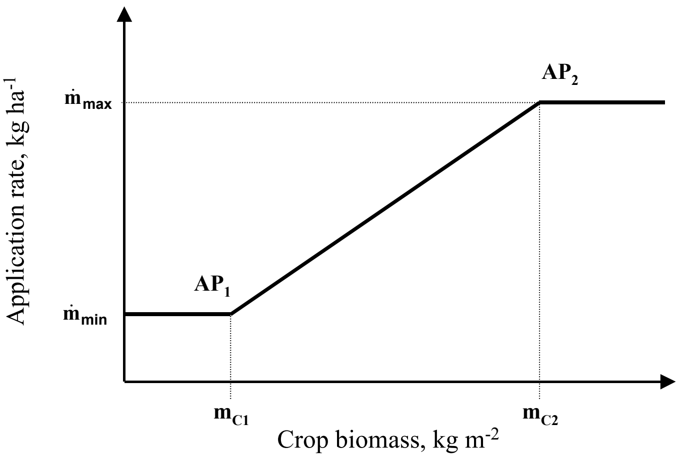


Figure 5: Principle of the application algorithm for agrochemicals

droplets in sparse crop stands, the application rate was decreased in these parts of the field. In some of the experimental fields, strip trials were arranged similar to the fertilisation trials. The variable rate application was performed in one tramline and the uniform application with the farmer's standard dose in the neighbouring tramline. Two strips per treatment plot were harvested by a combine harvester with a yield monitoring system.

Results

Nitrogen fertilization

In the years from 2000 to 2002 the spread solid fertilizer was calcium-ammonium-nitrate (CAN) with 27 % nitrogen mainly. In 2003 solid Alzon 47 with 47 % nitrogen and liquid Piasan 28 with 28 % nitrogen was applied. The Piasan 28 was distributed by the field sprayer. Based on the above described application algorithm, the following savings in nitrogen fertilizers were achieved in winter wheat (**Table 1**).

The savings in the trails were very different in the range from 5.0 to 30.8 %. In the average for all 9 fields the savings were 14.0 % nitrogen fertilizer. The different level of savings can be explained from the chosen set points for the application algorithm and the crop biomass distribution for each field.

To assess the effects of sensor based site specific fertilizing on the yields the harvested grain for each strip was measured by a scale platform (**Table 2**). For two experiments there were differences in the mean plant density at the application day. In the field 2001/2 the uniform fertilized strips had a 1.2° higher mean pendulum angle wile in the field 2003/2 the site specific strips had a 1.5 ° higher mean pendulum angle.

But nevertheless the total amount of nitrogen fertilizer was reduced and the yields were in the range of about 1.5 dt/ha^{-1} total and 3.1 % relatively. higher for the variable rate fertilized plots.

Growth regulators and fungicides

Table 3 shows the results from the variable rate growth regulator and fungicide trials in the for years. The values of the savings varied from 7.0 to 48 %. A visual assessment of diseases was performed in adjacent areas of uniform and variable rate fungicide treatment mainly at milk ripeness of cereals. There were no differences between the variable rate and the uniform plots [18].

Conclusions

The Crop-meter is an efficient, non-destructive and labour-saving sensor for the continuous determination of crop biomass distribution. The Crop-meter is of simple construction and robustness. It can be used for site-specific differentiated treatment with agro-chemicals under hard practical conditions. The sensor is suitable also for hard practical conditions to apply agrochemicals when moisture is the main growth-limiting factor. For this operation, the application rate can be reduced in poor parts of a field. This saves money for the farmer and reduces the danger of pollution.

The level of fertilizer, growth regulator and fungicide savings in the field trials

Table 1: Year, area, growth stage, application rates and savings for site-specific nitrogen fertilising in winter wheat

Year/Field	Area (ha)	Growth stage BBCH	Fertilising rate (kg ha^{-1}) uniform / variable	Savings (%)
2000 / 1 $^{1)}$	50	51 -59	53 / 7-68 (CAN)	9.4
2001 / 1 $^{1)}$	25	51 -59	68 / 7-68 (CAN)	11.7
2001 / 2 $^{1)}$	50	51 -59	65 / 7-65 (CAN)	12.3
2002 / 1a $^{2)}$	40	39 - 59.	120 / 60-160 (CAN)	5.0
2002 / 1b $^{3)}$		37 - 39	120 / 71-141 (Alzon 47)	30.8
2002 / 2a $^{1)}$	52	51 - 59	123 / 60-160 (CAN)	17.1
2002 / 2b $^{3)}$		37 - 39	100 / 60-120 (Alzon 47)	6.0
2003 / 1 $^{3)}$	66	37 - 39	100 / 60-110 (Alzon 47)	28.0
2003 / 2 $^{3)}$	45	37 - 39	51 / 18-68 (Piasan 28)	5.9
total	328		average	14.0

$^{1)}$ 3rd application only $^{2)}$ 2nd and 3rd applications $^{3)}$ 2nd application only

Table 2: Yields in winter wheat for uniform and variable nitrogen fertilizing

Year/Field	Area (ha)	Yield (dt/ha^{-1})		Yield difference (dt/ha^{-1})	Yield difference (%)
		uniform	variable		
2000 / 1 $^{1)}$	50	26.5	27.6	+ 1.1	+ 4.2
2001 / 1 $^{1)}$	25	78.5	78.1	- 0.4	- 0.5
2001 / 2 $^{1)}$	50	82.4	84.0	+ 1.6	+ 1.9
2002 / 1a $^{2)}$	40	61.5	63.0	+ 1.5	+ 2.4
2002 / 1b $^{3)}$		61.5	62.5	+ 1.0	+ 1.6
2002 / 2a $^{1)}$	52	56.0	56.6	+ 0.6	+ 1.1
2002 / 2b $^{3)}$		56.0	56.8	+ 0.8	+ 1.4
2003 / 1 $^{3)}$	66	52.0	56.8	+ 4.8	+ 9.2
2003 / 2 $^{3)}$	45	38.1	40.5	+ 2.4	+ 6.3
total	328	56.9	58.4	+ 1.5	+ 3.1

$^{1)}$ 3rd application only $^{2)}$ 2nd and 3rd applications $^{3)}$ 2nd application only

Table 3: Crop, year, area, growth stage, range of application rate and fungicide / growth regulator savings in cereals

Crop/ Year/Field	Area (ha)	Growth stage BBCH	range of application rate (l ha^{-1})	Savings (%)
winter wheat, 2000/1	44	47 - 51	100 - 250 2)	16.1
winter wheat, 2000/2	5	47 - 51	119 - 250 2)	12.8
winter wheat, 2000/3	5	47 - 51	175 - 300 1)	7.0
spring barley, 2000/4	6	61 - 65	104 - 300 2)	27.4
winter wheat, 2001/1	21	55 - 59	120 - 300 3)	25.0
spring barley, 2002/1	19	69 - 71	40 - 200 1)	37.5
winter wheat, 2002/2	44	59 - 61	55 - 200 3)	8.7
winter wheat, 2002/3	5	59 - 61	90 - 200 3)	15.0
winter wheat, 2003/1	49	55 - 59	50 - 250 2)	33.2
winter barley, 2003/2	8	39 - 42	50 - 180 4)	48.0
total	206			23,1

1) Juwel Top® 2) Opus Top® 3) Caramba® 4) Moddus®

depends on the extension of the vegetation heterogeneity within the field and the chosen maximum and minimum application amount.

Based on the presented results, it can be concluded that the sensor Crop-meter is a contribution to the sensor supported site specific technology and is suitable for a comprehensive use under practical conditions in cereal production.

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Acknowledgements

This project was funded by the ministry BMBF, Germany.

Particular thanks for the work in preparing, implementing and evaluating the tests for pendulum meter goes to the staff Dipl.-Ing. H. Schmidt, Dipl.-Ing. S. Kraatz, Dipl.-Ing. R. Adamek and U. Frank.

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