SENSORY MEASUREMENT OF ACTUAL PLANT PARAMETERS IN CEREALS FOR SITE-SPECIFIC FUNGICIDE APPLICATION

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ABSTRACT

Plant surface to be protected against fungal diseases differs on small-scale in heterogeneous cereal crops. Measurements of several years in winter cereals showed a linear relationship between the parameter plant height and plant surface when ears are fully emerged. Small-scale information about the actual plant height within the cereal stand can be obtained by indirect measurement with the „pendulum-meter“, a mechanical sensor to detect biomass. There was a high linear correlation between the deviation angle of the „pendulum-meter“ and measurements of plant height along transects within heterogeneous cereal stands. To obtain plant surface per unit area to adjust application rates knowledge about stem density is necessary. But correlation between the deviation angle of the „pendulum-meter“ and measurements of stem density at the transect sampling points was weak.

Keywords: Site specific fungicide treatment, plant surface, plant height, plant density, real-time scanning

INTRODUCTION

When spraying fungicides it has to be guarantied, that the plant surface per unit area is sprinkled by the spray mixture. The plant surface area has to be protected against fungi infections to avoid yield losses. It is a characteristic that in heterogeneous cereal crops plant mass differs on small-scale due to varying growing conditions.

At the end of ear emergence (GS 5), when the vegetative phase changes into the generative phase, plant surface does not any longer raise but remains constant. At this growth stage, small scale differences in plant habitués are often more obvious than in earlier growth stages. Raffel und Wolf (1994) reported that there exists a plant surface at ear emergence up to 125000 m² per hectare to be treated against diseases. In low yielding sites of cereal crops, a lower application rate is necessary to guarantee the same substance accumulation rate per plant surface in comparison to high yielding sites.

In European cereal crops, there are often two treatments against plant diseases. An early fungicide application is levelled at such diseases like eye spot (*Pseudo-cercosporella herpotrichoides* (Fron) Deighton), powdery mildew (*Erysiphe graminis* DC.), net blotch (*Drechslera spp*.) or wheat leaf spot (*Septoria tritici* Rob. Ex Desm.) to prevent a possible epidemic spread. A second application is practised between flag leave stage and flowering, to protect the upper three leaves and the ear against diseases like powdery mildew, net blotch, rust diseases (*Puccinia spp*.) or glume blotch (*Septoria nodorum* Berk.). While early fungicide spraying is levelled at some few diseases (i.e. eye spot or powdery mildew), for late application a broad-band fungicide is often used. In regions with early summer drought, farmers used to applicate fungicides only once between flag leaf stage and flowering stage, depending on disease occurrence. Because of high incidences for a differentiation of plant biomass and the high costs of broad-band fungicides, the potential for optimising application rate is highest at late timing of treatment.

A small-scale spatial surveying of plant surface would help quantifying the treatment area, and therefore, could be used to adjust the application rate of site-specific fungicide treatments. There is no vehicle based sensor for scanning plant surface available yet, but biomass sensors are just reality. At present, there are two sensor types, carried by a tractor for real-time scanning of plant biomass: optical and mechanical sensors. Optical sensors use the spectral reflectance of the crops. Disadvantages of this radiometric method are the considerable influence of shade caused by clouds, and the cereal leaves covering each other on the measurements. A mechanical method that overcomes this disadvantage uses the bending moment of resistance of the cereal stems. The measurement principle of the „pendulum-meter“ is described in the following paragraph. Earlier work with the „pendulum-meter“ gave a good correlation of the deviation angle and the actual fresh mass of cereals (Ehlert and Hammen, 1998) and Italian ryegrass (Hammen and Ehlert, 1999).

Because there is no rapid direct measurement method of plant surface on small-scale within the field, suitable plant parameters should be used, which can be related to plant surface. In the presented experiments, it was tested if the parameters plant height and stem density could be estimated by the deviation angle of the „pendulum-meter“.

Further on, results are presented, which investigate the correlation between plant height and plant surface of cereals. Under consideration of plant density this relation could be used to estimate the plant surface per unit area to be treated with fungicides for adaptation of the application rate.

METHODS AND MATERIALS

Estimation of plant height and stem density by the deviation angle of the „pendulum-meter“

Field trials were carried out in 1999 southwest of Berlin. Winter wheat, winter rye and spring barley were grown on the experimental sites. Transects along the tram-lines were selected, characterised by different plant growth. Therefore, a large range of plant parameters along these transects was guaranteed. Transect sampling was done every 10 meters between the tram lines. The sampling points were marked by a stick. Plant density was estimated by counting stems along a row of 1 meter length. According to Trommer (1984) this method is more accurate than using a frame to count stems within a certain area. Two rows beside the stick were counted and the mean was multiplied by 6 (12 cm row distance) to get an estimate of the number of stems per square meter.

Plant height was measured ones. A one meter stick was placed in a horizontal manner along the plant roof. So single stems which are to tall or to tiny were ignored.

Along these transects the crops were scanned mechanically by the „pendulum-meter“. This was done at different times beginning with growth-stage „stem elongation“. Table 1 shows the number of measurements and the growth stage of the cereals in the experimental sites.

As measurement principle of the „pendulum-meter“, a pivoted cylindrical body is moved horizontally through the cereal stand (Figure 1). While moving the „pendulum-meter“ along the transect with a speed of approximately 1 m/s, the deviation angle of the suspended pendulum was recorded by a lap-top PC with a frequency of 75 Hz. When reaching the positions of the sampling points, a mechanical trigger marked this in the recorded data. A mean value out of 100 angle measurements was calculated to get an estimate for the area of ± 0.5 m around the sampling points. The measurement equipment was carried by a light four-wheel platform.

Table 1. Experimental sites, number of sampling points (N), time of measurements and the stage of cereal development (according to Zadoks, 1974).

Culture/ Variety	Sample Size N	Field Site/ Time of Sowing	Time of Measurement/ Growth Stage
winter wheat „Batis“	30	Satzkorn / October 8th	May 6th (GS 32), May 18th (GS 39), June 3rd (GS 61)
winter wheat „Batis“	32	Grube / October 11th	May 20st (GS 39), June 3rd (GS 59)
winter rye „Amilo“	49	Bornim / October 12th	April 30th (GS 32), May 11th (GS 39)
spring barley „Henni“	29	Falkenrede April 2nd	June 8th (GS 51)

Fig. 1. Measurement principle of the „pendulum-meter“ (according to Hammen and Ehlert, 1999).

Multiple linear regression procedure was performed to detect if plant height and/or stem density used as predictors did have an influence on the deviation angle. According to the larger partial regression coefficient, either plant height or stem density were calculated as first variable in the forward stepwise regression procedure to decide which predictor has to stay in the model.

Estimation of plant surface by plant height

Measurements were done between 1988 and 1993 in the region around Berlin. From winter rye, winter wheat, and winter barley, up to 150 randomly selected stems were brought into laboratory (ear fully emerged). Plant height was measured in centimetres from the top of the ear to the stem base.

The surface of a single plant is the sum of the surfaces of stem, leaves and ear. The following equations were used to calculate the surface „A“ of the specific sections of the plant:

- stem (convex surface of truncated cone):

$$A_{stem} = \pi l_{stem} \frac{(d_1 + d_2)}{2}$$

l_{stem}:	length of the stem
d_1:	stem diameter at ear base
d_2:	basal stem diameter

- leaf (triangle):

$$A_{leaf} = 2\frac{a_{max} l_{leaf}}{2}$$

l_{leaf}:	length of the leaf
a_{max}:	maximal width of the leaf

- ear (convex surface of ashlar) after pressing under a defined force:

$$A_{ear} = 2(b_1 + b_2) l_{ear}$$

l_{ear}:	length of the ear
b_1, b_2:	width and depth of the ear.

Because growth conditions differ between years (weather), sites (soil, nutrients, moisture) and varieties (habitués), measurements were done in several years, locations and varieties.

Simple linear regression analysis was performed to characterise the relationship between plant height and plant surface.

RESULTS AND DISCUSSION

Correlation between plant height, stem density and deviation angle of the „pendulum-meter“

Figure 2 gives an example for the change of deviation angle, plant height, and stem density along the transects in winter wheat at the site Satzkorn on May 18th. Stem density fluctuated much more along the transects than plant height did. Similar to all the other experimental sites the plant height curves were smoother than the stem density curves. But the trends along the transects were simply the same. Also the deviation angle proceeded in the same manner as the two plant parameters did.

The characteristic of the winter rye site was an area with very short stems between the 10th and 15th sampling point, whereas stem density remains in the middle range (figure 3).

Multiple regression procedure was used to detect which plant parameter has the strongest influence on the deviation angle. For all sites and for all times the standardized partial regression coefficients of plant height were larger than for stem density. Plant height had a stronger influence on the deviation angle than stem density. To decide, if it was worthwhile to keep stem density as predictor in the model, forward stepwise regression procedure was carried out. Plant height were calculated as first variable in the model, and later stem density. Table 2 shows the R^2 change and the „F-to-enter“ statistic to decide if the entered variable has to stay in the model or not. The sampling size N can be seen in table 1.

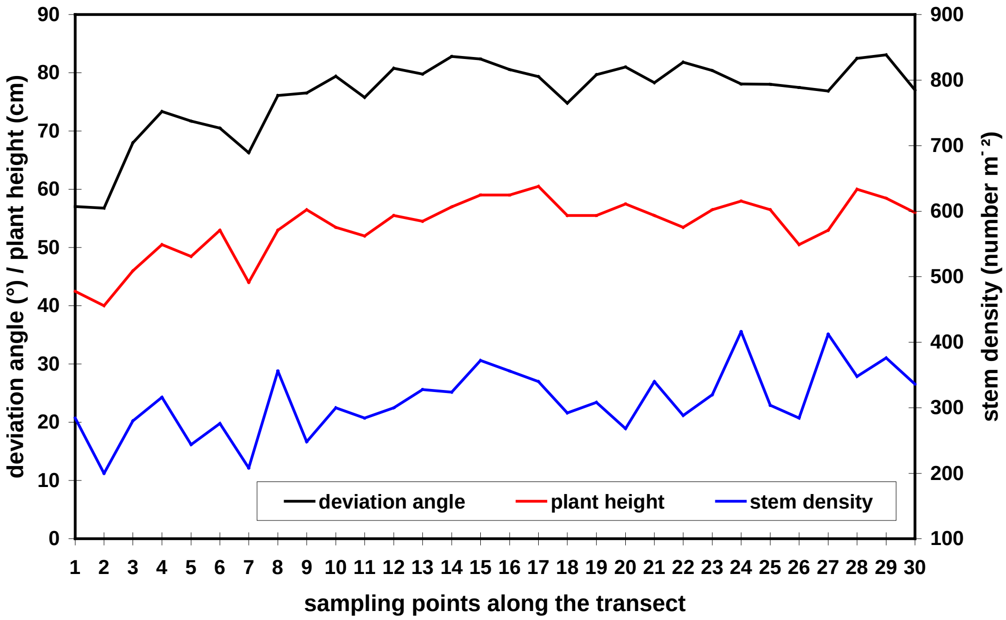


Fig. 2. Deviation angle of the „pendulum-meter“, plant height, and stem density along the transect in winter wheat at the site Satzkorn on May 18th.

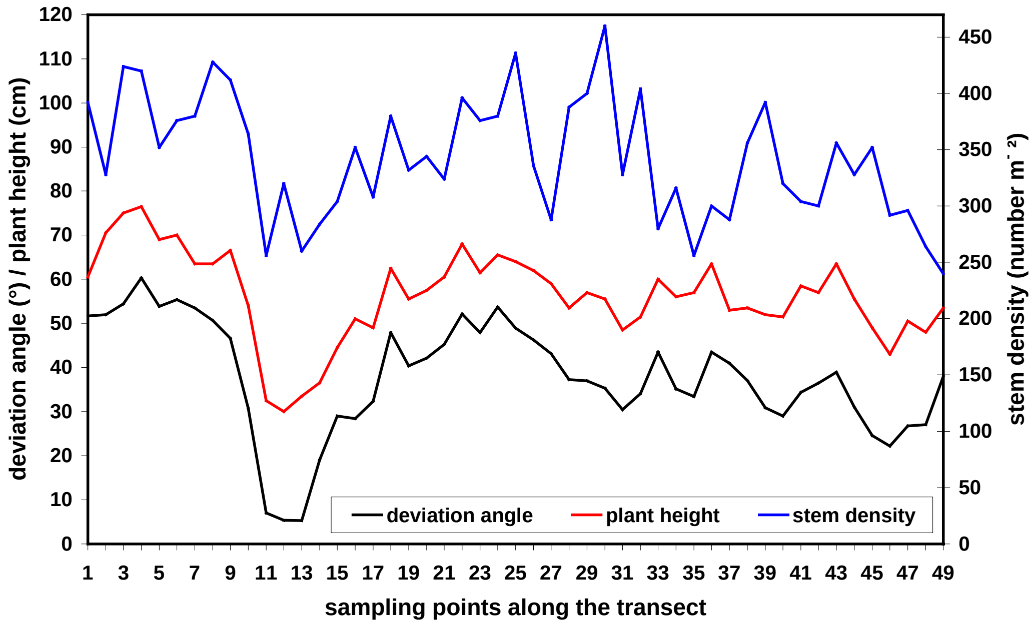


Fig. 3. Deviation angle of the „pendulum-meter“, plant height, and stem density along the transect in winter rye at the site Bornim on May 11th.

Table 2. Change of coefficients of determination R^2, F-to-enter value and p-level of the stepwise multiple linear regression (forward selection, predictors: plant height, stem density).

		Plant Height (cm)			Stem Density (number m^{-2})		
site	time	R^2 change	F-value	p-level	R^2 change	F-value	p-level
Satzkorn	06th May	0.73	75.82	0.00	0.02	1.68	0.21
	18th May	0.81	122.84	0.00	0.00	0.002	0.96
	03rd June	0.78	101.71	0.00	0.04	6.66	0.02
Grube	20th May	0.83	148.42	0.00	0.01	1.62	0.21
	03rd June	0.75	89.45	0.00	0.05	7.70	0.01
Bornim	30th April	0.80	184.17	0.00	0.00	0.01	0.91
	11th May	0.91	460.51	0.00	0.00	0.49	0.49
Falkenrede	08th June	0.86	171.81	0.00	0.02	3.45	0.07

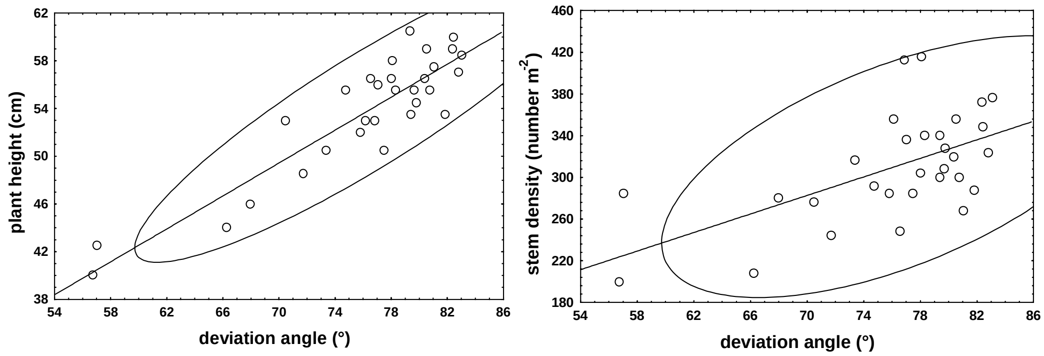
When adding stem density into the model, the gain for the prediction of the deviation angle was low to neglectable in general. When 5% as significance level was assumed, in both winter wheat sites at the late sampling time only 4 % and 5% respectively of the variability of the deviation angle was explained, when stem density was added additionally in the model. In the measurements, plant height explained the deviation angle sufficiently.

Because of nearly the same run of plant height, stem density, and the deviation angle (for example figures 2 and 3), it should be expected that stem density had also an influence on the deviation angle. But in the multiple regression procedure stem density was excluded from the model. This could be explained by the insufficient representativeness of stem density values at the sampling points. The small-scale variability of stem density had a considerable influence on the representative recording of this parameter. In general, counting two one meter row sections seems to few to get a representative value. Beside the high variability of this parameter, the time consuming recording method of counting stems contradict a improvement of accuracy of stem density values.

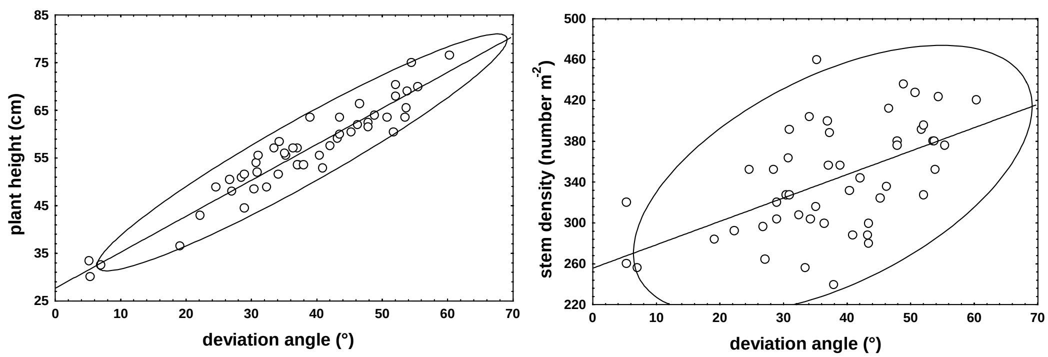
For practical purpose, the „pendulum-meter" should be used to get a real-time indirect measurement of the two plant parameters plant height and stem density. To estimate plant height and stem density by the deviation angle simple regression analysis was performed, where the deviation angle served as predictor. Linear and exponential models were tested. The coefficients of determination of the exponential models were similar and negligible lower or higher than those of the linear models. So it can be concluded, that the linear model describes adequately the relationship. Table 3 shows the parameters of the linear regression equations and the coefficients of determination. More than two thirds of the variability of plant height along the transects was explained by the deviation angle. For stem density, only the coefficient of determination at the sites „Satzkorn" 3rd of June, „Grube" 20th of May, and „Falkenrede", exceeded 0.50. At all sites and sampling times, the data points scattered much more around the regression line than in the case of plant height as predictor. For example in figure 4, the data cloud with the regression line and the prediction interval ellipse is shown for the winter wheat site „Satzkorn" on May 18th and the winter rye site „Bornim" on May 11th. The results from multiple linear regression analysis were confirmed. For plant height the prediction interval ellipse (95 % probability that pairs of plant height, stem density respectively and deviation angle values will fall within this area) is narrow to the regression line, while for stem density the ellipse approach to a circle indicating the weak linear correlation. While plant height was well estimated by the deviation angle, stem density was estimated with a high uncertainty.

Table 3. Intercept b_0, regression coefficient b_1, and coefficient of determination R^2 of the linear regression equation characterising the relationship between plant height, stem density respectively and the deviation angle.

Site	Sample Time	Plant Height (cm)			Stem Density (number m^{-2})		
		b_0	b_1	R^2	b_0	b_1	R^2
Satzkorn	06th May	8.37	0.57	0.73	16.37	6.77	0.33
	18th May	1.09	0.69	0.81	-28.63	4.45	0.34
	03rd June	3.31	1.25	0.78	-393.15	11.08	0.65
Grube	20th May	40.67	0.40	0.83	244.65	4.09	0.56
	03rd June	3.20	1.24	0.75	-401.54	13.78	0.30
Bornim	30th April	2.24	0.62	0.80	260.44	1.74	0.09
	11th May	27.67	0.75	0.91	225.80	2.29	0.30
Falkenrede	08th June	5.71	1.15	0.87	-125.49	15.85	0.53



a)



b)

Fig 4. Scatter plots with linear regression line and 95 % prediction interval ellipse showing the relationship between plant height (left), stem density respectively (right) and the deviation angle of the „pendulum-meter" along the transect in a) winter wheat at the site Satzkorn on May 18th , and in b) winter rye at the site Bornim on May 11th.

The parameters of the „pendulum-meter" (pendulum length, height of pivot point, mass of the pendulum) has a considerable influence on the deviation angle at constant biomass (Hammen and Ehlert, 1999). They have to be adjusted according to the actual biomass, which differs between the growth stages, cultivars and varieties, to secure sufficient measurement range of the deviation angle. But in winter wheat at the sites Satzkorn and Grube at June 3rd , the parameters of the pendulum were the same. The regression parameters b_0 and b_1 were more or less similar (table 3), indicating the same dependency at equal growth stages of the same cultivar. This statement has to be verified by further measurements in various years and various varieties. For the other sampling times and cultivars the regression parameters are different due to differences in existing biomass. As long as there are no specific regression equations for cultivars, varieties and growth stages, calibrations are still necessary. That means determining plant height and stem density at some characteristic sampling points which represent the actual range of existing biomass in the field to estimate the linear regression equations characterising the relationship between plant height, stem density respectively and the deviation angle of the „pendulum-meter".

Correlation between plant height and plant surface

a)
b)
c)

Fig. 5. Scatter plots with linear regression line and 95 % prediction interval ellipse showing the relationship between plant height and plant surface for a) winter rye, b) winter wheat, and c) winter barley.

There was a high linear correlation (figure 5) between plant height and plant surface. The prediction interval ellipse, the 95 % probability that pairs of plant height and plant surface values will fall within this area is narrow to the regression line. The slopes of the regression lines for the three cereals are more or less similar. This indicates the same change of plant surface at average, when plant height changes. In contrast the intercepts are different, indicating the difference between plant surface due to the special habitués of the winter cereal crops.

During the vegetative phase of cereals, plant surface increases. The presented results give an estimation of surface by plant height only when ears are fully emerged and surface remains constant. For earlier growth stages in the vegetative phase repeated measurements has to be done. As measurements of stem, ear and leaves presented in this paper are time consuming, it should be tested, if foliage area index measurements like hand-held optical sensors could be an alternative (Wells and Norman, 1991).

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