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Research Paper

A novel method for testing automatic systems for controlling the spray boom height

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Automatic boom height control (BHC) systems for sprayers have become more common in recent years. The accuracy of the BHC is dependent on the quality of the height measurement as well as on the control algorithm that should be tailored to the dynamic behaviour of the spray boom and its suspension. There is a need for evaluating BHC performance but there is no objective test method available. A protocol was developed for assessing the control accuracy of BHC systems based on a stationary test bench consisting of target area units placed below the height sensors of the sprayer simulating a ground or canopy surface profile. This study should prove the suitability of this test method, of the target area profiles used and of different statistical parameters describing the test results. The test bench and the protocol developed have proved appropriate for evaluating the performance of BHC systems in a stationary test under defined conditions. Test replications gave consistent results. Several statistical parameters were found suitable to characterise the BHC performance but the standard deviation from set point provided the best selectivity. A smooth and a rough field profile were used for the test in comparison to a synthetic profile consisting of different low frequency harmonics. The rough field and the synthetic profile gave similar results. Opposite to the smooth field, tests using these profiles appear sufficiently selective. It turned out that in some cases the profiles could alter comparative test results. This needs further examination.

The test bench developed for this study can be considered a potential basis of a standardised protocol for BHC assessment as well as for the definition of performance limits.

1. Introduction

Automatic boom height control (BHC) systems are optionally offered by many manufacturers of boom sprayers. These systems are designed for maintaining a constant distance of the spray nozzle tips from the target area (soil or canopy) independent from long-wave variations of terrain surface, crop canopy height or roll angle of the sprayer. It is known that an

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Symbols and abbreviations

a	Number of variants (number of BHC systems to be compared), –
d_l	Boom height deviation at left side, mm
d_r	Boom height deviation at right side, mm
f_{xx}	Percentage of measuring values with a deviation of ≤xx cm from set value, %
h_i	Boom height at instant i, mm
h_l	Height of the boom above the surface at left side, mm
h_r	Height of the boom above the surface at right side, mm
h_s	Set value of boom height, mm
HI	Hockley-Index, %
k	Sample size (number of replications for each BHC test), –
LSD	Least significant difference, various
LSD_n	Least significant difference, normalised with the average, %
LSD_t	Least significant difference of multiple t-test, various
MQ_R	Mean square of residues, various
n	Number of measuring values, –
s	Standard deviation, various
SD	Standard deviation from set value, mm
$t_{\alpha;g}$	Quantile of the t distribution for a significance level α and g° of freedom, –
BHC	Boom height control
FFT	Fast Fourier Transformation
US	Ultrasonic

optimum boom height is essential for achieving an even spray distribution (Jeon, Womac, & Gunn, 2004; Wolf, 2002) as well as for sufficient spray drift control (Miller, Lane, O'Sullivan, Tuck, & Ellis, 2008; Nuyttens et al., 2007;). BHC also helps to disburden the operator especially when spraying at high forward speeds as manual boom height control would require a considerable part of the operator's attention. Figure 1 shows the principle of a basic BHC system with one height sensor at each side of the boom.

All known control systems work with ultrasonic (US) sensors for detecting the distance of the boom either from the soil or the canopy. Those sensors may be directed vertically downwards or angled slightly forward in order to avoid disturbances by the spray fan. It can be assumed that US sensors are sensitive to reflections from a cone-shaped region with an angle of approximately 20°–30°. Hence, the shape of the contact area with the target is a circle or an oval.

The measuring values obtained from the height sensors at both sides of the boom are compared to a set value by a computer. This nominal height is chosen by the operator according to the characteristics of the nozzles mounted on the boom, i.e. spray angle and nozzle spacing. For the most common nozzles, flat-fan nozzles with a spray angle of 110° and a nozzle spacing of 0.5 m, the nominal boom height is 0.5 m. It is also possible to select a maximum deviation value tolerated by the control algorithm without any intervention. In case of exceeding this value on either side of the boom, hydraulic or electrical actuators for lifting or tilting the boom are activated in order to minimise the deviation of boom height from the set value.

The performance of the BHC is dependent on the accuracy of the height measurement as well as on the control algorithm that should be tailored to the dynamic behaviour of the spray boom and its suspension.

As BHC systems have been becoming standard equipment for boom sprayers in Europe, testing the performance of those systems should be an inherent part of sprayer examination protocols. This requires a reliable procedure providing reproducible test results obtained under defined conditions.

Currently there is no standard method available worldwide for objective testing the accuracy of these systems. When they are tested, the sprayers are usually operated on real fields and the system's boom height values are recorded. For the evaluation of such data Griffith, Strelioff, and Schnaider (2012) developed a statistical parameter describing the degree of matching the boom height set point, the Hockley-Index.

It is also possible to use artificial obstacles or earthwork for assessing BHC. The German Agricultural Society (DLG) have been using this approach for sprayer demonstrations on the DLG-Feldtage, a biennial agricultural exhibition and show (DLG, 2014). Sprayers have to pass a track with an artificial earth bank on one side of the boom that represents a short slope of the terrain. This is used for visual evaluation of the system performance only.

At Julius-Kühn-Institut (JKI), the German authority for testing of plant protection equipment, a test protocol for boom height control systems was developed on the basis of a test bench in co-operation with CheckTec, a manufacturer of testing equipment. This paper describes the test method and some preliminary studies necessary for its development. One part of the study should prove the suitability of the test equipment and of different statistical parameters describing the test results. Another part was to examine different profiles applied to the test bench and their potential influence on the test results.

2. Method

2.1. Test bench

As a basic principle, the official testing of sprayers shall be as reliable and reproducible as possible. Field tests seem to be inappropriate as they are difficult to reproduce. A controlled laboratory based test system was therefore developed.

The concept of the test protocol for evaluating the performance of BHC was based on a stationary test bench consisting of two target area units (Fig. 2) placed below the height sensors of the sprayer. Each of them consists of an artificial spray target area that can be moved in vertical direction with the help of linear guide units driven by an electric stepper motor. The master target area unit is equipped with a terminal which allows basic inputs as well as the transfer of the desired target area positions with a time increment of 0.02 s from a flash drive to the programmable controller activating the stepper