Torque-Controlled Bottom Conveyor Velocity for the Application of Solid Manure

Effect of a DLC System on Longitudinal Distribution

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To improve distribution accuracy during the spreading of solid manure and secondary raw material fertilizer in a longitudinal direction, a DLC (drive line control) system for solid manure spreaders has been developed. A control circuit allows the DLC system to keep the mass flow at the spreading elements constant. For the examination of distribution accuracy in a longitudinal and lateral direction, a spreading trial with collection trays was carried out. Three application rates (5 t, 10 t, 20 t ha^{-1}) were examined both with and without the DLC system. The experimental set-up over a driving distance of 120m enabled more detailed insight into the quality of longitudinal distribution on a small scale and over the course of the unloading distance to be gained.

The variation coefficients of lateral distribution (VK_Q) ranged between 11.7 % and 16.5 %. At values between 15.6 % and 35.7 %, the variation coefficients of longitudinal distribution (VK_L) were significantly higher both with and without the DLC system. In the test, the DLC system did not have any influence on VK_L. Variability was rather caused by small-scale differences than by differences over the examined travel distance. Nevertheless, the DLC system means significant progress since it provides torque control independent of real driving speed, for example.

Keywords
Solid manure spreader, accuracy of distribution, longitudinal distribution, torque control

Introduction

When spreading solid manure and secondary raw material fertilizers, the nutrients must be spread over the area as evenly as possible in order to avoid over- or under-fertilizing in certain locations. In addition, material cycles should be run while keeping nutrient losses into the atmosphere and the hydrosphere to a minimum. This requires the development of techniques which guarantee the precise spreading of manure and secondary raw material fertilizer. In order not to exceed a fluctuation of 10 kg of countable nitrogen during spreading, variation coefficients between 8 % and 46 % are necessary in the individual substrates depending on nutrient concentration [1]. While the variation coefficients of lateral distribution of current spreading units meet these demands using a combination of beaters and distributing plates, longitudinal distribution is still considered unsatisfactory [2]. Distribution in small areas [3, 4] and over the entire unloading distance [5, 6] exhibits high variation coefficients for longitudinal distribution. Uneven longitudinal distribution is attributed to different dung lying heights as well as slip between the load and the conveyor bottom [4]. The control of conveyor bottom advance by means of the torque at the spreading rollers [5] has long been considered a potential solution to this problem. For precise solid manure spreading in field trials, such a system has already been developed by [6]. Practical implementation, however, has failed so far due to the great technical requirements and the small importance of longitudinal distribution in the standardized test procedure (DIN EN 13080), during which longitudinal distribution is only evaluated based on weight loss over the entire unloading distance. Longitudinal distribution is not measured with the resolution used for lateral distribution.

Material and Methods

DLC System

In the present trial, the implementation of DLC System was realized in a large-volume solid manure spreader (Bergmann company, TSW 660) with a loading volume of 20 m³. The spreading unit of the solid manure spreader is equipped with two vertical beaters and two distributing plates.

The principle of DLC (drive line control) is based on the linear connection between the torque at the spreading elements and actual mass flow [7]. With the aid of a control circuit, bottom conveyor velocity is adapted to a given torque. In a job computer, torque curves are stored for different materials and application rates, which can be selected at an operating terminal in the driver´s cab (**figure 1**). Depending on the driving speed, which is measured at a wheel equipped with a rotational speed sensor (DW 20, Walterscheid company), the set torque value is calculated according to equation 1.

$$M_{set} = m * v + M_{idle} \quad (1)$$

M_{set} - set torque value [Nm]
M_{idle} - torque at idling speed [Nm]
m - inclination corresponding to a characteristic curve for application rate and material
v - driving speed [m/s]

The actual torque value at the beaters and distributing plates is measured at the drive shaft using a contactless inductive torque measuring hub (SF 250, Walterscheid company). The job computer compares the set value with the actual value and uses an electromagnetic proportional valve to control the speed of the oil-hydraulic bottom conveyor drive. An interface at the job computer allows the

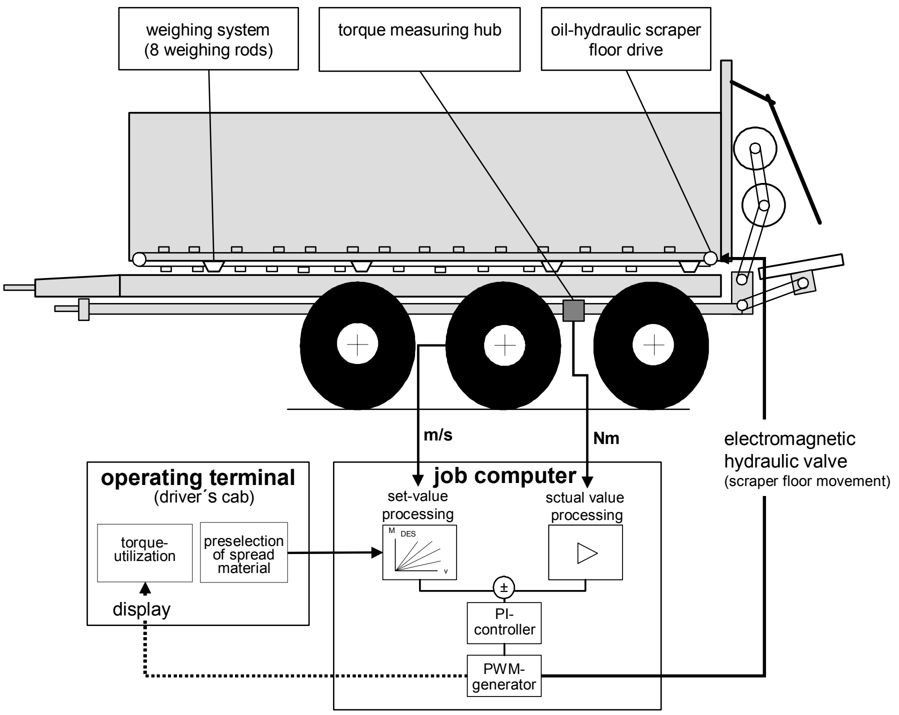

Figure 1: Functional diagram of the DLC system

data of the control process to be read out on-line with a PC.

When the rotational speed of the beaters is inquired (DW 20, Walterscheid company), the operational status is examined, and if the rotational speed of the beaters is too low, a blockage of the bottom conveyor advance prevents the beaters from getting stuck.

Experimental Set-Up

The spread pattern during solid manure spreading was determined in both a lateral and longitudinal direction with the aid of collection trays. Three application rates (10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1}) were examined both with and without the DLC system.

For the measurement of lateral distribution, the spread pattern was determined unilaterally using trays (50 x 50 x 5 cm) over a working width of 14 m in three blocks (**figure 2**). The variation coefficients of lateral distribution (VK_Q) were calculated for a working width of 12 m.

Longitudinal distribution was also measured with the aid of collection trays. Over a total length of 120 m and at a distance of 4 m and 8 m from the tramline, four rows of trays (blocks) were set up, which were 12 m long and comprised 20 trays each (58 x 34 x 11 cm). In order to calculate the variation coefficient of longitudinal distribution (VK_L), the tray contents of the 4m row of one block were added to the tray contents of the 8 m row of another block to simulate the spread pattern. In contrast to the standard technique (DIN EN 013080) for the examination of longitudinal distribution, where the weight loss of the spreading vehicle during the unloading process is measured, the collection trays allow conclusions about spatial distribution to be drawn.

The material used was fresh deep litter manure from a stall for mother cows. The quantity of litter in the stall was 8 kg of long straw per day. Without prior homogenizing, the solid manure was loaded by a telescopic loader in order to achieve great variability in spreader loading. After the two variants of an application rate had been spread, the spreader was loaded again. The first 10% of the loading volume was discarded and not considered in the trial procedure in order to reach the most uniform trial conditions possible.

The first measurement series was positioned after an initial travel distance of 10 m. It was therefore guaranteed that the spreader always worked at the set application rate.

A weighing system (MC2020 PTB, Moba company) installed at the spreading vehicle allowed the solid manure quantity actually spread to be measured. With the aid of eight weighing rods fitted to the vehicle frame, the weighing system determines the weight of the vehicle body. It is equipped with slope compensation. In the future, such a system could enable the documentation requirements for the spreading of farm manure to be fulfilled.

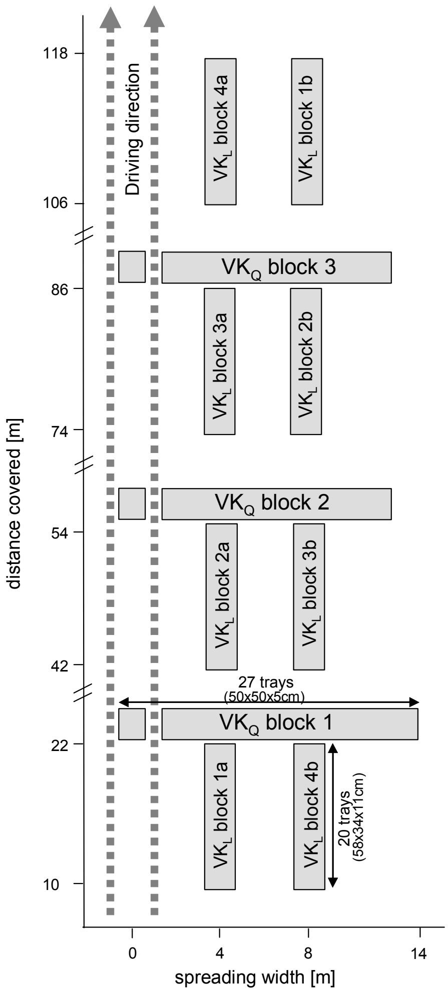

Figure 2: Set-up of each trial variant for the measurement of the variation coefficients of lateral distribution (VK_Q) and longitudinal distribution (VK_L).

Results

Depending on the application rate, the variation coefficients of lateral distribution (VK_Q) ranged between 11.7 % and 16.5 % (**table 1**). At values between 17.0% and 35.7 %, the variation coefficients of longitudinal distribution (VK_L) were significantly higher than those of lateral distribution. With increasing application rate, VK_L was lower (15.6 % to 31.6 %). It must be taken into consideration, however, that at a low application rate the variation coefficient is more strongly influenced by a deviation of 1 t ha^{-1} of fresh mass spread than at a large application rate. Thus, the variation coefficient does not allow different application rates to be evaluated. The variation coefficients do not show that the DLC system provided improved longitudinal distribution (VK_L).

Table 1: Variation coefficients of lateral distribution (VK_Q) and longitudinal distribution (VK_L) at different application rates

Quantity [t ha^{-1}]	VK_Q* -	VK_L without DLC-sytem	VK_L with DLC-system
5 t	16.5 %	35.7 %	31.6 %
10 t	11.7 %	21.6 %	25.1 %
20 t	14.4 %	17.0 %	15.6 %

* calculation based on a tramline distance of 12 m

The unilaterally recorded spread patterns of lateral distribution are shown in Figure 3 (left). At application rates of 5 t ha^{-1} and 10 t ha^{-1}, the spread flanks are rather flat, which enables overlapping errors to be kept small. **Figure 3** (right) shows the spread patterns of longitudinal distribution of the trial variants with DLC System over the tested distance of 120 m. It can be clearly seen that variance within the trial blocks is larger than between the trial blocks. Only at the largest application rate (20 t $_{\text{with DLC}}$) can a difference in the quantities applied be detected between the trial blocks at an average of 16 t ha^{-1} in block 1 and block 4 and 20 t ha^{-1} in block 2 and block 3.

The data of the job computer in **Figure 4** provide information about the function of DLC system. In all three trial runs with DLC system, there was an adjustment phase after start-off, during which the DLC system adapted the set torque value to the driving speed. At an application rate of 10t ha^{-1}, a travel distance of 20m after start-off was required in order to reach the set value. In the other two variants, the set torque value was reached after a shorter travel distance. The adjustment phase thus lasted longer than expected. As a result, part of the spreading process in the first block took place during the adjustment phase.

During the later spreading process, a set-value deviation and a torque-dependent control process of the DLC system only occurred in the trial series 20 t $_{\text{with DLC}}$. However, an improvement with regard to the accuracy of longitudinal distribution could not be established. Instead, the process data show that even exteme fluctuations occur after the control process has begun, which have a rather unfavourable effect on the spread pattern. After a travel distance of 80 m, the torque rose very sharply, which led to a reduction of bottom conveyor velocity. DLC system reduced bottom conveyor velocity and the torque, which led to the torque dropping below the set value and resulted in an upward adjustment of bottom conveyor velocity. For a short time, this fluctuation around the set value led to an uneven spreading process (cf. figure 4), which is not so clearly discernible in the spread pattern of the tray trial in block 3 (cf. figure 3, right).

Even though the solid manure spreader used for variant 20 t $_{\text{with DLC}}$ was loaded with enough material for the entire spreading trial, diminishing bulk density affected the torque values. After a travel distance of 110m, the torque decreased. As a result, bottom conveyor velocity was increased by the DLC system, and the set value was able to be kept virtually constant until the end of the trial.

The process data of the spreading trials without the DLC system (not shown in Figure 4) show an even torque course. Therefore, no torque-dependent control process would have taken place in these trial series. For this reason, a statistical evaluation of the data with regard to the function of the DLC system was impossible.

Discussion

The present trial showed that the lateral distribution of the tested solid manure spreader with a broadcast plate distributor from the Bergmann company (type TSW 660) is sufficiently optimized, whereas there are larger deficits with regard to longitudinal distribution, especially on a small scale.

Neither on a small-area scale nor over the longer unloading distance was any improvement in longitudinal distribution determined which was caused by the DLC system. Only in one out of six trials did the torque deviate from the set value, which would be the prerequisite for the start of a torque-dependent control process. Obviously, the design of the spreader guarantees sufficiently even material supply and thus virtually constant torque even if the materials are less homogeneous.

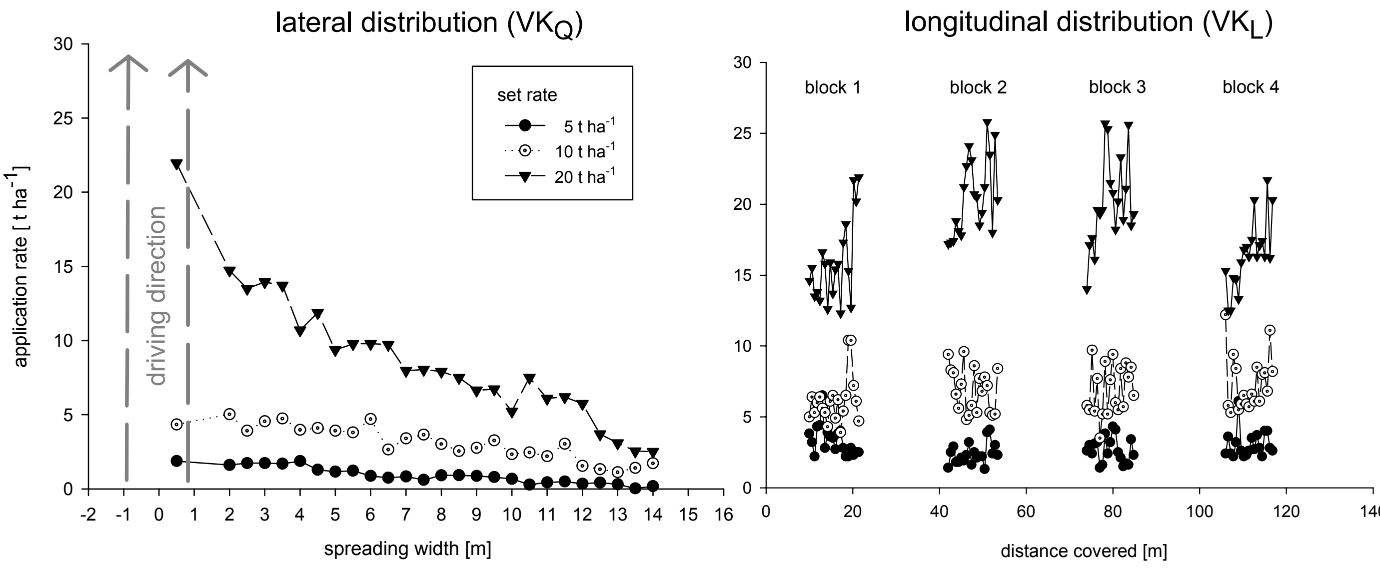

Figure 3: Unilateral spread pattern for the measurement of lateral distribution at different application rates (left) Solid manure distribution in a longitudinal direction with DLC system as a function of the application rate. The quantities applied are shown including the calculated value of overlapping (right).

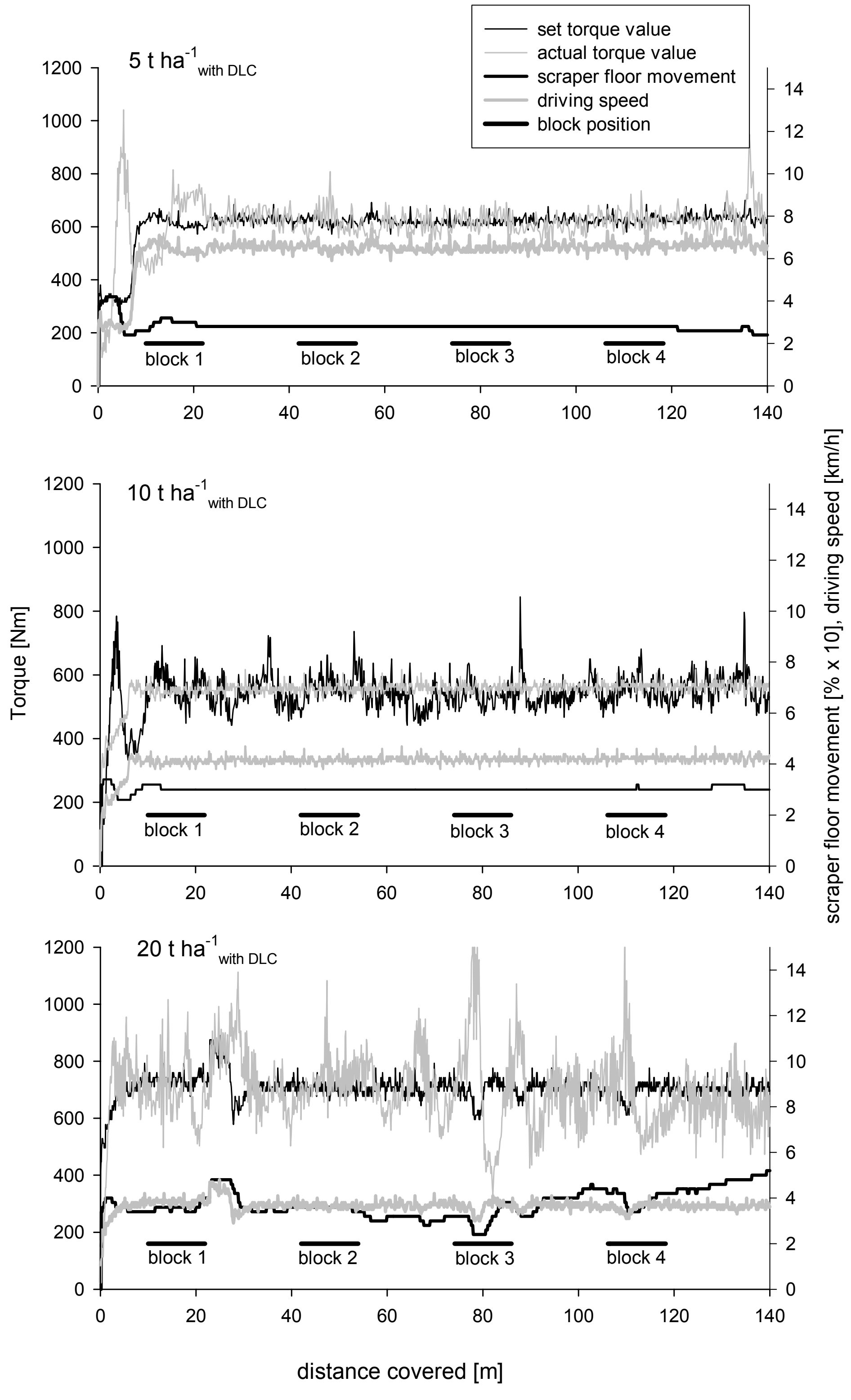

Figure 4: Process data during the spreading trial with the DLC system The location of the measurement series (blocks) is shown in the diagram.

In a study carried out by [6] with a comparable DLC system, torque control mainly became active at larger application rates. Even though control activity was also determined at the largest application rate (20 t $_{with\ DLC}$) in the present trial, the actual torque at the same application rate without the DLC system (20 t $_{without\ DLC}$) was so constant that no torque-dependent control process would have set in. Therefore, a direct connection could not be established.

The use of collection trays showed that longitudinal distribution (VK_L) over the travel distance of 120m is more strongly influenced by small-scale variability than by varying quantities over the unloading distance of 120m. For the smoothing of short-term torque fluctuations, physical transmission between the bottom conveyor and the torque at the spreading elements is too slow for the DLC system to exert an influence on the spread pattern on this scale. According to reference [8], small-area variability is rather influenced by material dissolution, which is more strongly dependent on the conditioning of the material than on the spreading technique. Spreading units with a combination of beaters and distributing plates cannot replace the treatment of the material required for an even spread pattern.

In the trial, it was determined that given the same dissolution of the material VK_Q was significantly better than VK_L. Therefore, the accuracy of longitudinal distribution should be considered and optimized in order to reach an appropriate balance between the two parameters. Since longitudinal distribution is subject to large fluctuations in particular on a small scale, it is sensible to use collection trays when measuring the accuracy of distribution in a longitudinal direction like for the determination of lateral distribution.

However, the process data showed that the described DLC system can make the following contributions towards increased process reliability during solid manure spreading:

- Material preselection and set value calculation allow for very easy and reproducible determination of the application rate The selection of application rates at the operating terminal meet the demand for greater ease of operation of solid manure spreaders using the aid of given setting aids [2].
- The DLC system enables application rates to be kept constant even under different load conditions. In the present trial, this was able to be discerned in the 20 t $_{with\ DLC}$ variant when the set torque dropped after a travel distance of 110m and bottom conveyor velocity was increased. Especially at the end of the spreading process, the DLC system enables bottom conveyor velocity to be adapted to the decreasing bulk height. In **Figure 5**, this is shown using data recorded outside the trial series. As bulk density decreases, the torque is stabilized at distances between 620 m and 660 m.
- Driving-speed-dependent torque measurement allows differences in driving speed to be evened out with the aid of the DLC system.
- The display of torque exploitation on the operating terminal allows the capacity of the spreading vehicle to be fully exploited while maintaining the optimal driving speed, which shortens the spreading time. Thus, economic aspects may also speak in favour of the use of the DLC system.

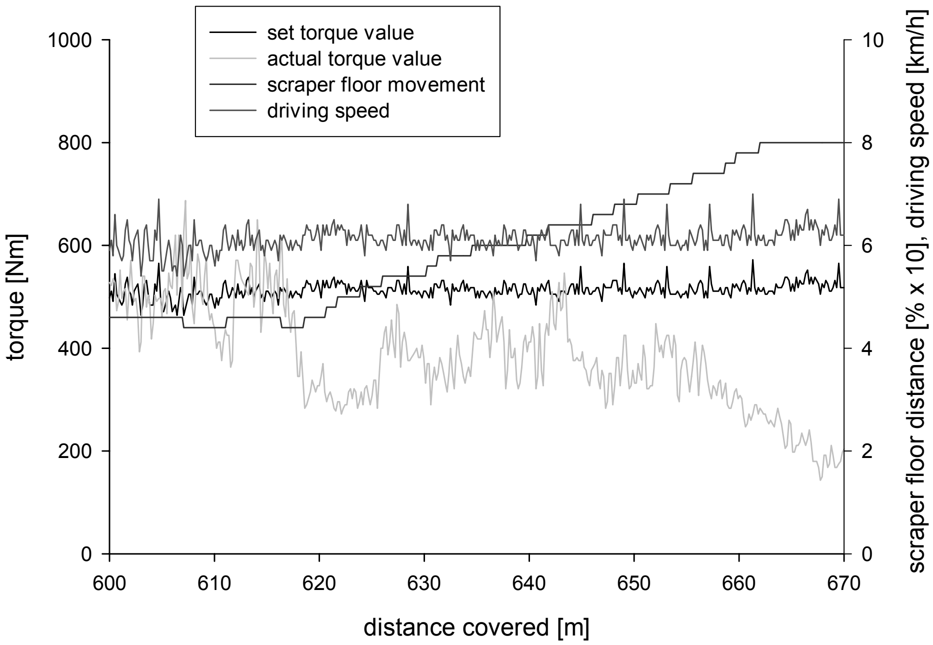

Figure 5: Process data of the DLC system at the end of the spreading process and decreasing bulk density

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Acknowledgements

For the development of DLC system and technical support during the realization of the trials, we would like to thank the companies GKN Walterscheid GmbH (Lohmar), Ludwig Bergmann Landmaschinenfabrik (Goldenstedt), contractor Gerold Dicke (Wildeshausen), and the company Pöppelmann (Lohne) for providing the collection trays. The financial support of the Federal Ministry of Consumer Protection, Food, and Agriculture (BMVEL) enabled this project to be realized.

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