Heiler, Benjamin; Morhard, Jörg; Ströbel, Markus and Köller, Karlheinz

Driving-dynamic characteristics of a studded roller-wheel compared to an agricultural tire

Self-propelled mowers or implement carriers for agriculture, viticulture and landscaping on hilly and steep slopes need a good transfer of traction and side forces, as well as low slip, suitable wheels, with tires or without, as an interface between the vehicle and the ground. With a test rig for single wheels, lateral forces and traction slip of a tire and a studded roller-wheel at different slip angles and different leafy tracks were identified. The median of the stationary lateral forces for the studded roller-wheel was for all variants higher than that of the tire. The slip of the tire, however, was only higher in context of the larger slip angles compared to the studded roller-wheel. As a result of the findings, favorable properties for hillside rides can also be derived for tracks of uncut grass and grass stubble.

Keywords
Studded roller-wheel, slip angle, lateral force, Implement carrier for steep slopes

Abstract
Landtechnik 67 (2012), no. 3, pp. 179–183, 6 figures, 1 table, 7 references

With improvements in the field of the wheel-ground interface and further technical innovations, the needs of agriculture, viticulture and landscape maintenance, on slopes and steep slopes are encountered. Already today, slopes up to 100 % gradient can be driven on [1]. The use of remote-controlled mowers and implement carriers are indispensable in the modern landscape maintenance. Applications in agriculture and viticulture will follow.

The interface between vehicle and ground has a significant impact on the preservation of the vegetation, as well as the safety and efficiency when driving on slopes [2]. The knowledge of lateral forces and traction slip of the wheels, at different slip angles, is important for the directional stability when driving on slopes, in fall line as well as in layer line. With the decrease of lateral guidance and lateral stability respectively and with increasing slip, furthermore the damage of the protective vegetative cover can be presumed [3]. In addition to wheels with tyres, having different treads, grid wheels or sprocket wheels are therefore used, especially for single-axle tractors and remote-controlled implement carriers. A version represents the spiked roller-wheel of the company Maschinen Steiner GmbH, where the cylinder of a spiked wheel is slipped over a tyre-wheel and force-fit connected by increasing the tyre inflation pressure [4].

Material and Methods

As part of a master's thesis at the Institute of Agricultural Engineering of the University of Hohenheim, a mobile test rig for single wheels has been developed that is rigid connected to a tractor by the lower links [5]. Wheels with a diameter up to 900 mm and a width up to 500 mm can be studied. Torque, wheel load and slip angle of the test wheel can be changed oil-hydraulically within a certain range, limited by the construction-design (**Figure 1**). Amongst others, the adjustable slip angle allows the simulation of rides in layer line on slopes.

In the present study, a tractor tyre (cross ply tyre, Trelleborg Extra Traction 463) of 12 inch diameter, 300 mm tyre width at 60 % flank height and a tyre pressure of 0.7 bar, was compared to a studded roller-wheel, (Brielmaier) with 506 mm inner diameter, 4 mm aluminium belt and 41 studs, which are located symmetrical in three rows (**Figure 2**). To install the studded roller-wheel for the test runs on the test rig, it was similarly to the „Maschinen Steiner"- Stachelrad slipped over a type Deestone 20 x 10-10 tyre-wheel and pressurized to an inflation pressure of 1.1 bar to ensure a force-fit connection. For all test runs, a constant torque was set at 200 Nm. The weight of the decoupled parallelogram of the test rig for single wheels is 230 kg, from which the wheel load can be derived for all test runs. The driving speed for the present variants was 2.5 km/h.

The test drives were conducted, each with 4 replicates, on flat grassland on the grounds of the Experimental Station for Horticulture at the University of Hohenheim. At the time of the study the average height of the pasture was 40 cm and the green mass yield was 45 t DM/ha. The average water content of the soil (Filderlehm) was 17.5 mass per cent.

Fig. 1

Test rig for single wheels on test run with small tractor tire

Fig. 2

Studded roller-wheel in test rig for single wheels on grass stubble

The studied track variants were: "grass uncut", "grass cut", with the mown grass as a mulch on the surface, as well as "grass stubble". The average cutting height was 80 mm. The studied variants are shown in **Table 1**. The test runs were carried out after setting the slip angle of the measuring wheel (stationary measurement). During the drives the occurring lateral forces on the wheel were captured by the 6-component-force-measuring-frame, built in the measuring device. The traction slip was determined by calculation from the distance covered by the measuring wheel and the distance covered by the trailing wheel of the test rig for single wheels, taking account of the slip angle [6]. To assess the sod damage, a visual scoring of the sward took place after the test runs.

Results and Discussion

The lateral forces, based on the tractor tyre and the studded roller-wheel, are shown in **Figure 3** and **Figure 4** as a function of the studied track types and slip angles. The primary abscissa (nonlinear) describes the slip angles of the test wheel, the secondary the track variants. On the ordinate the lateral forces F_y in kN are charted. The box-whisker plots show median, and 10, 25, 75 and 90 % percentiles, including outliers.

For a slip angle of 5°, the lowest lateral forces occurred at the tractor tyre, on "grass uncut" and "grass stubble" with an average of 0.4 kN (**Figure 3**). For slip angles of 10 and 20°, in this wheel variant, higher lateral forces of 1.0 and 1.6 kN on "grass cut" and 1.0 and 1.7 kN on "grass stubble" were measured. By the studded roller-wheel, compared to the tractor tyre wheel, significantly higher lateral forces with values up to 2.5 kN for "grass uncut" and 20° slip angle, can be transmitted (**Figure 4**). With increasing slip angle of 5 over 10 to 20°, an increase of the average lateral forces on "grass stubble" of 0.5 to 1.3 to 2.3 kN was observed. An influence of the studied track could not be verified for the studded roller-wheel. The values of the lateral forces on "grass cut" and "grass stubble" differ only slightly from the values on "grass uncut". At a slip angle of 5°, for both types of wheels the mean values of the lateral force were in the range of 0.4–0.5 kN. Slip angles of 10 and 20° on the other hand, led on the studied track variants to significantly higher lateral forces on the studded roller-wheel compared to the tractor tyre-wheel. The difference was with 0.9 kN highest in the "grass uncut" variant at 20° slip angle.

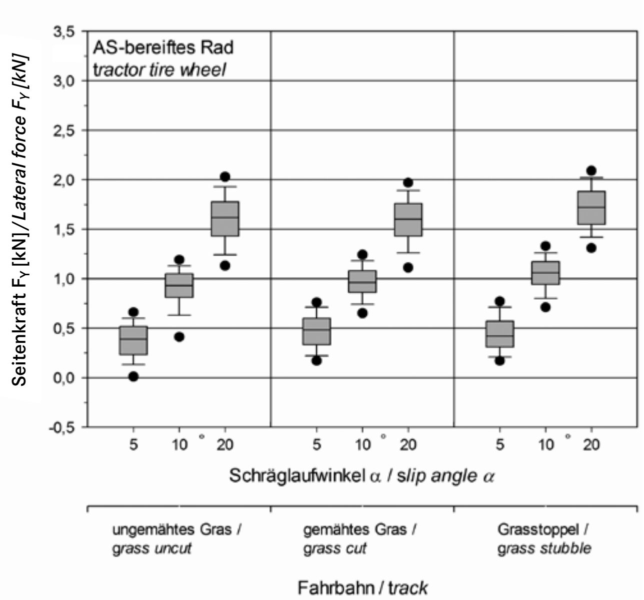
The results of the traction slip calculations are shown in **Figure 5** and **Figure 6**. The plot was analogous to the lateral force. It was found, that with 3.6 % the slightest slip i_T occurred at the tractor tyre, for 0° slip angle, on "grass uncut" and "grass stubble" (**Figure 5**). With larger slip angles, there was an increase of slip. Only on "grass uncut", up to 5° slip angle, no increase was observed. Higher values were observed for all the studied slip angles with a maximum of 18.0 % at 20° slip

Table 1

Overview over the variants shown

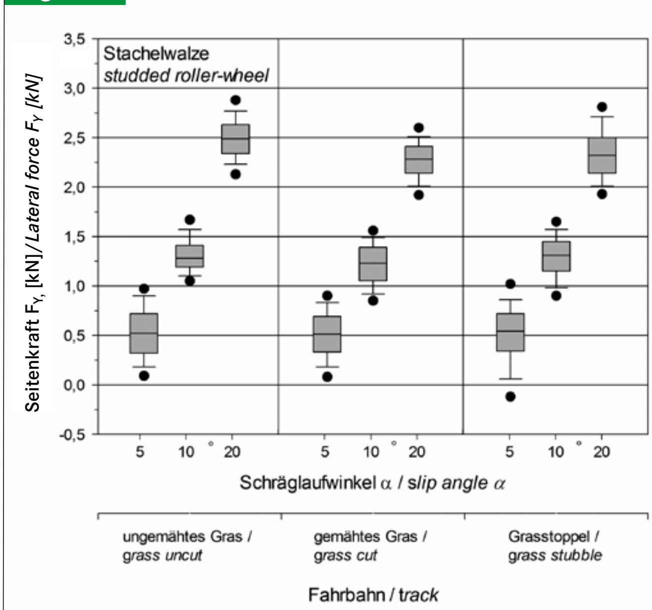
Rad *Wheel*	**Radlast FZ [kN]** *Wheel load FZ [kN]*	**Antriebs-moment M_T [Nm]** *Driving torque M_T [Nm]*	**Fahrbahn** *Track*	**Schräglaufwinkel α [°]** *Slip angle α [°]*
Trelleborg Extra Traction (AS) *Tractor tire Trelleborg Extra Traction*	2,3	200	ungemähtes Gras *grass uncut* gemähtes Gras *grass cut* Grasstoppel *grass stubble*	Seitenkraft F_Y *Lateral force F_Y* *5/10/20* Treibschlupf i_T *Slip i_T* *0/5/10/20*
Brielmaier Stachelwalze auf Deestone 20x10-10 *Brielmaier studded-roller wheel on Deestone 20x10-10*				

Fig. 3



Lateral force F_Y, tractor tire at 3 slip angles α and 3 different tracks

Fig. 4

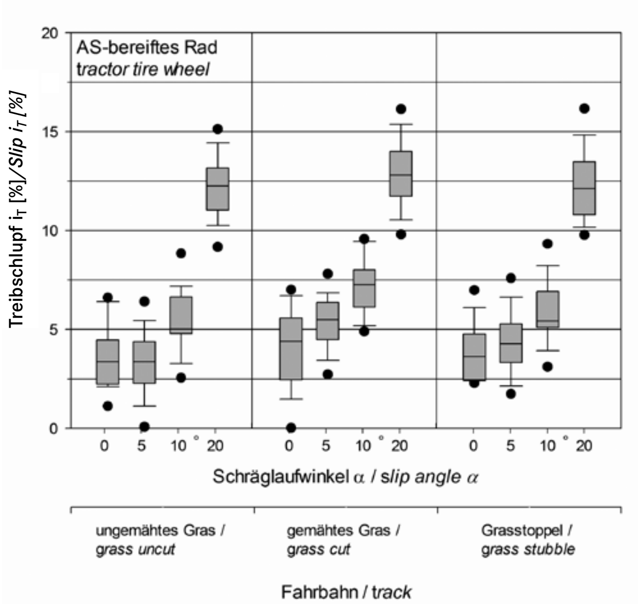


Lateral force F_Y, studded roller-wheel at 3 slip angles α and 3 different tracks

angle on "grass cut". On "grass uncut", for the studded roller-wheel, up to a slip angle of 10° no increase of the slip could be detected (**Figure 6**). The lowest values at these angles showed the track variant "grass stubble". The largest slip occurred on "grass cut". During the test runs in this variant, at slip angles of 20°, values up to 15.1 % were detected. At this slip angle there were nearly no differences between the drives on "grass uncut" and "grass stubble". With increasing slip angle, for the studded roller-wheel, the associated increase of slip is smaller, compared to the tractor tyre wheel. The traction slip values of the studded roller-wheel were on "grass uncut" and "grass cut" only for slip angles of 0 and 5° above those of the tractor tyre wheel. On "grass stubble" and at angles of 10 and 20° higher values for the tractor tyre were observed.

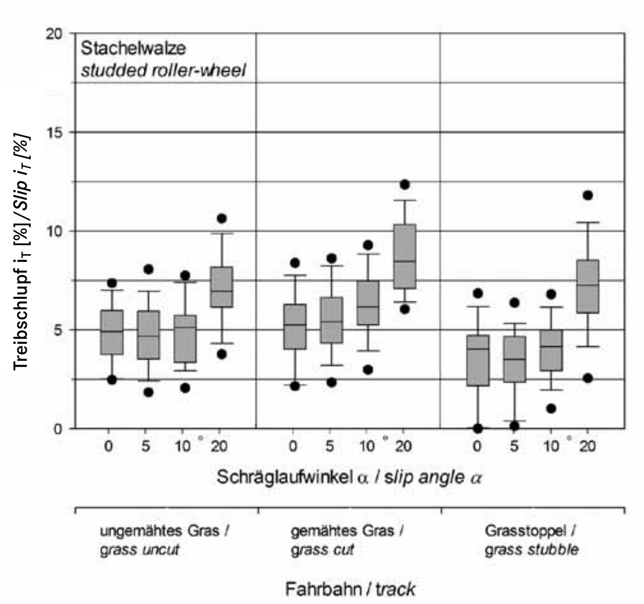
The results confirm the observation that in contrast to the cleats of the tractor tyre, the studs of the studded roller-wheel penetrate the soil form-fit on "grass uncut" as well as on "grass cut" and thus generally higher lateral forces can be retained. However, the point-like contacts of the studs at a slip angle of 5 ° initially result in lower lateral forces. The better linkage to the

Fig. 5



Slip i_T, tractor tire at 3 slip angles α and 3 different tracks

Fig. 6



Slip i_T, studded roller-wheel at 3 slip angles α and 3 different tracks ground on grass and grass stubble for the studded roller-wheel is seen as a reason for a significantly slower increase of the slip with increasing slip angle, in contrast to the tyre. The type of construction low cleat height of the tyre, certainly has a significant proportion on results. For non-cut grass the green mass forms a labile intermediate layer, which negatively affects the wheel-ground contact of the tractor wheel by shearing and loosening the grasses and prevents the linkage between the tread and the ground. This effect is even strengthened by a hard and dry soil. A mulch layer, which consists of deposited cut grass, has also the effect of an overlay, which is moved by the driving force and set against the driving direction, so that by trend the highest slip and the lowest lateral forces were observed in the variant on mown grass. On sloping terrain a complete, intact sward provides the best protection against erosion. Finally the damage on the crossed areas was evaluated by visual scoring. At small slip angles, for both wheels nearly no damage was observed. At high slip values and large slip angles, damage was mainly observed by the tractor wheel – mostly in the form of contusions and shearing – rarely in torn parts of the vegetation cover. The studs of the studded roller-wheel penetrated the ground, even under the dry soil conditions during the test runs and left especially on “grass stubble” truncated conical cavities. High slip angles resulted, under the experimental conditions, in tearing of parts of the sward. Under humid weather conditions, respectively higher soil moisture, for the tractor tyre as well as for the studded roller-wheel, more damage to the sward and the soil surface cannot be excluded.

Conclusions

The studded roller-wheel, force-fit connected to a tyre-wheel, was regarding the driving-dynamic parameters such as lateral force and slip, superior to the agricultural tyre. Due to the stationary change of the slip angle, the influence of the soft edges of the inner wheel can be neglected for the result [7], which allows the transferability of the results on studded roller-wheels of the same design that are rigid associated to a drive axle.

For large slip angles, the damage of the sward was more serious by the studded roller-wheel. However, the measured lateral forces show that smaller slip angles are required to reach comparable values to those of the tractor tyre, when driving in layer line. How far the penetration of the studs leads to a critical damage of the vegetation cover cannot be deduced from the experiments. Also a positive tillering-supporting effect cannot be excluded.

The test runs were carried out on a very dry soil. Therefore, the results cannot be readily applied to soils with higher water contents. However, it can be assumed that especially dewy pastures intensify the observed differences between the studied wheels.

In future studies, the results should be supplemented and proved by experiments with a transient change of the slip angle, as well as extended by the study of other types of tyres and studded roller-wheels.

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Authors

B.sc. Benjamin Heiler is a master student, **Dr. sc. agr. Jörg Morhard** is a research associate, Markus Stroebel is a technical staff member at the Institute of Agricultural Engineering, University of Hohenheim, Department of Process Engineering in Plant Production (Head: **Prof. Dr. Dr. h.c. mult. Karlheinz Köller**) Garbenstraße 9, 70599 Stuttgart, e-mail: joerg.morhard@uni-hohenheim.de

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