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Soil protection and tillage: How high is the wheel load in the plough furrow?

Even before laws and restrictions raised the awareness of soil protection, tillage is under suspicion to cause enduring damage to the subsoil. Industry has been trying, on the one hand, to develop alternatives like on-land ploughing but, on the other hand, long-term studies show that the compaction zone at the plough pan on German fields had not increased in the past 50 years, but rather reduced. Which stresses actually occur due to the passage of tractor wheels in the plough furrows? The results presented here provide a surprising answer.

Keywords
Tillage, soil protection, tire deflection, wheel load

Abstract
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With a tractor in a horizontal position, the wheel load of both wheels on an axle is nearly equal and about 50% of the total weight is supported on each side of the tractor. When the tractor tips to the long axle - such as while driving in a plough furrow - the weight distribution changes (**Table 1**). The vertical centre of gravity of the tractor points to the plough furrow side. Thus the question emerges: which impact does the attached plough have on the weight distribution during ploughing? Relevant scientific publications [1; 2] say that during ploughing a shift of the weight to the furrow wheels occurs at a ratio of ca. 60/40 (**Table 1**, Var. a). Renius [2] states a load on the rear furrow wheel of up to 45 % of the total load.

Whether this holds true in soil tillage today with the current ploughs with a greater working width is of great interest with regard to the compaction problematic under the furrow wheels.

While standing, the wheel loads of a vehicle can be calculated with simple weighing. Dynamic readings during passage are, however, very complicated. The usual methods of force measurement in mechanical engineering via multi component measurement collars or strain gauges are difficult to implement on a standard tractor chassis.

A New Method

New possibilities have opened with a method which was already presented in the 3/2011 issue of Landtechnik with regard to tire pressure adjustment: a tire-specific characteristic curve for each level of tire inner pressure can determine the wheel load from the tire suspension measured in the wheel rim. The method can document and diagram the dynamic load levels during driving operations for each wheel individually directly at the interface between vehicle and soil. The transfer of the measurement values from the turning wheel is accomplished by radio transmission.

In the Institute of Agricultural Technology and Biosystems Engineering of the Thünen Institute (vTI) in Braunschweig studies on the furrow wheel load have been carried out since spring 2010 with this new method. For this project, a tractor was used with front and rear wheel on one side equipped with the new technology (**Figure 1**). A 4-share rotating plough type Lemken Opal 140 was used. A roller attachment served as front weight. With this assembly, although it was not possible to document the weight distribution on all wheels simultaneously, the land and furrow sides could be monitored alternately through the rotating of the plough. In comparison of the land and furrow side results, system-caused deviations were prevented by us-

Fig. 1

Wheel load measurement in the plough furrow

Table 1

Data from variants a and b of the tractor-plough combinations and the resulting wheel loads on the rear axle of the tractor

Parameter/*parameter*	**Variante a/*Variant a***	**Variante b/*Variant b***
Anzahl Schare/*Number of shares*	3	4
Arbeitsbreite pro Schar [cm]/*Working width per share [cm]*	28	40
Arbeitstiefe [cm]/*Working depth [cm]*	30	25
Vertikalkraft des Pfluges F_{VP} – Gewichtskraft + vertikale Bodenkraft – Stützkräfte am Pflug durch Sohlen und Tast-/Stützrad [daN] *Vertical force of the plough F_{VP} - weight force + vertical soil force – support force on the plough through the sole and feeler/support wheels [daN]*	650	1 200
Horizontaler Abstand Mitte Hinterachse – Vertikalkraft des Pfluges [mm] *Horizontal distance centre real axle – vertical force of the plough [mm]*	1 700	2 500
Leermasse des Traktors [kg]/*Empty mass of the tractor [kg]*	4 000	5 500
Radstand [mm]/*Wheelbase [mm]*	2 450	2 750
Lastverteilung ohne Ballast und Pflug Vorderachse: Hinterachse [%] *Weight distribution without ballast and plough front axle: rear axle [%]*	40 : 60	45 : 55
Spurweite [mm]/*Track width [mm]*	1 800	1800
Frontballast [kg]/*Front ballast [kg]*	300	700
Horizontaler Abstand Schwerpunkt Frontballast – Mitte Vorderachse [mm] *Horizontal distance centre of gravity – centre front axle [mm]*	600	1 400
Breite der Reifen an der Hinterachse [mm]/*Width of tires on the rear axle [mm]*	480	700
Schwerpunkthöhe mit Ballast [mm] *Height of centre of gravity with ballast [mm]*	650	900
Hinterachslast mit Ballast ohne Pflug G_{TH} [daN] *Rear axle load with ballast without the plough G_{TH} [daN]*	2 320	3 220

	Landrad HA *Land wheel rear axle*	**Furchenrad HA *Furrow wheel rear axle***	**Landrad HA *Land wheel rear axle***	**Furchenrad HA *Furrow wheel rear axle***
Traktor in Ebene (mit Ballast, ohne Pflug)/*Tractor on level surface (with ballast, without plough)*				
Radlast [daN]/*Wheel load [daN]*	1 160	1 160	1 610	1 610
Anteil an Hinterachslast [%]/*Percentage on rear wheel load [%]*	50	50	50	50
Traktor in Furche (mit Ballast, ohne Pflug)/*Tractor in furrow (with ballast, without plough)*				
Radlast [daN]/*Wheel load [daN]*	970	1 350	1 410	1 810
Anteil an Hinterachslast [%]/*Percentage on rear axle load [%]*	42	58	45	55
Traktor beim Pflügen/*Tractor while ploughing*				
Radlast [daN]/*Wheel load [daN]*	1 360	2 000	3 150	2 000
Anteil an Hinterachslast [%]/*Percentage on rear axle load [%]*	41	59	61	39
Anteil an Gesamtradlasten [%]/*Percentage on total wheel load [%]*	27,4	42,9	37,5	26

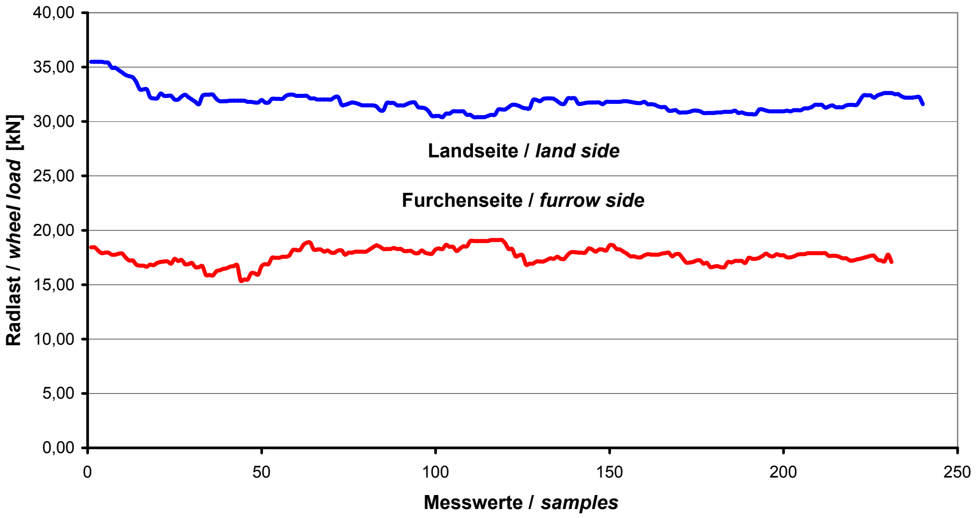
ing one measurement system for both sides. In order to ensure otherwise technically optimal conditions, the alignment of the plough in combination with the tractor was controlled and optimized by a specialist from the manufacturer. The measurement trips were carried out on an area with no mentionable slope, so that apart from the slanted level of the tractor in the plough furrow, no further slope-caused influences on the weight distribution had to be considered

Reverse Ratio

Even during the measurements a surprising trend was indicated: The higher loads were found not on the furrow wheel but rather on the land wheel (**Figure 2**). Instead of the expected ratio furrow wheel load/land wheel load of 60/40, the measurements showed a ratio of 40/60. The wheel loads in the measurements varied by only +/- 2.5 kN related to the mean value.

In order to verify the results, which at first glance appear to contradict existing statements, and to exclude the possibility of errors in the carrying out of the trials, the complete technology was rechecked and the measurements repeated in multiple trials. Even in ploughing on a slope with additional tilt of the tractor in the driving direction, the results were confirmed. Since first no plausible explanation for the unexpected weight distribution could be found, additional measurement passages were conducted in the furrow with a tractor without a plough. Here the results were as expected: the wheel load on the furrow

Fig. 2



Comparison on wheel loads land side/furrow side of the rear wheel of a tractor while ploughing. Mean values of six subsequent measurement passages of about 200 m in length, each.

wheel was, with about 23 kN, 5 kN greater than on the land wheel with about 18kN. This represents a weight distribution of 44/56 %.

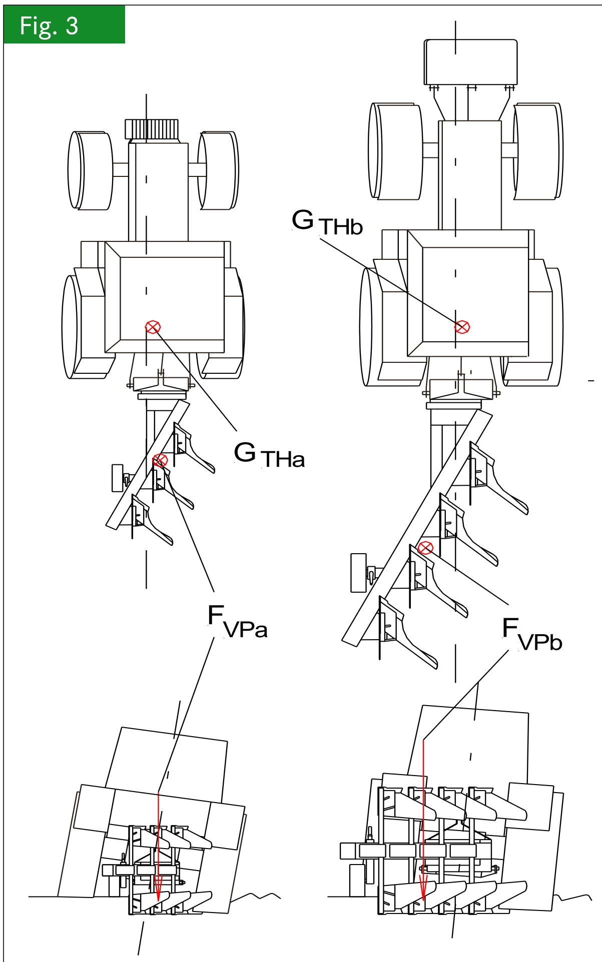
Plough reduces load on furrow wheels?

The cause for the unexpected reduction of load on the furrow wheels can be found in the combination of the tractor and the plough. Using the theoretical consideration of the impact of the force between tractor and aggregates known since the 1950s in “Basics of Agricultural Engineering” [3–5], the wheel loads for a tractor with a three-share plough and a tractor with a 4-share plough (**Figure 3**) were calculated. The combination of the “narrow” three-share plough with the according draft force of the tractor served as the basis of the statements by Renius and the tractor with the 4-share plough simulated the testing set-up. The results of the calculations confirmed both the statements by Renius (version a: 3-share plough) as well as the study results (version b: 4-share plough). The assumptions and calculation results are summarized in **Table 1**.

In both versions the contact point of the weight force of the tractors GTH first shifted in the direction of the furrow wheel during the passage in the furrow. The wheel load on the furrow wheel increases and the load on the land wheel drops.

The main cause of the weight distribution of the total vehicle is, however, the placement of the application point of the vertical force Fvp of the plough. This is not identical with the gravity centre of the plough, since in addition to the pure weight force of the plough, also the vertical components of the ground forces during ploughing and the support force through the plough pan and feeler/support wheels are influenced. It can be seen that with the increasing working width of the plough, the application of the vertical force shifts to the land wheel side. Thus in version b the ground wheel is more intenely loaded than the furrow wheel.

Fig. 3



Frontal and rear view of a tractor while ploughing with a small (a) and a greater working width (b). The point of contact of the vertical power components on the plough are in the contact plane (standing level) of the tractor in variant a on the furrow wheel side F_{VPa} and in variant b on the land wheel side F_{VPb}. G_{TH} describes the rear axle load with ballast without the plough.

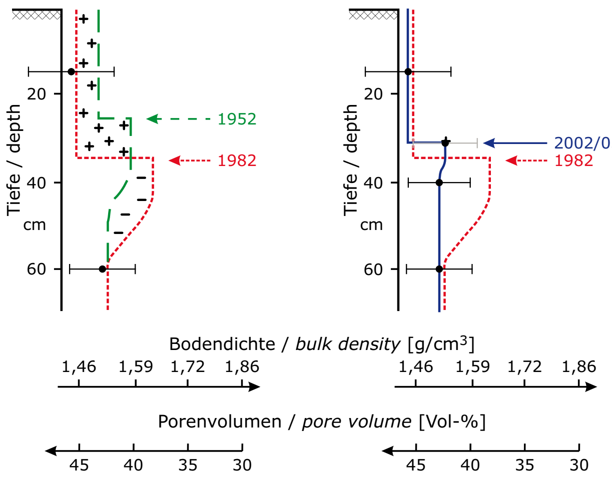
Significance for Soil Protection

With the use of a new technique to measure the wheel load, an interaction was uncovered which had received no real attention up to now: the working width of the plough has a major impact on the load distribution on the wheels of the pulling tractor. The theoretical basics according to which this can be calculated have been known for decades, but have not been used accordingly. The wheel load distribution of 60/40 furrow wheel/land wheel which is unfavourable in terms of soil protection, and which was, as a rule of thumb, valid in times of small working widths with three-shares has now been surpassed when one considers the current technical equipment standards. Developments such as the on-land ploughs must be re-evaluated in terms of soil protection impacts. For conventional ploughing the trend seems to indicate that with an increase in the working width, the potential for damage by the furrow wheels through a weight shift to the land side lessens. Planned studies with a 5-share plough should support these conclusions.

The tractor plough combinations used in the study (120 kW tractor and a 4 share fully reversible plough) have been broadly distributed on mid-sized farms over the past 25 years. As a consequence the impact on the soil structure – in 1985 some 80 percent of the land, and today only about 50 percent of the land are ploughed – were measureable in some studies for the purpose of having “the soil write the history of agricultural engineering” [6]. Here a status survey in a region of southern Lower Saxony is exemplary, with measurements from 1952, 1982 and 2002 (**Figure 4**).

For the purpose of a yield increase from 1952-1982, a deepening of the topsoil immersion and calcification were recommended. Through four-wheel drive and use of fully reversible ploughs, it is possible to work at a deeper level, although often off-season and with much slippage. Here a critical topsoil basis compaction results. The 2002 study– made 20 years later – shows that this trend has not continued. A reduction in the working depth for cost reasons and technical detail improvements such as radial tires with low inner tire pressure of one bar, slippage control, ploughing only at acceptable soil moisture levels – made possible through a high power of impact and avoidance of passage in the furrows through an expansion of conservation tillage practices (nationally at 50 percent today) – could first be cited as causes. Recent measurements on dynamic wheel load while ploughing provide a further explanation for the reduction of stress on the topsoil basis. Since already in the case of 4-share ploughs a weight shift to the land wheel takes place, this trend will be increased in 5- and 6-share ploughs. This means a load relief for the topsoil basis during ploughing and passages in the furrows.

Fig. 4



Bulk density/pore volume of 144 locations in southern Lower Saxony – a tendentious comparison [6; 7]

Conclusion

The decisive reduction of soil compaction in the topsoil basis is extremely important for the promotion of permeability for air, water and roots.

For the future of farming this means: The expansion of conservation tillage must be promoted and for necessary ploughing at least 4-share or broader ploughs must be used at acceptable soil moisture levels and with an inner tire pressure level of a maximum of one bar.

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