# Soil compaction and tractive force of big tractors and caterpillars (challenger 65 & 45)

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## Introduction

For the cultivation of big agricultural areas high performance machinery is needed. The need to increase working productivity also leads to powerful machinery. The total weight of new tractor generations increases and with it their axle and wheel weight reaches a soil damaging extend. Besides carrying the mass of the tractors and harvesting-machines the chassis must transmit driving force onto the ground (Tab. 1). To decrease soil damaging compaction a number of technical solutions have been developed. Broad tyres are being used to minimise the contact-area pressure by using low tyre air pressure. For enlarging the contact area there are two possibilities; to build a brought or a long contact area, done for instance in caterpillar tracks.

## Soilpressure and soil compaction

Soil compaction is a result of the force in the contact area. It should be kept below soil compacting extend. Loose soil, e.g. after plowing, can be compressed already with of 0.2 bar - 0.5 bar. This pressure is already reached by sheep foot roller (fig. 1). At the time of harvest surface soil and deeper soil layers have pore voluminas of 40-45 %. Pressures up to 1.8 bar do not influence the pore size distribution. Therefore the contact pressure is the effecting physical value.

## Soil pressure measurement

Soil pressures were measured with a hydraulic probe. For evaluation the maximum pressure has been taken.

Tractors with engine power of 169-194 kW and total masses of 10-11 to were examined (Tab. 2). Such machines are commonly in use on big farms for soil working. Additionally the Caterpillar (Cat 45) was examined.

The results of the soil pressure measurements show that the smaller tyre (620) (fig. 2) with higher air pressure (1.6 bar) leads to the highest soil pressure. The broader

tyre (710) with reduced air pressure (1.0 bar) leads to little less soil pressure. The differences are not significant. The pressure of the two tyres vanishes in deeper soil horizons. Beneath the topsoil (40 cm) only low pressure rates are detectable. This pressure does not lead to soil compaction (fig. 1) for the underground has a high load bearing capacity.
Compared to tyres the caterpillar track has a long standing area at a low overall construction height. With similar machine-masses, soil pressure is significant less and does not reach into deep horizons. No pressure can be detected in 40 cm depth. Note that the pressure in 10 cm depth is twice as high as the estimated contact pressure of 0.4 bar. This is due to the fact that the pressure distribution under a caterpillar track is very unequal.

Large tyre masses of big machinery does not lead to soil compaction if the contact area pressure is kept low. The pressure of great tyre masses do go into deep soil zones, but below soil damaging extend.

## Special features of tyres

A, to the needs of working condition not optimal adjusted air pressure, leads to a bad distribution of pressure in the contact area. Especially at changing loading situations of bunker machines (e.g. harvester) these problems occur (fig. 3).

The big wheel mass of 8.7 t, with air pressure of 1.6 bar, leads to a homogeneous pressure distribution under the tyre. The tyre shows a decrease in pressure in the shoulder area. A by 2.3 t decreased wheel mass leads to an increase in contact pressure from the shoulder area to the centre of the lug area. This is the situation comparably with an empty bunker harvester. In the centre of the standing area more than 2 bar are measured. The demand of a mass-depended tyre air pressure control derives from these facts.

Comparable changes in pressure distribution occurs with changing of surface. Pressure distributions on firm or soft surfaces have complete different shapes. Maximum pressure rates on soft surface, e.g. a tilled field, are located in the centre of the standing area (fig. 4). There is a decrease towards the shoulder area. On firm surfaces the maximum pressure rates are in the shoulder area. The reason for this is the differing deformation ability of the tyre and the surface. On soft surfaces both media deform. The tyre however keeps its form of the standing area nearly constant. On firm surfaces the tyre alone deforms. In the area located inbetween the standing and the side wall area of the tyre, high tension occurs.

## Special features of caterpillar tracks

The pressure distribution in the standing area of the caterpillar track is very inhomogeneous (fig. 5). Very obvious, areas of high pressure rates can be located. The pressure is concentrated underneath the carrier and return rolls. The differences are due to measuring circumstances. Here also the pressure decreases towards the sides of the track. The side part of the track which is not supported by the rolls, doesn't carry any weight. Therefore these parts of the belt increase the calculated contact-area but without carrying their share. Between the carrier and return rolls the decrease of strain is larger than between the carrier rolls. The reason is the bigger distance between carrier and return roll. The belt is here more elastic. Towards the middle of the belt the transverse force decreases by square to the distance "Rüdiger and Köller (1987)" (fig. 6).

Different wheel suspension constrictions influence the caterpillar track's ability to adapt itself to soil roughness. This context shall be explains by fig. 7. The lower part of the graphic shows a soil roughness in form of a plough been. The position of the sensors are in equal distance to the soil surface.
The graphic shows that pressure rates of a suspended under carriage show only little differences. The tract adapts itself to the surface roughness. Pressure rates beneath the stiff undercarriage vary. Soil unevenness leads to high pressure rates for the carrier rolls can't evade. Between two soil roughnesses, pressure rates drop. Under certain circumstances the entire mass of one vehicle side can stand on one single carrier roll "Olf (1993)":

## Tractive force transmission

One of the main function of an under-carriage is to transmit pulling and driving power onto the surface. For the valuation of under-carriages in respect of their rolling and pulling ability, energy rates play an important role. Some of the energy provided by the vehicle is lost by friction and deformation between tyre and surface. This loss is not available as pulling power.

A number of technical- and soil physics parameters are involved in tractive force transmission. The contact area between tyre and surface is to be taken into special consideration. Tractive force transmission of a lug-tyre can be described by fig. 8. Underneath the lug contact area bigger pressure arises than in between. The power is transmitted in form of shearing force. There is no powerloss. The vertical force can be calculated as a product of normal force plus the friction coefficient. The friction coefficient depends on the material of the soil and tyre, as well as their

nature. On wet soils and soils with a high amount of clay, the friction coefficient becomes worse. In the negative lug area friction force plays a subordinate role. Here the power is transmitted by shear force. It is a product of shearing area and thrust stability. Thrust stability is a product of fractional force, which occurs while a soil fraction slides along the shearing area.
The circuit force is the sum of shear- and friction force, depending on wheel mass, contact area and their shape.

Comparing the diagrams of tractive force and slippage, from tractor and caterpillar the differences of the two systems can be shown.
The tractive force-slippage diagrams were determined on a corn stubble field. The two carriage systems are described in Tab.2.

Dry, firm soils allow intensive contact between carriage and soil, tractive force stays high (fig 9). With little slippage the caterpillar is able to transfer tractive force very well.
Loose soil leads to a different situation (fig 9). The average stays lower. The curve's ascent is shallow at the stage of low slippage. The difference between caterpillar and tractor becomes less. Similar happens at humid soil conditions. Practical experiences show that under bad soil conditions the advantage of the caterpillar vanishes. Specially when the soil is firm and wet, tyres tend to slip on the surface. There is not sufficient contact between lug and soil because the lug doesn't reach below the surface. The amount of shearing force on the total driving force is little (fig. 7).

## Summery

With modern wide tyres it is possible to apply great wheel masses onto the soil without the danger of soil compaction. Presupposition that pressure is evenly distributed in the contact area.
In respect of soil pressure the caterpillar has only a little advantage. High pressure rates are beneath the carrier rolls. At low slippage conditions the caterpillar is superior to the tractor. Same tractive force supposed, the caterpillar runs with 10% less slippage. The caterpillar is 10% faster with the same engine power. All other influences constant, the output per unit area could be 10% bigger.

References

1. Olf, W. 1993. Beurteilung von bodenschonenden Fahrwerken. Dissertation Kiel
2. Rüdiger, A. and Köhler, U. 1987. Abschäzung des mittleren Bodendrucks unter Gleisbandfahrwerken. Agrartechnik, Berlin 37(2) S. 76-7

Tab.1.: vehicle and wheel load

| vehicle | wheel load [t] |
|---|---|
| tractor (190 kW) | 4,5 |
| harvester | 6,0 |
| carting off suger beet harvester | 10,0 |
| slurry tank trailor | 10,0 |

Tab.2: tractor types

| | tractor 1 169 kW | | tractor 2 194 kW | | caterpillar 178 kW |
|---|---|---|---|---|---|
| total load [t] | 10 | | 10 | | 11 |
| tires | front<br>480/70R34 | reat<br>620/70R42 | front<br>600/65R28 | rear<br>710/70R34 | width: 64 cm<br>length: 220 cm |
| air pressure [bar] | 1,6 | 1,6 | 1,4 | | - |
| contakt press. [bar] | 1,6 | 1,6 | 1,4 | | 0,4 |

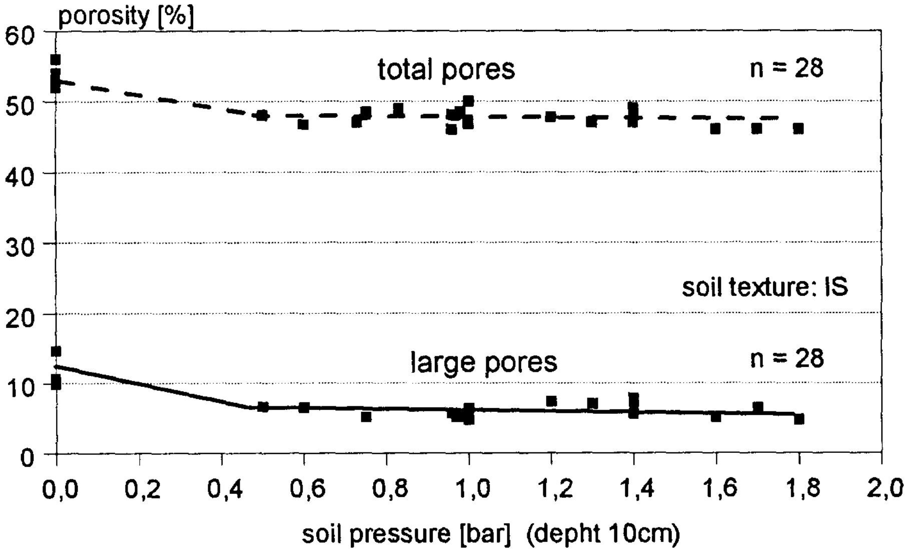


fig.1: soil pressure and porosity

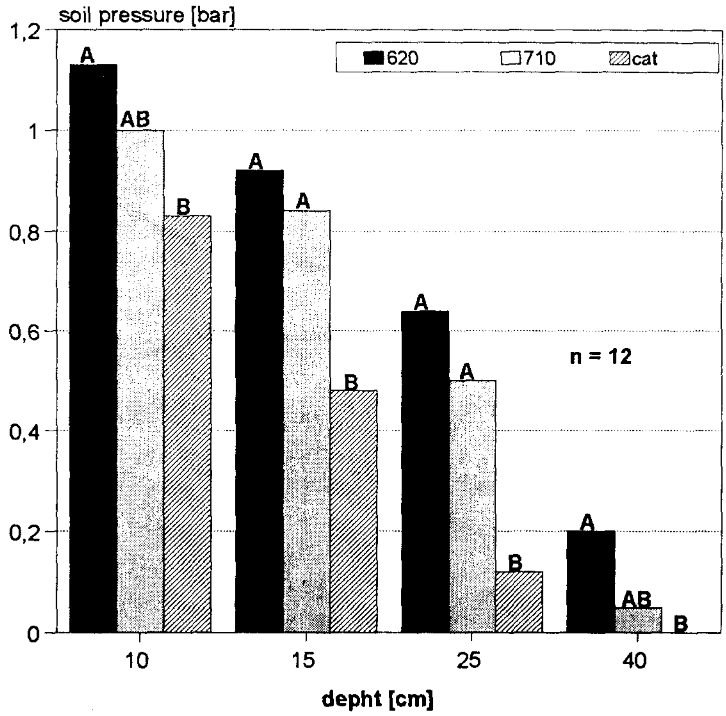


fig.2: soil pressure in differt dephts

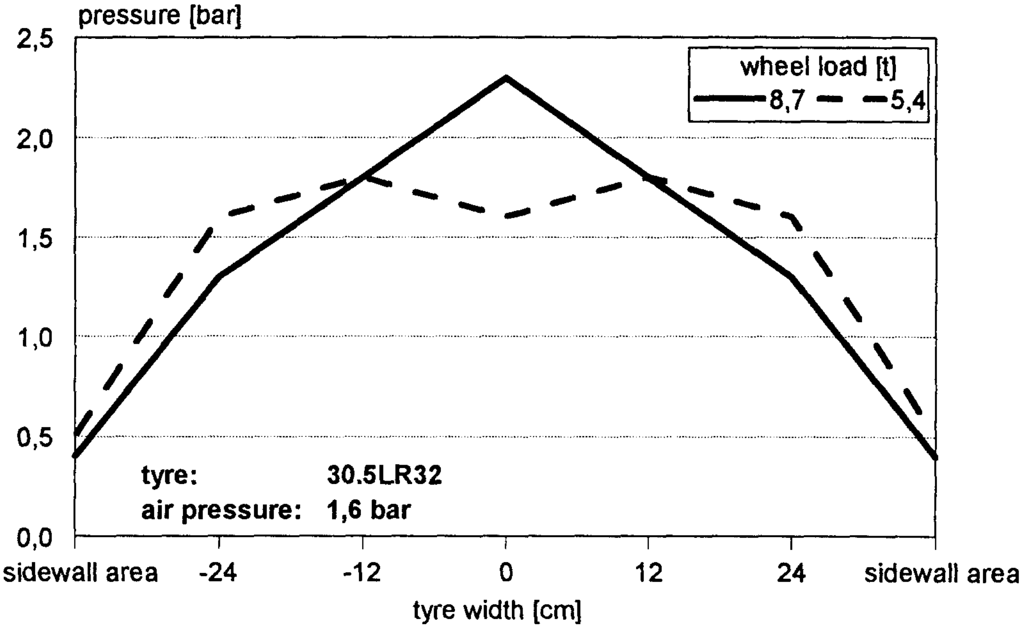


fig. 3: wheel pressure beneath the contact-area at different wheel loads

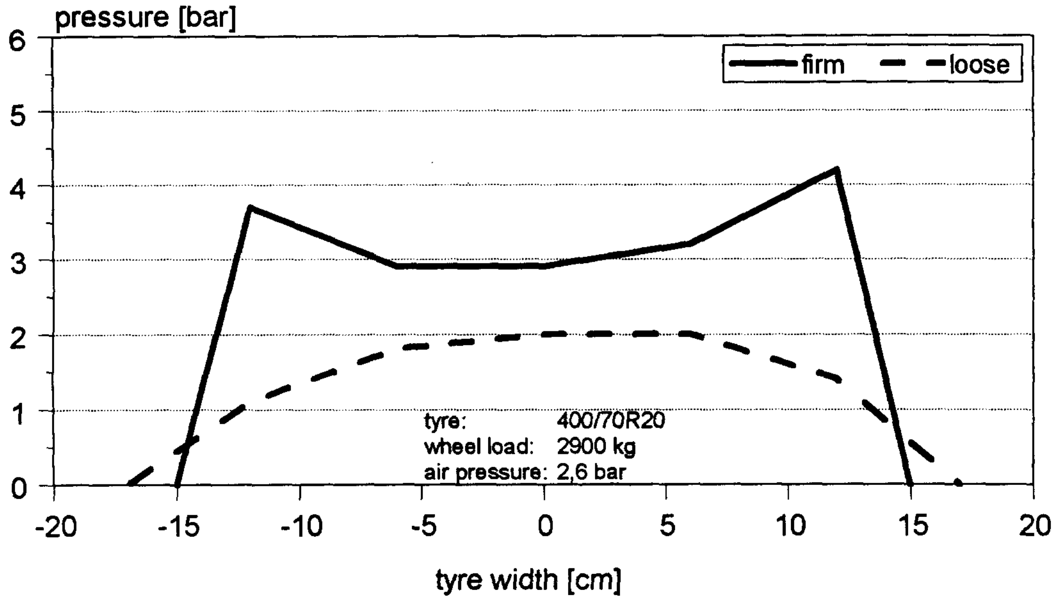


fig. 4: contact preesure upon firm and soft surface

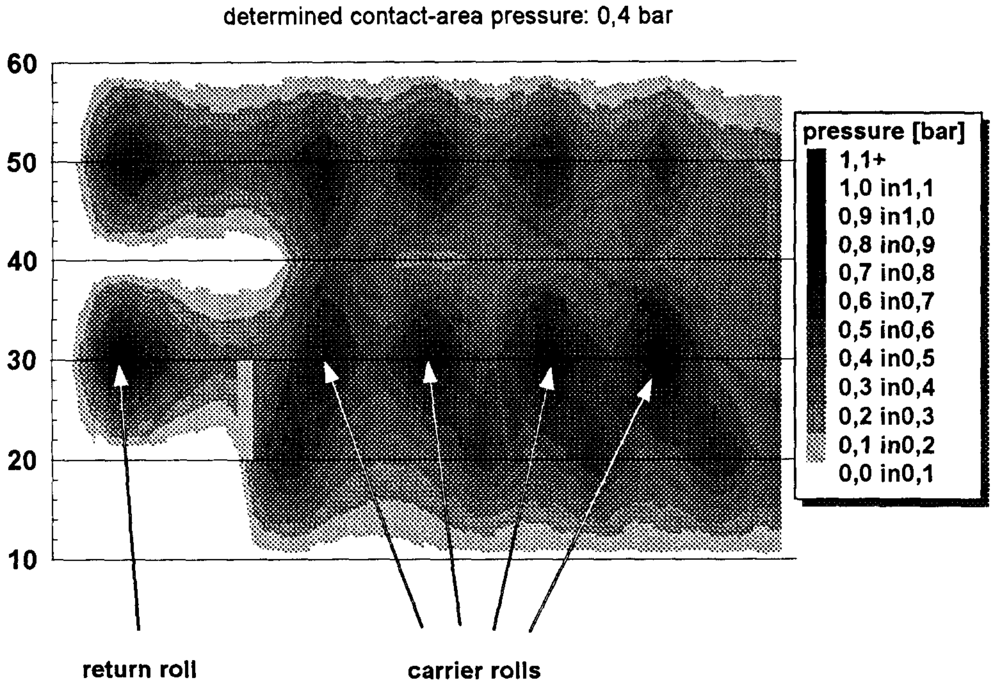


fig.5. pressure dispersion in the contact area of the caterpillar trac (Cat 65)

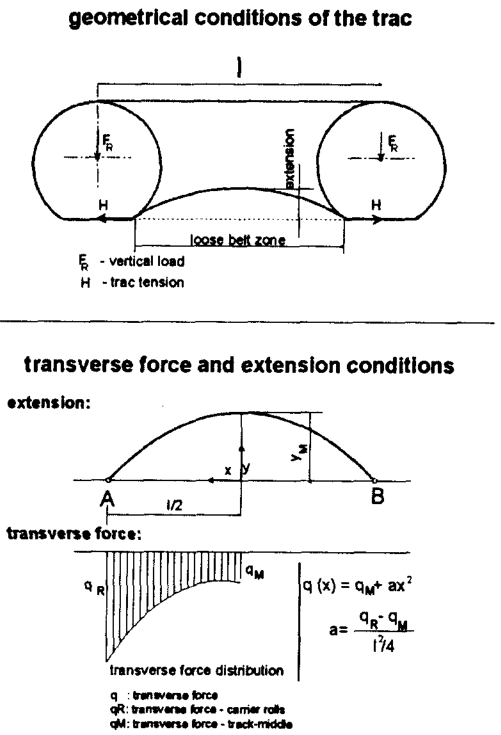


fig.6: force beneath the caterpillar trac "RÜDIGER und KÖHLER (1987)

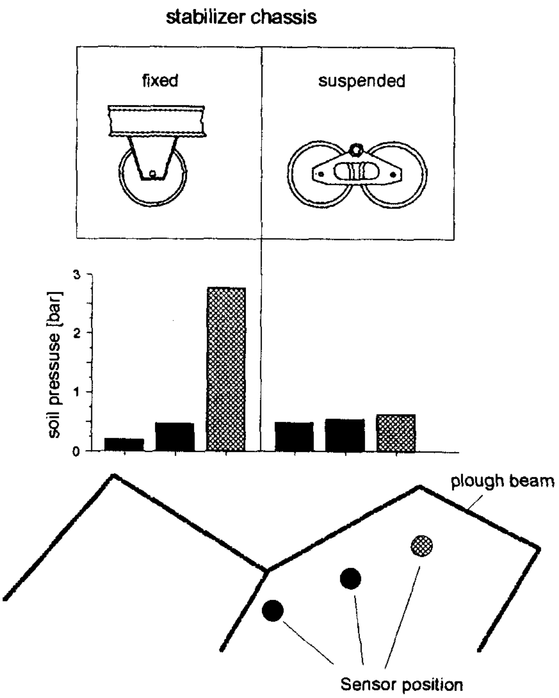
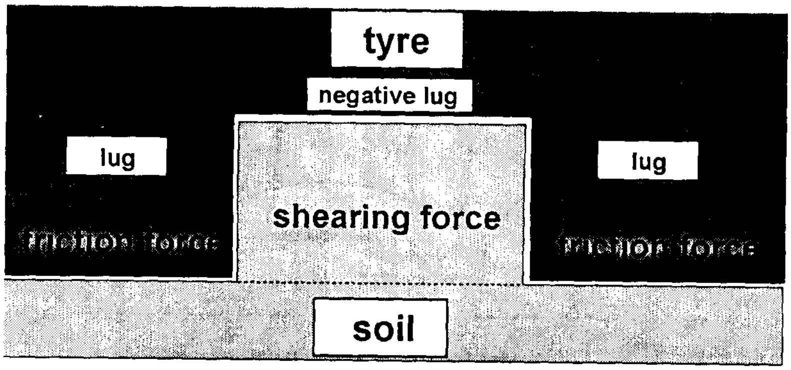


fig. 7: effect of the carrier rolls suspended "OLF (1993)"



peripheral force $F_U$ = friction force $F_R$ + shearing force $F_S$

**friction force** + **shearing force** + **friction force**

$F_R = \mu * F_N$ $F_S = \tau * A$ $F_R = \mu * F_N$

F : vetrtical force
A : shearing areaa
μ : friction coefficient
τ : shearing strain

fig. 8: traction forces between lug and soil

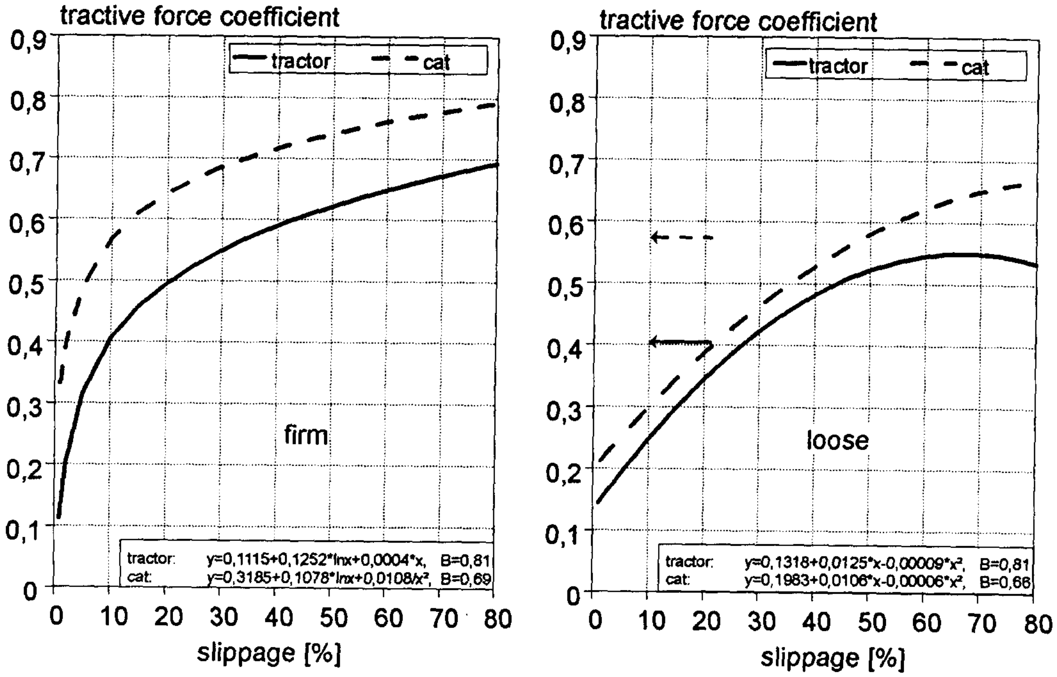


fig. 9: tractive force