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Soil Damaging Compaction

Strategies and Technologies for Physical Soil Protection

An integral aspect of sustainable agriculture is to avoid or reduce negative influences on soil functions from anthropological causes. The interests of the farmer and the Federal Soil Protection Law (BBodschG 1998) require that land cultivation focuses on precautionary and protective measures. In the field of physical soil conservation, this pertains to soil erosion and compaction. Soil conservation measures are not only set by „best practice management.“ All people responsible and participating are challenged to continuously further develop this, as well as strategies and innovative technologies.

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Keywords

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Soil damaging compaction is the type of soil compaction which, through its soil structural changes, causes permanent negative effects on the soil functions (yield, regulation and habitat functions). It can take place in the topsoil, in the base of the topsoil („pan layer“) and in the subsoil. Even though soil damaging compaction can more or less be rectified in the arable layer with normal soil tillage, such problems in the subsoil can only be „repaired“ with difficulty, with substantial input and only subsequent treatments. That is why it is necessary to keep the soil pressure – caused while driving on cropland – at such a level that (in the normal case) it does not lead to soil damaging compaction. For this purpose, the process technical and crop farming possibilities offered by „best practice management“, which are available for the location, the farm and for the rotation of a specific farm [1, 5], with a particular look to the subsoil, are not adequate at the moment.

Indicator concepts and sensor systems can contribute to characterising the mechanical soil load and the soil bearing capacity and to creating decision-making aids for soil-conserving passage on cropland.

Indicators for the problem of soil damaging compaction

Precautions, danger prevention and rectification are the three legally required protection steps against damaging soil changes. For this, in accordance with the limits introduced in the field of plant protection – discussion of such thresholds is being carried out for the physical soil protection. Debated are the indicators that are to be drawn for analysis in the case of the problem of soil damaging compaction. In *Figure 1*, the definitions and a selection of possible indicators (vehicle and soil parameters) have been put together.

While the soil parameters can be used mostly to recognise soil damaging compaction as well as to monitor the success of protection measures, in the case of vehicle parameters, the question is which, under practical conditions, are appropriate to set as guideline values for the protection of soil damaging compaction.

The wheel load (or rather axle load) can be calculated with reasonable effort as the total vehicle mass (empty or full) divided by the number of wheels (or axles) and in given cases can be calculated with sensor technology. Hence the wheel load is decisive for the soil pressure in deeper soil layers. The consequences of a wheel load (plus the number of passes and slip) are very directly linked to the current soil moisture at a given location. Thus the soil moisture in the subsoil during the passage is a key indicator for which, up til now has not been any practicable online measurement methodology. Soil moisture can vary strongly according to time and location. Setting wheel load values would only make sense in combination with the current soil moisture (dry soil can carry more load as wet soil) measurements. This is not yet realisable under practical conditions. The parameter wheel load is thus considered unsuitable as the single indicator for thresholds for soil bearing capacity.

The projected pressure is simple to determine as the ratio of the wheel load and the projection area of the tire with a given wheel load. It is advantageous for comparing vehicle, but not with regard to soil stress (see wheel load).

Table 1: Normal and shear stresses in loamy sand in the contact area below the wheel centre of the single wheel measuring device depending on deformation criteria acc. to fig. 2 and the parameters traction coefficient, wheel load and slip; mean values of 10 wheel rotations

Wheel load (t)	3,9				5,5	
Tire inflation pressure (kPa)	200		250		250	
Slip	10	20	10	20	10	15
Traction force (kN)	14,9	17,4	14,0	16,8	18,1	20,3
Normal stress (kPa)	162	144	172	150	238	224
Shear stress (kPa)	59	62	59	62	76	81

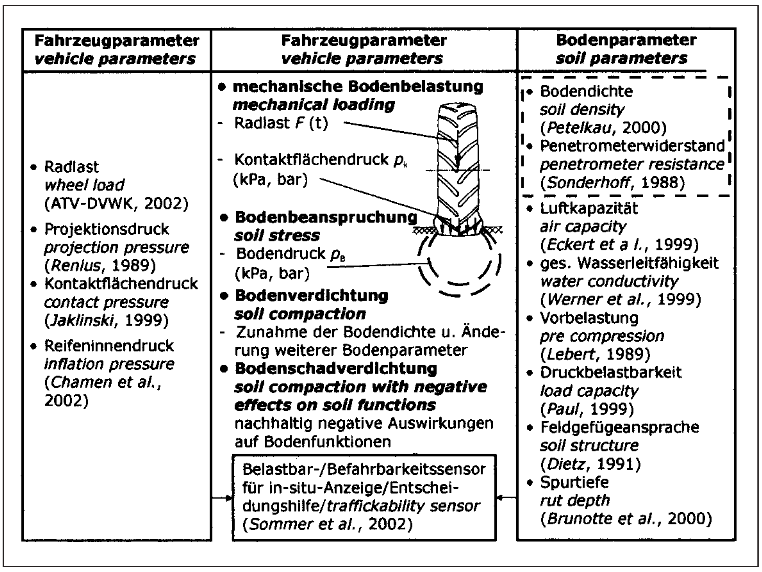

Fig. 1: Indicators regarding the problem of soil compaction

The contact area pressure p_k, as a mean value of the wheel load and traction force divided by the contact area of the tire/soil determines the initial stress near the soil surface during the travelling. It is comprised of normal (as a consequence of vertical stress) and shear stress (as a consequence of the horizontal stress through driving and breaking power). Thus, due to the different distributions within the contact area and particularly due to the unknown contact area, the use of the average contact area pressure as an indicator for in-situ decisions is problematic.

A further indicator is the tire inflation pressure p_i. It is easily checked nowadays , and with low cost sensors and with „tire controllers“ [6], it can be adapted to the most differing conditions (roads, dry or wet fields, dependent on wheel load). Modern radial tires permit lower inflation pressure, the advantages of which (among others larger contact area, more traction force, lower diesel consumption, shallower track depth) are seldom used on farms today. As target values for the inflation pressure, <1.0 bar on loose soil (around the planting time in the spring) and <2.0 bar on more solid soil (around the harvesting time in late summer) have been given [3] today.

Today's field tractor radial tires can be operated in the field with 0.8 bar, or in a more soil conserving manner with 0.5 bar. The suggestion of an EU working group [2] to define soil classes of the compaction sensitivity maximal values, related to maximum values of inflation pressure. Finally, with given inflation pressure in the tire table, the maximum allowable wheel load is also determined.

Development of a model supported sensor system

For the implementation of machinery use, the development of sensor systems is well suited to support short term decisions for soil conserving passage. The first prototype of a laser sensor is based on the indicator „track depth“ for the classic assessment of the trafficability by the farmer, which does not suffice as an integrated parameter for all factors affecting the traffic, particularly for subsoil protection. That is why for the complex problem of subsoil damaging compaction, further technical approaches are included: among others a model supported sensor project to evaluate the actual contact area pressure, currently being studied in field tests.

According to the model Jaklinski [in 5], a module makes it possible to calculate normal and shear stresses within the contact area from the parameters α_0, β_0, γ_0, z_0 and e of the tire deformation (*fig. 2*) as well as the indicators wheel load, traction force and slip.

It is known that with increasing wheel load in the case of constant inflation pressure, the contact area pressure increases, and at constant wheel load with decreasing inflation pressure, the normal stress on the contact area reduces. This is reflected in the measurement with the single wheel measurement equipment and the calculations according the Jaklinski model (*Table 1*).

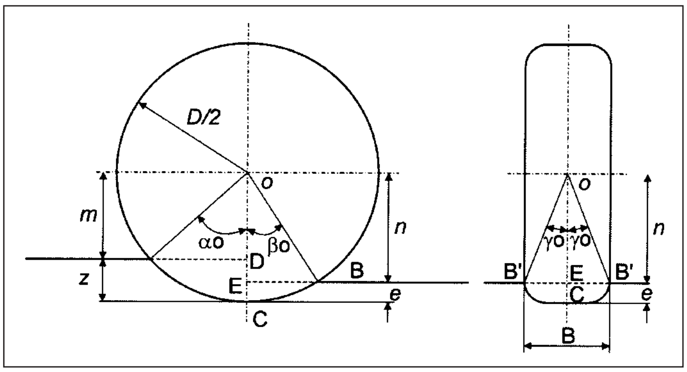

Fig. 2: Parameters of the Jaklinski model to determine the contact area and the tire deformation

Perspectives

Agriculture needs high performance machinery and equipment. A consequence of appropriate technology are the wheel and vehicle loads which, in contrast to mechanical stress previously experienced, has a greater and deeper impact on the soil structure.

Today's wheel loads [7] really do provide a cause for concern that the soil damaging compaction exists or can occur as a consequence of traffic under wet soil conditions. This can have a permanent negative influence on soil functions.

Possible conflicts of interest between the economic and ecological aspects of farming are to be counteracted with measures from best practice management as well as with innovative technologies. From a process engineering perspective, a practice appropriate further development of trafficability sensors (trafficability is understood as the mechanical soil bearing capacity tolerance of soil, without negatively affecting the soil functions) where the protection of the subsoil is the main concern.

Literature

[1] Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL): Gute fachliche Praxis zur Vorsorge gegen Bodenschadverdichtungen und Bodenerosion, Bonn, 2001, 105 S.
[2] *Chamen, T., L. Alakukku, S. Pires, C. Sommer, G. Spoor, F. Tijink and P. Weisskopf*: Prevention strategies for field traffic-induced subsoil compaction: A Review (in press)
[3] Deutsche Landwirtschafts-Gesellschaft: Bodenschonung mit moderner Technik, Arbeitsunterlage B/2001, 29 S.
[4] *Jassinki, B.*: Mündliche Mitteilung, 2002
[5] *Sommer, C., K. Walter, M. Lebert, L. Jaklinski und B. Jasinski*: Effiziente und bodenschonende Triebkraftübertragung vom Reifen zum Boden. Landtechnik 56 (2001), H. 5, S. 316-317
[6] *Volk, L.*: Soester Agrarforum, 2003
[7] *Weißbach, M.*: Bodenschonende Reifen für Großmaschinen und Schlepper. Rationalisierungs-Kuratorium für Landwirtschaft, Kiel, 2001, S. 341-395