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Comparison of risk assessment methods to determine the subsoil compaction risk of agricultural soils in The Netherlands

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ABSTRACT

Subsoil compaction is a recognised threat in the European Soil Strategy and knowledge concerning the vulnerability of subsoils to compaction in Europe and the Netherlands is information required for the determination of priority areas (or risk areas) in the future European Soil Framework Directive. In Europe two risk assessment methods (RAM) are used in more than one country to determine the subsoil compaction risk. The first one (RAM-A) initially determines the susceptibility of soils to compaction as a function of texture and packing density. In the second step the vulnerability to compaction is determined as a function of susceptibility and climate. The second RAM (RAM-B) is a mechanistic model in which the soil mechanical strength determines whether a subsoil is susceptible to compaction. The RAMs are used to produce maps presenting the susceptibility and vulnerability to compaction of Dutch subsoils (RAM-A) and maps with the compression strength and maximal allowable wheel load of a Terra Tire to prevent compaction of Dutch subsoils (RAM-B). Both RAMs have weaknesses. RAM-A is an expert model and can be rather arbitrarily with results that are not in agreement with our experience. RAM-B suffers from lack of good data and probably underestimates subsoil strengths. Results of both RAMs are compared to each other and to a map showing the probability that the subsoil is already overcompacted. This probability map is based on bulk density data in the Dutch Soil Database (BIS). There is a good match between the results of both RAMs, however, the match with the probability map (presumed to be "reality") is not good. In both RAMs sand and loamy sand soils are indicated as more vulnerable than clay soils, while in the probability map sand subsoils suffer less of subsoil compaction than clay soils. Of concern is that, according to the probability map, about 50% of the most productive and fertile soils of The Netherlands have overcompacted subsoils.

1. Introduction

Ever increasing wheel loads in agricultural machinery presents an increasing risk of subsoil compaction. Van den Akker et al. (2003) concluded that European soils are more threatened by compaction than ever before in history. In arable land with annual ploughing, both topsoil and subsoil compaction should be considered. From the short-term economic and environmental point of view topsoil compaction has more impact than subsoil compaction. However, from the sustainable point of view subsoil compaction is the most serious threat. This was also the conclusion of the European Soil Strategy Working Groups (Van-Camp et al., 2004). It should be noted that in the definition of subsoil used by Van den Akker and Schjønning (2004) and Van-Camp et al. (2004) the so-called plough pan or hard pan is the upper part of the subsoil, and in most cases the most severely compacted part of the subsoil. Soil tillage and natural loosening processes can remedy topsoil compaction and within several years good soil quality is regained. Subsoil compaction is an ongoing cumulative process, leading in the end to homogeneously compacted subsoil. The resilience of the subsoil to compaction is low and subsoil compaction is at least partly persistent (Allakukku, 2000; Voorhees, 2000). There is a strong relationship between compaction, erosion and flooding because topsoil and subsoil compaction seriously reduce the water infiltration capacity of soil.

Knowledge concerning the vulnerability of subsoils to compaction in Europe and the Netherlands is required for the determination of priority areas (or risk areas) that will probably be requested in the future European Soil Framework Directive. Once subsoil damage occurs, it can be extremely difficult and expensive to alleviate (Jones et al., 2003). Subsoil compaction risks are increasing with growth in farm size, increased mechanization and equipment size, and the drive for greater productivity. The response of the engineering industry to the demands of agriculture has been impressive over the past 30 years. Larger machines have

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been developed but, from the soil standpoint, the result has been a significant increase in axle loads not always matched by reductions in ground contact pressures to prevent or minimize compaction (Tijink et al., 1995). The detrimental effects of compaction go beyond agricultural concerns of restricted root penetration, decreasing crop yields and increasing management costs. According to Jones et al. (2003) the overall deterioration in soil structure that may result from compaction, aggravated at times by a buildup of water above the compacted layer, can:

1. increase lateral seepage of excess water over and through the soil, accelerating the potential pollution of surface waters by organic wastes (slurry and sludge), pesticides, herbicides and other applied agrochemicals;
2. decrease the volume of the soil system available to act as a buffer and filter for pollutants;
3. increase the risk of soil erosion and associated phosphorus losses on sloping land through the concentration of excess water above compacted layers;
4. accelerate effective runoff and associated nutrients and agrochemicals from and within catchments;
5. increase green house gas production and nitrogen losses through denitrification under wetter conditions.

Assessing the vulnerability of different subsoils to compaction is, therefore, an increasingly important issue. In the European project RAMSOIL (www.ramsoil.eu) it was concluded that European wide two methods are used to assess the subsoil compaction risk. The first one (RAM-A) is described by Jones et al. (2003) and selected in the European project ENVASSO (www.envasso.eu) as a method to assess the vulnerability to subsoil compaction in Europe. The second method (RAM-B) is based on calculations with the soil compaction model SOCOMO (Van den Akker, 2004), which is in fact part of a family of mechanistic methods that are all based on the strength and bearing capacity of the soil (Horn et al., 2005; Simota et al., 2005; Van den Akker, 2004).

The aim of this paper is to compare these two risk assessment methods (RAMs) using the Dutch Soil Database and to compare the resulting priority area maps with an assessment of the estimated actual subsoil compaction in the Netherlands based on bulk density measurements in the Dutch Soil Database (BIS). This allows conclusions regarding the suitability of the investigated RAMs for determination of priority areas (risk areas). In addition, data that is needed for accurate determination of priority areas but which is missing in the Dutch Soil Database (BIS) is identified.

2. Methods and materials

2.1. Mapping compaction or vulnerability to compaction

The first method (RAM-A) is described by Jones et al. (2003), the second method (RAM-B) uses data from National soil maps in model calculations with the soil compaction model SOCOMO (Van den Akker, 2004). These maps can be derived quite easily without additional data collection and are of immediate value to policy makers. In addition, maps of the actual compaction and predicted increase of the compaction in time are produced, based on approximately 450 bulk density measurements in the Dutch subsoil since 1960 and the Dutch National soil map scale 1:250,000.

2.2. RAM-A: determination of the susceptibility and vulnerability to compaction with the procedure of Jones et al. (2003).

RAM-A described by Jones et al. (2003) first identifies the susceptibility to compaction based on the FAO–UNESCO soil texture classes and the packing density (PD). Originally the packing density is determined visually in a soil pit, however, for use in combination with databases, a pedotransfer rule (PTR) for estimating the packing density of the subsoil density was developed by Van Ranst et al. (1995). More detailed information about the packing density and the procedure of Jones et al. (2003) can be found on www.ENVASSO.com or http://eusoils.jrc.ec.europa.eu/projects/envasso/. PD effectively integrates the bulk density, structure, organic matter content of mineral fraction and clay content, to provide a single measure of the apparent compactness of the soil. This has proven to be a very useful parameter for interpretations that require a measure of the compactive state of soils (Jones et al., 2003). In situations where the actual bulk density is known, PD can be determined from the following equation: $PD = Db + 0.009 \times C$ (Van Ranst et al., 1995), where Db is the bulk density in g cm^{-3}, PD the packing density in g cm^{-3}, and C the clay content (wt.%). Three classes of PD are recognized: low <1.40, medium 1.40–1.75 and high >1.75 g cm^{-3}. Soils with high PD (>1.75 g cm^{-3}) are generally not very susceptible to further compaction whereas those with medium and low PD (<1.40 g cm^{-3}) are vulnerable at critical moisture contents and loads. The susceptibility to compaction as a function of soil texture and packing density according to Jones et al. (2003) uses 6 texture classes of the EU Soil Map (coarse, medium, medium fine, fine, very fine and organic), however, because this is too rough we used the susceptibility table of Spoor et al. (2003) as presented in Table 1. The table of Spoor et al. (2003) is similar to Jones et al. (2003) except that the soil texture classes "Medium" and "Medium fine" are subdivided into those with >18% clay and those with <18% clay.

The susceptibility classes given in Table 1 are linked to the 21 classes of soil physical units from the Dutch Soil map 1:250,000 (Wösten et al., 1988) which are based on the soil texture of the upper subsoil layer just below ploughing depth. Clay soils (>25% clay) have an estimated ploughing depth of 22 cm, clayey loam soils (18% < clay < 25%) have an estimated ploughing depth of 27 cm and sandy and sandy loam soil (clay < 18%) have an estimated ploughing depth of 32 cm. The upper subsoil depth starts directly below the ploughing depth and the soil texture at this depth is taken from the soil physical units in the 1:250,000 Dutch soil map. The packing density (PD) is assumed to be

Table 1
Susceptibility to compaction depending on soil texture and packing density (after Spoor et al., 2003).

Texture class	Packing density		
	Low <1.4 g cm^{-3}	Medium 1.4–1.75 g cm^{-3}	High >1.75 g cm^{-3}
Coarse	Very high	High	Moderate
Medium (<18% clay)	Very high	High	Moderate
Medium (>18% clay)	High	Moderate	Low
Medium fine (<18% clay)	Very high	High	Moderate
Medium fine (>18% clay)	High	Moderate	Low
Fine	Moderate	Low	Low
Very fine	Moderate	Low	Low
Organic	Very high	High	–

Table 2
Vulnerability to compaction according to susceptibility and climate (after Jones et al., 2003).

Susceptibility class	PSMD in [51–125 mm]	PSMD in [126–200 mm]
Very high	Extremely vulnerable	Vulnerable
High	Vulnerable	Moderately vulnerable
Moderate	Moderately vulnerable	Marginally vulnerable
Low	Marginally vulnerable	Marginally vulnerable