Techniques to diagnose plow and disk pans

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Chen, Y. and Tessier, S. 1997. Techniques to diagnose plow and disk pans. Can. Agric. Eng. 39:143-147. The phenomena of plow or disk pan formation have recently been given considerable attention, as it is associated with important agronomic consequences. However, most reports only describe such phenomena on a qualitative basis. This note describes and validates the use of a new procedure to objectively diagnose the occurrence of mechanically induced hard pans. Data from experiments carried out at three locations, featuring tillage management systems based on mouldboard plow and heavy disk harrows, were reviewed to illustrate the use of this procedure. A plow pan was assumed responsible for differences in bulk density \( \rho_b \) or cone index (CI) at two reference depths, one above and the other below the bottom of the tilled layer. The occurrence of a plow pan was diagnosed based on statistical confidence interval comparisons of \( \rho_b \) or CI values between these two depths. However, CI profiles seem less reliable to diagnose plow pans. Based on the same principle, a disk pan could be diagnosed on the account of differences in micro-cone index (MCI) at two reference depths.

One grande emphase a été placée à l’identification du phénomène qu’est la formation de couches indurées comme les semelles de labour ou de disques. Cependant, la plupart des études rapportant ce phénomène ne concluent souvent que sur des bases qualitatives quant à la présence ou non de couches indurées. Une nouvelle méthode d’étude a été élaborée pour diagnostiquer objectivement l’apparition d’une couche indurée. Des essais ont été effectués à trois sites en comparant des systèmes de travail du sol comportant la charrue à versoir et la herse à disque. Une semelle de labour semble responsable de différences de masse volumique apparente \( \rho_b \) et de résistance à l’enfoncement (CI) entre deux profondeurs de différence, l’une au dessus et l’autre sous l’interface entre la zone influencée et non-influencée par le travail du sol. La présence d’une semelle de labour a été vérifiée par des comparaisons statistiques (intervalles de confiance) des valeurs de \( \rho_b \) ou CI entre ces deux profondeurs. Cependant, les mesures de CI semblent moins concluantes pour le diagnostic de semelles de labour. Avec le même principe, on peut conclure sur l’apparition d’une semelle lissage sous les disques de houes lourd et des mesures de la résistance à l’enfoncement (MCI) avec un micro-pénétromètre.

INTRODUCTION

The mouldboard plow remains among the most effective tools for crop residue burying and soil loosening (Bowen 1981). However, the development of a compacted soil layer, referred to as a “plow pan”, is often associated with using this implement (Brady 1990). The detrimental impacts of plow pans on crop production have been reported for years. For example, Garcia et al. (1988) observed that a Clarison soil with a simulated plow pan having a \( \rho_b \) of 1.6 Mg/m\(^3\) markedly reduced total corn root dry weight as compared to the uncompacted soil.

The plow pan has been hypothesized to be a result of the downward reaction force and the smearing effect of the plow sole sliding over the soil (Gaultney et al. 1982). Koolen and Kuipers (1983) suggest that the plow itself may not be the primary cause of plow pan formation; rather the cause may well be the practice of keeping tractor wheels in the open furrow during the plowing operation. Since the most common plows in use in Québec and many other temperate regions are rear-mounted mouldboard plows operated in the aforementioned way, plow pans have been reported often (e.g. Kelly 1985; Bernier et al. 1989). Heavy concave disk harrows, commonly substituted for mouldboard plows to cut up the residues and partially incorporate them into the soil, require considerable downward force to remain at the desired depth of operation. Since depth control is usually obtained by adjusting the harrow disk working angle to allow the concave disk’s back to rest and slide over the soil immediately below the tillage depth, a disk pan was reported with such tillage implements (Bowen 1981).

A plow pan has often been defined as a notable increase in either \( \rho_b \) or CI in the subsoil top layer (e.g. Gaultney et al. 1982; Chaplin et al. 1986). Although plow pans seemed visually obvious in their studies, such a basis for drawing this conclusion is questionable since the \( \rho_b \) or CI value of the upper tilled layer is normally lower than that of the untilled soil beneath it. Interestingly, Bernier et al. (1989) concluded that deep tillage effects on \( \rho_b \) cannot be analysed adequately by classical statistical analysis, namely comparing average \( \rho_b \) values by depths. The averaging process often erases such a “notable increase” of \( \rho_b \) in the soil profile, for which a plow pan is probably responsible. Classical analyses, therefore, are seldom adequate for interpretation of plow pans, although they were often used in interpreting the overall picture of the soil profile. The objective of this paper was to propose a data analysis technique to diagnose the presence of plow pans and disk pans, within the specific context of tillage and soil compaction studies.

MATERIAL AND METHODS

Sites and treatments

Field studies on tillage and compaction were carried out on two clay and one silt loam soils at three locations in Québec,
Canada, from 1992 to 1995 (Table I). Soils on these three sites were previously plowed before the experimentation. One of the tillage treatments, plowing, consisting of fall plowing to depths from 200 to 230 mm and spring cultivating for seedbed preparation, was performed on all three sites. To assess disk pans and soil compaction, disking was performed using a modified one-way disker (MOD) on one of the three sites (Corbeil site). The three disking scenarios included using MOD as a once over tillage in the spring, as both fall primary tillage and spring secondary tillage, and as fall primary tillage with S-tine cultivation for spring secondary tillage. The details of the treatments and the implement are described in Tessier et al. (1997). Soil contained moderate moisture levels at the time of tillage with a range of 25 to 30% (volumetric) for fall and spring tillage of three years.

### Measurements

Distributions of $p_b$ and CI in the soil profile were measured at all of the three sites for plow pan studies and MCI was taken only at the Corbeil site for disk pan studies. Measurements at the Domaine du Parc (Dom. Parc) site (a heavy clay soil) were carried out in the spring before two passes of a S-tine cultivator and in the fall immediately after corn harvest. Measurements at the Corbeil site (a heavy clay soil) were made 40 days after seeding and those on the Leblanc site (a silt loam) were taken in late fall. Care was taken to avoid sampling under tractor wheel tracks resulting from post-seeding or harvesting operations.

CI measurements were taken by a motorised vehicle equipped with a hydraulic ram to push the core into the soil at a constant speed. CI samplings of each plot were obtained at a depth of 600 mm and taken at 11 to 15 locations. At the same time as CI measurements were taken, undisturbed soil cores (47-mm diameter) for determining $p_b$ were collected to a depth of 600 mm using a sleeve-type coring device (Tessier and Steppuhn 1990). Three soil cores per plot were taken close to the CI sampling locations. To test disk pans, MCI measurements were taken for a 120 mm of soil strata, inclusive of the tilled-untilled interface below the disking depth, were collected using a portable micropenetrometer (Chi and Tessier 1995). MCI measurements were taken after seeding but before row crop cultivation at two locations within each plot. Instruments and procedures for all measurements were previously described by Tessier et al. (1997).

### RESULTS AND DISCUSSION

#### Classical definition of plow pan

In general, $p_b$ profiles in an agricultural soil subjected to some form of tillage show two typical patterns. A first pattern presents a smoothly increasing or uniform $p_b$ with depth within each of the tilled layer and subsoil, while a second pattern features a suddenly increasing $p_b$ under the tilled layer and then decreasing in the subsoil. The latter case indicates the occurrence of a compacted layer which can be a result of tillage operations such as mouldboard plowing (Kelly 1985; Bernier et al. 1989) and often observed in clay soils (Koolen and Kuipers 1983). The latter pattern was demonstrated by the $p_b$ profiles in the study at the Corbeil site where there was a large increase in $p_b$, centered around a depth of 325 mm, and then a decrease in $p_b$ below 350 mm depth (Fig. 1a). According to the classical analysis (Kelly 1985; Bernier et al. 1989), one could conclude qualitatively the presence of a plow pan at the Corbeil site. While a qualitative identification of plow pans seems obvious in this extreme example, such an assessment remains subjective and is often inaccurate for various data sets from different soil and tillage conditions. For example, at the Leblanc site (Fig. 1b), one can not see an obvious compacted layer through the depth beyond the tilled layer (0-200 mm) and it is difficult to judge whether or not a plow pan exists according to the classical, qualitative definition of plow pan.

#### Profile analysis to diagnose for plow pans

Tillage tools loosen soil into the tilled layer and plow pans are thus usually observed at some depth beyond this layer. We can hypothesize that there are two depths of interest, corresponding to the tillage "influenced" and "uninfluenced" layers. Under an assumption of a homogeneous soil textural profile, it is logical to conclude that a plow pan exists whenever the $p_b$ or CI value at the influenced layer is significantly greater than that at the uninfluenced layer. To compare the $p_b$ or CI values between these two layers, a simple statistical test is described hereafter using the data taken from the above studies.

Data from the Corbeil site are chosen to demonstrate the proposed statistical analysis procedure for plow pan diagnosis. Firstly, two reference depths, 325 and 525 mm, associated with the influenced and uninfluenced layers, re-

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**Table I: Description of field experiments for three sites**

<table>
<thead>
<tr>
<th>Term</th>
<th>Dom. Parc</th>
<th>Corbeil</th>
<th>Leblanc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Soil compaction study</td>
<td>Conservation tillage evaluation</td>
<td>Study on plow type vs. depth</td>
</tr>
<tr>
<td>Soil type</td>
<td>Sainte-Rosalie clay</td>
<td>Sainte Rosalie clay</td>
<td>Silt loam</td>
</tr>
<tr>
<td>Plot size</td>
<td>15 x 5 m</td>
<td>15 x 30 m</td>
<td>9 x 9 m</td>
</tr>
<tr>
<td>Replications</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>Continuous corn</td>
<td>Corn-corn-barley-soybeans</td>
<td>Pasture-barley-barley</td>
</tr>
<tr>
<td>Present crop</td>
<td>Corn</td>
<td>Corn</td>
<td>Barley</td>
</tr>
<tr>
<td>Tillage (depth)</td>
<td>Plowing (200 mm)</td>
<td>Plowing (230 mm) and disking (100 mm)</td>
<td>Plowing (205 mm)</td>
</tr>
</tbody>
</table>
Fig. 1. Dry soil bulk density ($\rho_b$) resulting from mouldboard plowing. a) for a Sainte-Rosalie clay at the Corbeil site in 1993; b) for a silt loam at the Leblanc site in 1995; c) for a Sainte-Rosalie clay at the Dom. Parc site in the spring and fall, 1993 (data at 600 mm were missing). Each point is the average of three sampling locations over replications.

respectively were selected by examining the $\rho_b$ profile (Fig. 1a). The $\rho_b$ value at 325 mm was deemed representative of the soil layer subjected to compaction, while that at the depth of 525 mm should be well beyond the effect of tractor and other machinery traffic (Håkansson et al. 1988). Secondly, as the standard errors of the mean $\rho_b$ often differ between depths, a test based on the $\rho_b$ confidence intervals (Steel and Torrie 1980) for each depth was used to compare $\rho_b$ means between these reference depths. The confidence interval about a $\rho_b$ mean is established as:

$$
\bar{\rho}_b = \rho_b - t_{\alpha/2, df} \cdot S\rho_b
$$

$$
\bar{\rho}_{bu} = \rho_b + t_{\alpha/2, df} \cdot S\rho_b
$$

where:

- $\rho_{bl, \rho_{bu}} =$ lower and upper limits of the confidence interval, respectively,
- $t_{\alpha/2, df} =$ t-statistic of the Student’s t probability distribution at a level of $\alpha/2$ and “df” degrees of freedom.

$$
\bar{\rho}_b = \text{population means, and}
$$

$$
S\rho_b = \text{population standard deviation.}
$$

When $\rho_{bl, 325\text{mm}}$ is significantly greater than $\rho_{bu, 525\text{mm}}$, there likely is a plow pan in the soil profile located at a depth of 325 mm. In other terms, one simply has to test the ranges of likely $\rho_b$ values at both depths. An equivalent procedure would be a Student's t test (Steel and Torrie 1980) for differences in $\rho_b$; however, this test adds the complexity of calculating the pooled $S\rho_b$ for these two reference depths.

Hence, data from the Corbeil site indicate a $\rho_{bl, 325\text{mm}}$ significantly greater than that of $\rho_{bu, 525\text{mm}}$, at a probability level ($\alpha$) of 0.1 (Table II). Thus, according to the definition presented above, under the assumption of a uniform soil textural profile, a plow pan definitely occurred at the Corbeil site. For the Dom. Parc site, the two reference depths were chosen as 275 and 525 mm by examining the $\rho_b$ profiles (Fig. 1c) at this site, owing to a slightly shallower plowing depth. Both spring and fall results showed significantly greater $\rho_{bl, 325\text{mm}}$ relative to $\rho_{bu, 525\text{mm}}$ (Table II). In this field, plow

Table II: Dry bulk density ($\rho_b$) of two depths selected to diagnose plow pans for three different sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Reference depth 1 (mm)</th>
<th>$\rho_b$ (Mg/m$^3$)</th>
<th>$S\rho_b$</th>
<th>Reference depth 2 (mm)</th>
<th>$\rho_b$ (Mg/m$^3$)</th>
<th>$S\rho_b$</th>
<th>Plow pan$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corbeil</td>
<td>325</td>
<td>1.47</td>
<td>0.017</td>
<td>525</td>
<td>1.37</td>
<td>0.009</td>
<td>Presence</td>
</tr>
<tr>
<td>Dom. Parc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>275</td>
<td>1.50</td>
<td>0.035</td>
<td>525</td>
<td>1.35</td>
<td>0.009</td>
<td>Presence</td>
</tr>
<tr>
<td>Fall</td>
<td>275</td>
<td>1.48</td>
<td>0.013</td>
<td>525</td>
<td>1.34</td>
<td>0.031</td>
<td>Presence</td>
</tr>
<tr>
<td>Lablanc</td>
<td>250-350</td>
<td>1.21-1.25</td>
<td>0.060</td>
<td>525</td>
<td>1.24</td>
<td>0.040</td>
<td>Absence</td>
</tr>
</tbody>
</table>

1 Standard error of the $\rho_b$ means
2 The test confirming the existence of a plow pan was significant based on a confidence interval comparison at a probability level of 0.1.
pans effectively persisted from spring to fall in a stratum ranging from 230 to 330 mm.

The same diagnosis technique was finally applied on \( \rho_b \) profile of the Leblanc site (Fig. 1b). No significant differences in \( \rho_b \) between influenced and uninfluenced layers were found between any depth measured within a range of depths associated with potential plow pans (250 to 350 mm) and values at 525 mm (Table II). No plow pan was formed yet in this soil. This could relate to both the site's shorter history of plowing (two years only) after long term use as pastures and the lower clay content of this soil compared to the other two sites.

The results clearly reiterate that annual plowing is a major cause for plow pan occurrence. However, plow pans may not necessarily arise in all cases where an annual plowing practice was applied, depending on factors such as soil texture and structure as well as plowing technique. Clay soils seem to have higher potential for plow pan formation as found in this study. Well-structured soils, as at the Leblanc site after grass production for many years, may require more than three years of plowing before such appearance of a plow pan, if at all.

The above inferences could not be highlighted by usual comparisons of average values on a depth-by-depth basis, as experimental errors between plots may mask treatment effects. Furthermore, it is interesting to note that these plow pans all occurred at depths greater than plowing depths at both the Corbeil and Dom. Parc sites. This is not the consequence of measurement nor data transformation and analysis. One can only speculate that compaction under the plow layer occurs not only at the interface of the plow layer and the subsoil, but also at a few centimetres below the tractor tire treads, as substantiated by the simulations reported by Tessier et al. (1996).

**Incidence of a disk pan**

The profile analysis concept described above was also used to examine the MCI data obtained at the Corbeil site to detect potential disk pans. One would expect disk pans to be reflected by a marked increase in MCI in the soil profile somewhere below the operation depth of a concave disk tool. The different disking treatments produced various degrees of soil loosening at depths below 40 mm (Tessier et al. 1997), but no significant changes in MCI were detected with depths for any of the treatments (data not shown). On the basis of the aforementioned confidence interval test, it was concluded that a disk pan did not occur in this case, according to the MCI data, probably due to the disk's high working angle (45°) which prevented compression or soil smearing under the tilled layer by the disk's back (Gill et al. 1980). Further comparative trials are however required to validate the measurement and proposed analysis technique for this particular application.

**Comparison of \( \rho_b \) and CI and techniques to detect plow or disk pans**

Compacted soils usually demonstrate higher \( \rho_b \) and higher soil shear strength (Ohu et al. 1986) which translate into higher CI (Ayers and Perumpral 1982). Therefore, both \( \rho_b \) and CI values can theoretically be used for plow pan tests. However, no conclusion on plow pans could be drawn from the CI measurements taken in these studies.

A main advantage of CI measurements is their easier and faster collection in the field. However, CI is dependent on water content, with CI values increasing at lower water content (Ayers and Perumpral 1982). The magnitude of CI will also vary with penetrometer type and penetration rate. As a result, CI and \( \rho_b \) profiles could show different patterns or even contradictory results. For instance, both the \( \rho_b \) and CI values increase with depth in the Corbeil site, but the maximum values are at different depths (Fig. 2). Similar results were obtained in another study on soil compaction at the same site (Bédard et al. 1997). All these show that for plow pan diagnosis, simultaneous measurements of \( \rho_b \) with CI will help data interpretation, particularly when the water content distribution greatly varies with depth.

**SUMMARY AND RECOMMENDATIONS**

As mentioned above, plow pans may occur at depths other than immediately below the tilled layer in the soil profile. On that account, all measurements should be carried out throughout a minimum depth of 550 mm to include both influenced and uninfluenced soil layers. Furthermore, the sampling intervals should be as small as possible (e.g. 25 to 50 mm) to locate a potential plow pan layer. Larger measurement intervals will likely mask identification of the compacted layer.

This profile analysis technique for diagnosing plow pans also should be applicable to disk pans or any other seedbed stratification studies. MCI measurements are hypothesized to
be adequate to depict disk pans, as MCI has been demonstrated to represent the compaction zones in seedbeds accurately (Tessier et al. 1990). Because of the different mechanisms involved in the formation process of compacted layers, a disk pan layer should be thinner than a plow pan. The upper soil layer needs to be examined in even smaller intervals (e.g., 1 mm) to locate a potentially compact soil smearing zone, which appears impossible to be achieved with current \( \rho_b \) measurement techniques. However, more field testing with implements known to produce disk pans are warranted to support the usefulness of this measurement technique for this application.

The phenomenon of a plow pan cannot be interpreted satisfactorily using classical analysis of soil data by layers. The profile analysis method used in this study allows an objective comparison of two reference depths to conclude quantitatively on the presence or absence of a hard pan (plow or disk pan). In the analyses of the CI profile alone, depth did not depict clearly the presence of existing plow pans. Therefore, it is suggested to use \( \rho_b \) as the preferred parameter for plow pan identification. The analysis technique used in this study indicates that plow pans are likely to result from annual plowing of fine textured soils with integral or rear-mount mouldboard plows.

**ACKNOWLEDGEMENTS**

The project was supported by the Conseil de Recherches en Pêches et Agro-alimentaire (CORPAQ) and the Fonds de Formation de Chercheurs et d’Aide à la Recherche (FCAR) of the Quebec government. The authors express their acknowledgements to B. Lachance, Dr. L. Chi and N. Ravonison of Université Laval for their help on data collecting and processing.

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