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In the Western Australian wheatbelt, the soils are predominantly strongly weathered and have poor physical properties for crop growth. Many of the fine textured subsoils have undesirable structural characteristics, the majority is sodic, highly dispersive and poorly permeable, and bulk densities greater than 1.7 g cm^{-3} are common at maximum swelling. This study aims at showing that the high bulk densities in clayey subsoils can have resulted from a process involving cycles of shrinking and swelling and the infilling of the vertical crack network of the subsoil with topsoil.

We examined dense low activity clay soils (Grey clay soils) in Western Australia in which the dominant physical feature of the subsoil was coarse prismatic structure. The prisms were approximately hexagonal in horizontal section with an average side length of 0.66 m. The top of the prisms reached to within approximately 0.07 m of the soil surface, their sides becoming indistinguishable below approximately 0.9 m. The vertical faces of the prisms were coated by material similar in composition to the topsoil and separated from it by a transition material of intermediate composition. Soil within the prisms had a bulk density at maximum swelling which reached a maximum of 1.86 g cm^{-3} in the upper subsoil, between 0.07 and 0.15 m depth.

We developed a model based on the hypothesis that the high bulk density have developed as a result of a simple three stage process: (1) soil shrinkage as the profile dries over summer leading to widening of cracks between prismatic peds, (2) infilling of cracks by detached topsoil which adds to coating thickness and (3) swelling during the winter, now partially restricted by coating material, leading to compression of the prismatic peds.

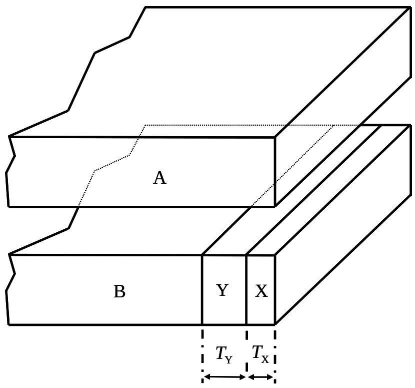

Figure: Sampling design showing the location of samples in the tilled layer A, the coating X of which the thickness is T_X, the transitional zone Y of which the thickness is T_Y and bulk soil B in the subsoil.

The model considers that the subsoil can be described as a succession of layers, every layer having two coatings X and Y at one of its ends comprising different mixtures of materials A (surface soil) and B a given horizon in the subsoil (Figure). Then:

$$C_X = tC_B + uC_A , \qquad (1)$$

$$C_{\mathrm{Y}} = vC_{\mathrm{B}} + wC_{\mathrm{A}}, \quad (2)$$

with:

$$t + u = 1, \quad (3)$$

$$v + w = 1, \quad (4)$$

where C_{A}, C_{B}, C_{X} and C_{Y} are the clay contents of the materials A, B, X and Y respectively, *t* and *u* are the ratios of material B and A respectively in material X, and *v* and *w* are the ratios of material B and A respectively in material Y. Then by combining Equations (1) and (2) then Equations (3) and (4) we obtain the following relationships:

$$t = \frac{C_{\mathrm{X}} - C_{\mathrm{A}}}{C_{\mathrm{B}} - C_{\mathrm{A}}}, \quad (5)$$

$$v = \frac{C_{\mathrm{Y}} - C_{\mathrm{A}}}{C_{\mathrm{B}} - C_{\mathrm{A}}}, \quad (6)$$

According to that model, the thickness of material X is T_{X} and it results from the mixture of a thickness $T_{\mathrm{B}}^{'}$ of material *B* with a certain amount of material *A*. Thus:

$$T_{\mathrm{B}}^{'} = t\frac{D_{\mathrm{X}}^{*}}{D_{\mathrm{B}}^{*}}T_{\mathrm{X}}, \quad (7)$$

with D_{B}^{*} and D_{X}^{*} the field bulk density of the material B and coating X at maximum swelling, respectively. Following the same reasoning, we can write:

$$T_{\mathrm{B}}^{''} = v\frac{D_{\mathrm{Y}}^{*}}{D_{\mathrm{B}}^{*}}T_{\mathrm{Y}}, \quad (8)$$

with T_{Y} the thickness of material Y, $T_{\mathrm{B}}^{''}$ the thickness of material B which has been mixed with material A to give the coating Y and D_{Y}, the bulk density of the coating Y. Thus the width of the crack (W_{crack}) which has been filled by pure material A is given by the following relationship

$$W_{\mathrm{crack}} = 2\left(T_{\mathrm{X}} - T_{\mathrm{B}}^{'}\right) + 2\left(T_{\mathrm{Y}} - T_{\mathrm{B}}^{''}\right), \quad (9)$$

and by using Equations (5), (6), (7) and (8) we obtain

$$W_{\mathrm{crack}} = 2T_{\mathrm{X}}\left[1 - \frac{D_{\mathrm{X}}^{*}}{D_{\mathrm{B}}^{*}}\left(\frac{C_{\mathrm{X}} - C_{\mathrm{A}}}{C_{\mathrm{B}} - C_{\mathrm{A}}}\right)\right] + 2T_{\mathrm{Y}}\left[1 - \frac{D_{\mathrm{Y}}^{*}}{D_{\mathrm{B}}^{*}}\left(\frac{C_{\mathrm{Y}} - C_{\mathrm{A}}}{C_{\mathrm{B}} - C_{\mathrm{A}}}\right)\right] \quad (10).$$

Results showed that the development of the very dense upper subsoil can be indeed explained by that model developed on the basis of the geometry of the peds and their coatings (Bruand et al., 2001). Results showed also that the coating process that is responsible for the very dense upper subsoil has occurred under native vegetation but is much more active when the land has been used for agricultural and pastoral activities as indicated by thicker sandy-clay coatings on the vertical faces of prisms and the higher bulk densities in the subsoil (Buand and Gilkes, 2002). Finally, the mean bulk density was 1.71 and 1.86 g/cm^3 at 20–25 cm depth under native vegetation and crop respectively. Thus, the kinetics of the process modelled was strongly increased when the land has been used for agricultural and pastoral activities.

Bruand A., Cochrane H., Fisher P., Gilkes R.J., 2001 - Origin of the high bulk density in the subsoil of a Grey Clay soil in Western Australia. Eur. J. Soil Sci., 52, 37–47.

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