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Slumping Dynamics of Tilled Sandy Soils in North-East Thailand

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Abstract: Recompaction of tilled layers, under the effect of rainfall or irrigation only (i.e. without any external loading), was called slumping by Mullins et al. (1990). It has been observed in various soil types with negative effects on plant production. Our objective was to characterise the dynamics of slumping at the ploughed layer scale in a sandy soil of North East Thailand. An experimental field was tilled to two depths (20 and 40 cm) with or without ridges and furrows and was submitted i) to natural rainfall during two months (214mm in June and July 2007) or ii) to experimental flood irrigation (100 or 200 mm over some hours).

Changes in bulk density with time were observed, particularly under flooding and after heavy daily rainfall. Final bulk density of 1.60 Mg m 3 has been measured over 20 cm depth while initial bulk density after tillage was 1.25 Mg m 3. Bulk density profiles were often characterised with two maximum values, either in the top layer (0-5 cm) or at the bottom of the ploughed layer (15-20 or 35-40 cm). We demonstrated that several processes occurred simultaneously: i) a redistribution of sand particles from the top of ridges to the bottom of furrows that decreased soil roughness, ii) a 2 to 5 cm topsoil collapse when water infiltrated, iii) a soil collapse at greater depths due to overburden pressure. These phenomena agree with the theory of granular material and the decrease in capillary forces between sand grains during wetting. The specific changes in bulk density profiles induced by rainfall should allow the occurrence of slumping to be predicted or identified as a function of soil, climate and tillage conditions.

Keywords: bulk density, capillary forces, internal force, recompaction, soil water potential .....

INTRODUCTION

Recompaction is commonly attributed to external loading on soil from farm machinery or livestock (Hamza & Anderson, 2005; Lipiec, 2003). However, even in the absence of any external loading, soil reconsolidation was observed in tilled layers (Ley et al., 1989; Mullins et al., 1992). Increased bulk density after wetting, without the application of an external load, was termed 'slumping' (Mullins et al., 1990). The effect of rainfall has also largely been studied but concerned mainly the first millimeters or centimeters where crusting occurred (Fohrer et al., 1999). Slumping was observed under natural or simulated rainfall events with different kinetics. For example, a single rainfall event (20 mm in one hour) (Mead & Chan, 1988), two natural rainfall events (80 mm in 2h40min) (Hartmann et al., 1999), during 8 weeks of monitoring (Osunbitan et al., 2005), during a cropping season (Hamblin & Tennant, 1979), or over a period of 8 years (Buscher et al., 2002). Moreover, slumping can affect the tilled layers from the surface to the undisturbed horizons, whatever its depth is and can have same negative effect as mechanical loading (Kozlowski, 1999).

Even if slumping was recognized as an important degradation, factors and processes involved have not yet been studied, so that proposing adapted

management is still challenging. Our objective was to characterise the dynamics of slumping at the ploughed layer scale in a sandy soil and highlight the effect of natural (rainfall) and managment (ploughing depth and initial water content) factors.

MATERIALS AND METHODS

Field description

A site was selected in a village named Baan Nong Sang (16°10' N, 102°48' E), 30 km south of the city of Khon Kaen in Thailand. This soil was representative of the region with a sandy texture (less than 4 % clay), low organic matter (less than 5 g kg¬-1), and high bulk (higher than 1.6 g cm-3). In 2006, this field was planted with cassava and was harvested in February 2007. Before the tillage for our experiment (may and June 2007), all the residues (cassava branches and leaves, weeds, etc.) were taken out. To prevent weed growth and subsequent soil porosity disturbance, herbicides were applied. The experimental field was shared in two parts for complementary experiments:

Experiment 1: Control of tillage depth

Two tillage depths of 20 cm and 40 cm, called shallow (S) and deep (D) treatments respectively, were applied. Each treatment had five elementary plots (9 m×15 m) as replicates. Tillage was made using a 120-horse-power tractor equipped with disk plough (50 cm in diameter). To increase soil structural homogeneity, large clods left by mechanical tillage were broken into smaller pieces by manually using rakes. To mimic farmers practices who want to avoid flooding of seeds, ridges and furrows were built up every 40 cm width; their height ranged from 12 to 17 cm.

The soil changes were monitored from the ploughing day (25 May), monitoring days were characterised by the number of days after ploughing (25 May as DAP0) and by accumulated rainfall (AR in mm).

Soil water potential was measured using a set of ceramic tensiometers (SDEC 2150, SDEC Company) and electronic transducer (model SMS-2500S, SDEC Company). Changes in soil level were measured using a horizontal frame as a stable benchmark. The horizontal frame consisted of four metallic rods inserted 70 cm below the soil surface and fixed by cement, on the top of which a 1 m² square frame was put and set horizontal. The distance between the frame and the soil surface level was measured along a 5 × 5 cm grid using a laser beam (Lasermeter Leica Disto 6A, Leica Geosystem, Switzerland). The reference level was taken at the bottom of the furrow immediately after furrow and ridges were built. For each treatment (D and S), three replicates of that device were installed in different subplots. Bulk density (BD) and water content (WC) were measured using cylinders of undisturbed soil at a 5 cm interval.

Shear strength (ST) was measured using a scissormeter (Model 14.10, Sols Mesures, France), and the resistance to penetration (RP) was measured by pocket penetrometer (Model 06.03, Eijkelkamp Agrisearch Equipment Company). They were measured on cylinders collected in the same pits as for BD and WC (5 replicates at each depth).

Experiment 2: control of initial water content

To change the rainfall amount and distribution, in the second part of the experimental field some plots were protected from rainfall when others were left under natural rainfall. Soil protection consisted in six green houses (1.5 m wide, 40 m long and 0.8 m high) opened at both ends so that air could circulate, avoiding overheating and water condensation. On the 6 July (DAP'0), the greenhouses were taken out; both protected and unprotected plots were tilled at 20 cm depth with the same procedure as S treatment in Exp.1. Treatments were named Y for dry initial conditions (previously under green house) and W for wet initial conditions (left under natural rainfall). There were 5 replicates for each treatment. On the day of tillage (DAP'0), water content was significantly ($P<0.05$) lower in Y than in W treatments: 0.04-0.06 g g-1 and 0.08-0.10 g g-1 respectively.

In each treatment (Y and W), a set of four tensiometers were installed from 10 to 25 cm depth in a 5 cm interval below the furrow. Changes in soil level were measured using horizontal board as a stable benchmark. The horizontal board consisted in two metallic rods inserted 70 cm below soil surface and fixed by cement, on the top of which a 1 m long rigid board was put and set horizontal. The distance between the frame and the soil surface level was measured using a laser beam every 2.5 cm along the board. For each treatment, five replicates of that device were installed in different subplots. Bulk

density, water content, shear strength and resistance to penetration were measured using the same procedure as in Exp.1.

RESULTS

Rainfall and matric potential

Fig.1 a) presents the individual rainfall events and the accumulated rainfall (AR). AR in Exp.1 with 212 mm was nearly two times of Exp.2 with 114 mm. Unlike rainfall amount which were very different, rainfall patterns were very similar characterised by a single big event (20-30 mm) just after ploughing, a long dry spell with several smaller events and two big events occurring at the end of the experiment; Exp.1 differed from Exp.2 by one more big event (approximately 30 mm).

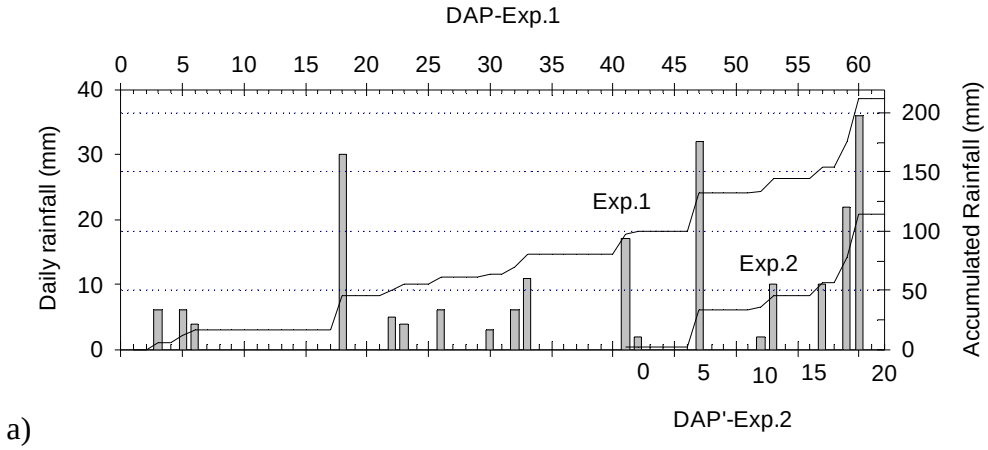
Matric potential (Fig. 1 b) ranged from -40 hPa immediately after a rainfall event to -120 hPa after the longest dry spell. Similar results were obtained for Exp.2 (data not shown). The last measurements on DAP60 were made only 1 h after the end of a heavy rainfall: despite water logging still observed on the soil surface, the matric potential was lower than zero, indicating the absence of free water inside the profile.

Soil water content

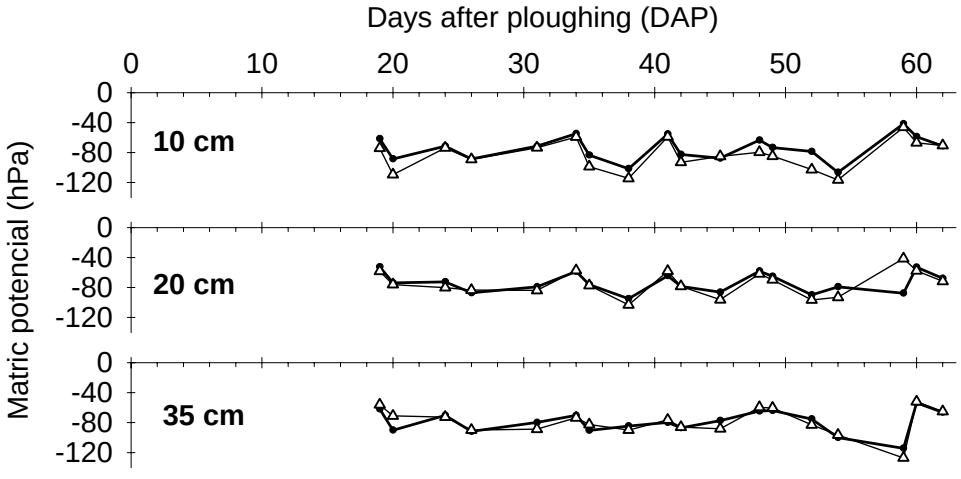
The soil water content ranged from 0.15 to 0.13 g g-1 for all the layers (Fig.2). The ploughing depth did not affect water content, as profiles for D and S were not significantly different at all measured dates. Despite the different initial water content, there was no significantly difference between Y and W which ranged from 0.07 to 0.10 g g-1.

Soil bulk density

Fig.3 presents the profile of average bulk density under furrow for EXP.1 and 2. The bulk density increased with time and accumulated rainfall.



a)



b)

Fig. 1. a) Rainfall distribution and accumulated rainfall in Exp.1 and Exp.2. DAP is day after ploughing for Exp.1, which started from 25 May. DAP' is day after ploughing for Exp.2, which started from 6 July. b) Matric potential of D (40 cm ploughing) under furrow ( ) and under ridge ( ).

Ploughing depth had no effect on recompaction. By paired comparison, no difference in bulk density was detected between deep tilled and shallow treatments. In Exp.2, the density was lower when the soil was dry during tillage operation, BD was lower between 5 and 15 cm compared to tillage made on wet soil: as 1.32 g cm-3 compared to 1.38 g cm-3. This difference was not significant due to soil heterogeneity but the trend was confirmed at DAP'6: after a total of 34 mm rainfall, there was slightly increase for Y treatment but nearly no change for W treatment. Final bulk density was similar in both treatments. As a conclusion, when ploughed in dry conditions, BD is lower but this difference disappears after some rainfall events.

Soil surface level change

During the experiment, the soil topography decreased: ridges seemed to melt while furrows were filled with sand material (Fig.4). The average height above reference level (i.e., bottom of the furrow at DAP0) was calculated for each plot. The changes in relation with Log accumulated rainfall are presented Fig.4. This figure shows a regular decrease of soil level with log of accumulated rainfall.

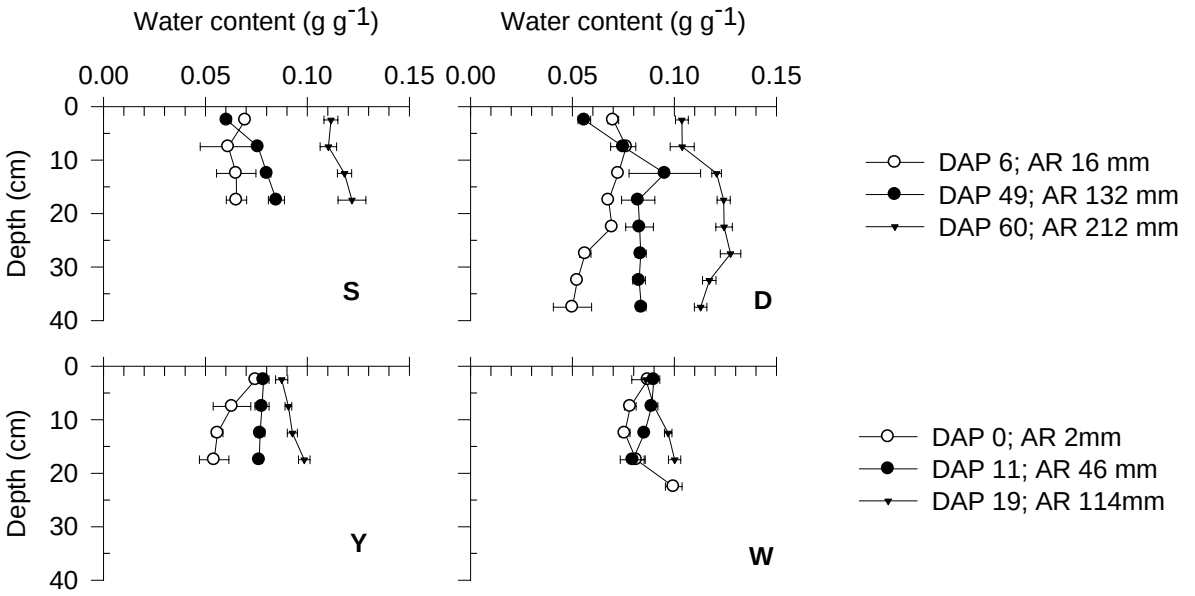


Fig. 2. In Exp. 1 and Exp.2, water content evolution at different time after major rainfall under Furrow (F). Error bar indicates standard error of mean (SEM) (n=9). DAP means day after ploughing in Exp.1, DAP' means days after ploughing for Exp.2, AR means accumulated rainfall from day of ploughing.

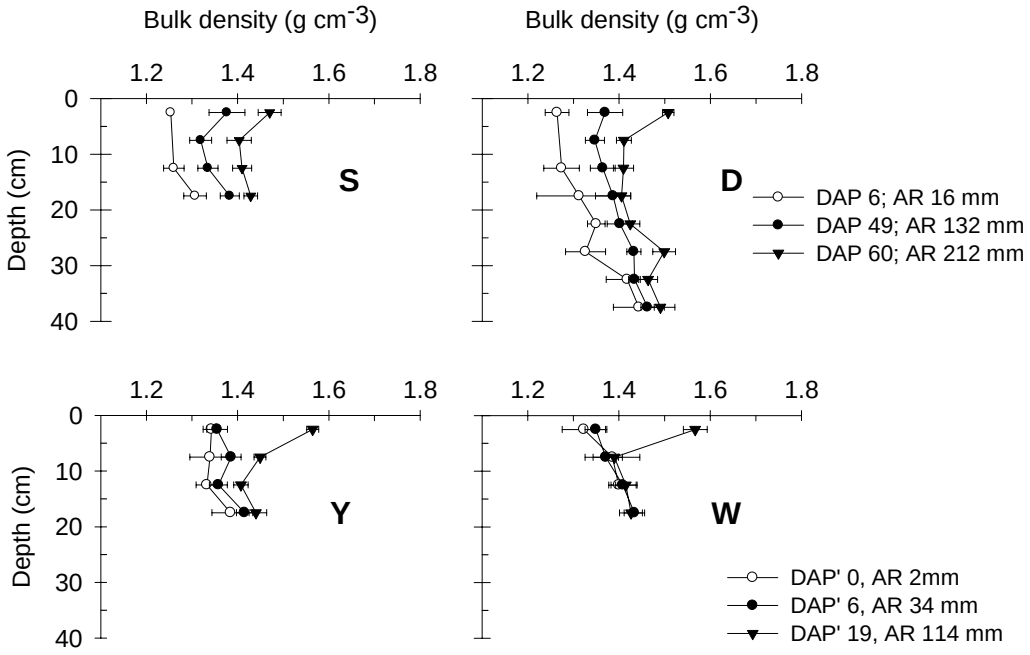


Fig. 3. Bulk density collected under furrow after major rainfall events during Exp. 1 (top) and Exp. 2 (bottom). D and S are Deep (40 cm) and S shallow (20 cm) ploughing respectively (n=5); W and Y indicate tillage made in wet and dry soil respectively (n=9). DAP and DAP' are the number of days after ploughing for Exp.1 and Exp.2 respectively; AR is the accumulated rainfall since ploughing day. Error bar indicates standard error of mean (SEM).

Resistance to penetration and shear strength

From the day ploughing until the end (July 30, 2007) of Exp.2, the instruments (penetrometer with data logger, scissormeter, and pocket penetrometer) were not sensitive enough to collect data. These showed that for sandy soils, despite soil recompaction and rearrangement of solid particles, the mechanical resistance remains quite low as long as the soil remains wet.

DISCUSSION

Our data make it possible to detail the dynamic of structural changes and slumping in a tilled sandy soil in relation with successive rainfall events, those changes are presented in Fig. 5.

First, during tillage, bulk density was theoretical low that should be identical in all layers (Fig. 5, line 1). Just after, the loose soil will settle down and recompact (line 2). Between zero and 15 cm depth, bulk density was 1.25 g cm-3 and increasing with depth: 1.30 and 1.40 g cm-3 at 20 and 40 cm depth respectively (Fig.1, S and D treatments).

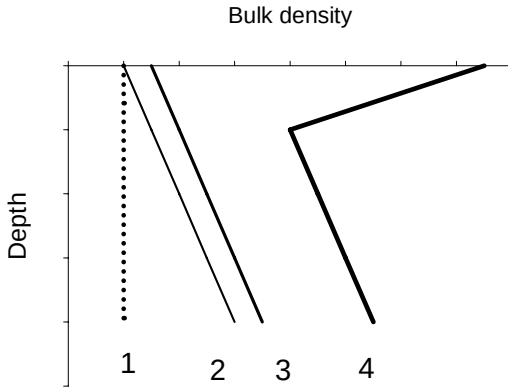


Fig.5. Schematic diagram showing the possible slumping processes.

This increase can be interpreted as the effect of overburden pressure. When tillage was done on a wet soil (Fig.1, W treatment), similar increase with depth was observed, but the bulk density reached higher value compared to dry soil (1.4 and 1.30 g cm-3 at 20 cm depth respectively).

For wet soil, rearrangement in a more compact assemblage during soil settling could be related i) to a lower cohesion between solid particles or ii) to a

lubricant effect of water reducing the friction between the solid particles.

Monitoring the changes in soil level after tillage, provided a general measurement of soil slumping. As no erosion was observed, the decreased soil level was interpreted as directly related to a loss of porosity at profile scale (Wilton, 1964). Dynamic of slumping was fast during the first rainfall events and became slower with time and rainfall events (Fig.4). Anyway, the soil level decrease was approximately 2 cm for all treatments, in agree with previous result under rainfall simulations (Hartmann et al., 1999).

The changes in bulk density profiles provides information on depth at which slumping occurred and intensity of slumping in each layers (Fig.3). We observed that i) slumping concerned all tilled layers and ii) in the end, it was more important in surface layers (0-5 cm) compared to deeper layers. These changes are presented on lines 3 and 4 on Fig. 5. On dry soil, slumping was observed on the profile after only 34 mm of accumulated rainfall (Fig. 3, Exp.2); therefore slumping was triggered even with limited amount of water. But there was not direct relation between amount of water and bulk density increase: after only 100 mm of rainfall in Exp.2, the bulk density profile was the same as in Exp.1 with 200 mm of water (>1.4 g cm-3 below 10 cm).

Unlike water amount, water matric potential seemed to be a more relevant factor explaining soil slumping. After rainfall event, fast and large changes in matric potential were observed in all the tilled layer (even if buffered with depth) and values as high as 0 hPa reached after the major events (Fig. 1). In a medium made of rigid quartz particles, low matric potential is a major factor of stability and increase in matric potential (i.e. decrease in capillary forces) are a major factor of instability (Hornbakker et al, 1997). With only some percent of clay, aggregation is limited and tilled sandy soils behave like sand piles. In a tilled sandy soil a sudden increase in matric potential to values close to '0' (free water), even for a short time of some minutes, would decrease the internal cohesion of the layer, leading to a more compact arrangement (Or and Ghezzehei, 2002; Mitarai and Nori, 2006).

Higher slumping in the surface layer compared to deeper layers was in relation with two major factors: 1) there is a higher probability to reach high matric potential close to the surface and ii) with limited overburden pressure, interloocking and friction between solid grains was lower, making rearrangement easier. We observed that when tilled in wet conditions the initial bulk density was higher but structural stability was also higher as slumping was less sever (except in surface layer): this is consistent with observation made on stability of aggregate in clay soil which was higher when prewetted compared to dry aggregate (Le Bisonnais, 1988). Therefore, the gradient of matric potential can have an effect of slumping dynamic what is also in agreement with the physics of granular material (Mitarai and Nori, 2006).

Conclusion

The decrease in capillary forces between sand grains during wetting can cause the soil structure loose its previous balance. These phenomena agree with the theory of granular material and the decrease in capillary forces between sand grains during wetting. The specific changes in bulk density profiles induced by rainfall should allow the occurrence of slumping to be predicted or identified as a function of soil, climate and tillage conditions.

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REFERENCES

Bissonnais, Y. Le, 1988. The behaviour of soil aggregates when subjected to the actions of water: mechanisms of aggregate breakdown. Agronomie 8 (10): 915-924.

Busscher, W. J., P. J. Bauer, J. R.Frederick, 2002. Recompaction of a coastal loamy sand after deep tillage as a function of subsequent cumulative rainfall. Soil and Tillage Research 68 (1): 49-57.

Fohrer, N., J. Berkenhagen, J.M. Heckler, A. Rudolph, 1999. Changing soil and surface conditions during rainfall—single rainstorm/subsequent rainstorms. Catena: 355–375.

Hartmann, C., R. Poss, V. Singhatat, 1999. Soil compaction and plant growth in Northeast Thailand: The case of the Nam Pong soil serie. In Ecoregional Approaches to Natural Resources Management in the Korat Basin, Khon Kaen, Thailand, 1999. Ed IRRI/Khon Kaen University.

Hamblin, A.P., D. Tennant, 1979. Interactions between soil type and tillage level in a dryland situation. Australian Journal of Soil Research 17(1): 177 – 189.

Hamza M. A., W. K. Anderson, 2005. Soil compaction in cropping systems, a review of the nature, causes and possible solutions. Soil & Tillage Research 82:121-145.

Hornbaker, D. J., R. Albert, I. Albert, A.-L. Barabási, P. Schiffer, 1997. What keeps sandcastles standing? Nature 387:765.

Kozlowski, T. T. (1999). Soil compaction and growth of woody plants Scandinavian Journal of Forest Research 14(6): 596-619.

Ley, G. J., C. E. Mullins, R. Lal, 1989. Hardsetting behaviour of some structurally weak tropical soils. Soil & Tillage Research 13: 365– 381.

Mead, J. A., K. J. Chan, 1988. Effect of deep tillage and seedbed preparation on the growth and yield of wheat on a hard-setting soil. Aust. J. Exp. Agric. 28: 491-498.

Mitarai, N., F. Nori, 2006. Wet granular materials. Advances in Physics 55:1-45.

Mullins, C.E., D. A. Maceod, K. H. Northcote, J. M. Tisdall, I.M.Young, 1990. Hardsetting Soils: Behavior, Occurrence, and Management. Advance in Soil Science 11: 37-108.

Mullins, C. E., P. S. Blackwell, J. M. Tisdall, 1992. Strength development during drying of a cultivated, flood-irrigated hardsetting soil: I. Comparison with a structurally stable soil. Soil & Tillage Research 25: 113-128.

Or, D., Ghezzehei, T. A., 2002. Modeling post-tillage soil structural dynamics: a review. Soil & Tillage Research 64: 41-59.

Osunbitan, J. A., D.J. Oyedele, K. O. Adekalu, 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil & Tillage Research 82: 57-64.

Wilton, B., 1964. Effect of cultivations on the level of the surface of a soil. Journal of Agricultural Engineering Research 9:214-219.