# Changes of soil bulk density during the growing season under three tillage systems

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Chen, Y., McKyes, E. and Tessier, S. 1994. **Changes of soil bulk density during the growing season under three tillage systems.** Can. Agric. Eng. 36:045-049. Field experiments were conducted to measure soil bulk density on a sandy loam and a clay soil under three tillage and two fertilizer management schemes. Measurements were taken of tillage energy input to the soil and bulk density throughout the growing season for two cropping years. Soil bulk density was shown to decrease linearly with increasing of input tillage energy within the range of this study. Based on the field data, soil bulk density was estimated in the tillage zone. The change of soil bulk density with time and depth after tillage varied among the soil, tillage and fertilizer treatments. The approach shows potential in predicting and describing soil bulk density changes related to tillage practices. However, data from further experiments are required to assess the validity over a wider range of soils and tillage practices.
Keywords: soil bulk density, tillage energy, growing season

La densité du sol est un des principaux facteurs qui détermine plusieurs processus dans le sol. Des expériences en champ ont été entreprises pour mesurer la densité apparente sur des sols argileux et sablonneux sous trois types de travail du sol et deux régies de fertilisation. Les mesures ont été prises pour l'énergie de travail du sol et la densité du sol durant tout la saison de croissance pendant deux années. La densité apparente du sol diminue linéairement avec l'accroissement de l'énergie de travail du sol selon les variations de cette étude. En se basant sur des données aux champs, la densité du sol est estimée dans la zone de travail. Le changement de densité du sol avec le temps et la profondeur après le travail varie selon les sols, les types de travail du sol et les régies de fertilisation. L'approche démontre le potentiel pour prédire et décrire le changement de la densité du sol liée aux pratiques de travail du sol. Toutefois, les données de l'expérience supplémentaire seront requises pour évaluer la validité sur plusieurs types de sols et les pratiques de travail du sol.

## INTRODUCTION

Soil bulk density is important to the soil and plant environment as it affects parameters such as heat and mass transfer. Also, soil bulk density is an indication of soil water and air storage capacity and it can be used to indirectly evaluate soil aeration status and soil suitability for root and plant growth. The usefulness of existing models for soil physical processes and crop growth can be greatly enhanced if physical models are available to describe the effects of tillage on soil physical properties (Gupta et al. 1991).

During the past years, various studies on soil bulk density have been carried out, but quantitative descriptions on the variations of soil bulk density over the growing season have been rarely made. Gupta and Larson (1979) developed a packing model to simulate the density of an aggregated soil. The packing model was based on the concept that during the packing process certain aggregates will be randomly enclosed in the void spaces of packing assemblages formed by other aggregates of larger radii. Gupta and Allmaras (1987) reviewed some of the soil compaction models in the literature and indicated that most of these models calculated the soil density using volumetric strains calculated from stresses using material constitutive relationships. As mentioned by Gupta et al. (1991), the models simulating compaction and the bulk density of the untilled zone are more developed than the models for predicting the density of the tillage zone.

Tillage is known to cause a significant change in soil bulk density. Generally, zero tillage maintains the highest upper soil bulk density, followed by reduced tillage and conventional tillage (Gantzer and Blake 1978; Kay et al. 1985; Hill 1990; Weill et al. 1990). This effect is strongly related to the season. Previous research has indicated that soil tends to become more consolidated over the growing season (Gantzer and Blake 1978; Weill et al. 1990). Blevins et al. (1977) reported no difference in soil bulk density under no-tillage as compared to conventional tillage systems after approximately one year after the last tillage operation. The previous studies have been dominated by qualitative observations, and the lack of quantitative evaluations supported by field data has limited the generalization of research findings.

Tillage tools are used to apply mechanical energy to soil and the soil reacts to the applied force (Gill and Vanden Berg 1967). As a tool advances, soil may move as a continuous mass, or its aggregates may break apart. The soil response to tillage can be described most simply as the change in bulk density. Energy is required to break up and loosen an existing soil structure. In general, the more intensive the tillage operation, the higher the energy requirement (Wolf et al. 1981). When tillage implements of different shapes, such as moldboard plows, chisels, and disks, are used to cultivate soil, some of their total energy input is used to loosen soil, while the rest is lost to friction and to soil compaction. The relative amounts of useful and lost energy depend on the soil properties as well as the geometry and surface material of the tillage tool.

The objective of this study was to examine the variations of soil bulk density in the tilled zone as a function of input tillage energy and density variations with depth, and over the growing season in sandy loam and clay soils.

## MATERIALS AND METHODS

A 2x3 factorial long term tillage experiment was established in 1981 (Kelly et al. 1984) on a Macdonald clay (51% clay, 36% silt, and 13% sand) and a St. Benoit sandy loam (16% clay, 15% silt, and 69% sand) near Montreal, QC. These sites were under grain corn (Zea mays L.) with 0.75 m row spacing and constant tillage management treatments for eight years previous to the present study. The three tillage treatments were: (1) C, conventional, fall moldboard plowing followed by two spring diskings; (2) R, reduced, two spring diskings, and (3) Z, zero-till, corn seeded directly into the previous year's stubble. The two fertilizer treatments were: (1) M, manure, consisting of 40 Mg/ha fresh dairy, supplying 170 kg/ha of N and 240 kg/ha of $K_2O$ (Chemical fertilizer was also added to the M plots supplying 80 kg/ha of $P_2O_5$); (2) I, inorganic fertilizer, comprising 170 kg/ha of N, 80 kg/ha of $P_2O_5$, and 75 kg/ha of $K_2O$. Six combinations of tillage and fertilizer were replicated three times on 10x12 m plots in each soil, forming a total of 36 plots.

The present study was conducted in 1990 and 1991 on the long term tillage plots and used the same tillage treatments as the long term tillage experiment.

A Troxler 3401 single probe gamma ray density gauge (Troxler Inc., Box 12057, Research Triangle Park, NC) was used to measure wet density at 50 mm increments to a depth of 300 mm in each plot through the growing season. The gauge was calibrated by comparing with direct soil core measurements (Gameda et al. 1987). Three positions for each plot were chosen randomly between the corn rows over which there was no wheel traffic. Soil samples were taken at the same time by a 50 mm diameter auger for determining gravimetric soil moisture contents for each depth by the oven drying method. Wet bulk density values were then converted to dry bulk density. The measurements were made five times during the growing season in both 1990 and 1991.

A hydraulic cylinder and mechanical pressure gauge apparatus was used as a tractor drawbar dynamometer to measure horizontal soil resistance of the implements for conventional and reduced tillage treatments. The system was calibrated over a 0 to 14.3 kN range on a Riehle tension machine. The soil resistance for disking and plowing was measured in the spring and the fall of 1991, respectively. Two sampling runs per plot were carried out to estimate disking draft and four runs for plowing. Readings were taken every five seconds for 200 seconds per run and average values calculated. The working speeds used for the moldboard plow and disk were 2.74 km/h and 6.0 km/h, respectively. The disk mass was 585 kg and disk spacing was 0.3 m.

The specific tillage energy per unit volume, $E$, can be defined as the horizontal soil resistance, $R$, times the distance travelled, $x$, divided by the original soil volume tilled, $V_0$.

$$E = Rx/V_0 \qquad (1)$$

A tillage system may include several implement operations for seedbed preparation. In that case the specific energy input from the system would be the summation of the energy contributed by each implement operation.

Empirical relationships between tillage energy, soil bulk density and time were obtained by multiple linear regressions. The analysis of variance was used to test the main effects of the variables and their interaction effects. When interactions occurred, the simple effects were tested. The means of the variables were tested by using the least significant difference test.

**Table I. Measured values for the horizontal soil resistance of the moldboard plow and disk, 1991**

| Treatment | Tool | Depth (m) | Width (m) | Total Resis.* (N) | CV** (%) |
|---|---|---|---|---|---|
| Clay soil | | | | | |
| C | Plow | 0.19 | 0.6 | 8590 | 5 |
| C | Disk | 0.08 | 2.0 | 4040 | 20 |
| R | Disk | 0.05 | 2.0 | 3520 | 15 |
| Sandy loam | | | | | |
| C | Plow | 0.19 | 0.6 | 5940 | 3 |
| C | Disk | 0.10 | 2.0 | 3690 | 19 |
| R | Disk | 0.07 | 2.0 | 3220 | 11 |

*Soil resistance which is the average of 40 readings for the plow and 22 readings for the disk per treatment.

**Coefficient of variation of the observations.

C = Conventional tillage; R = Reduced tillage.

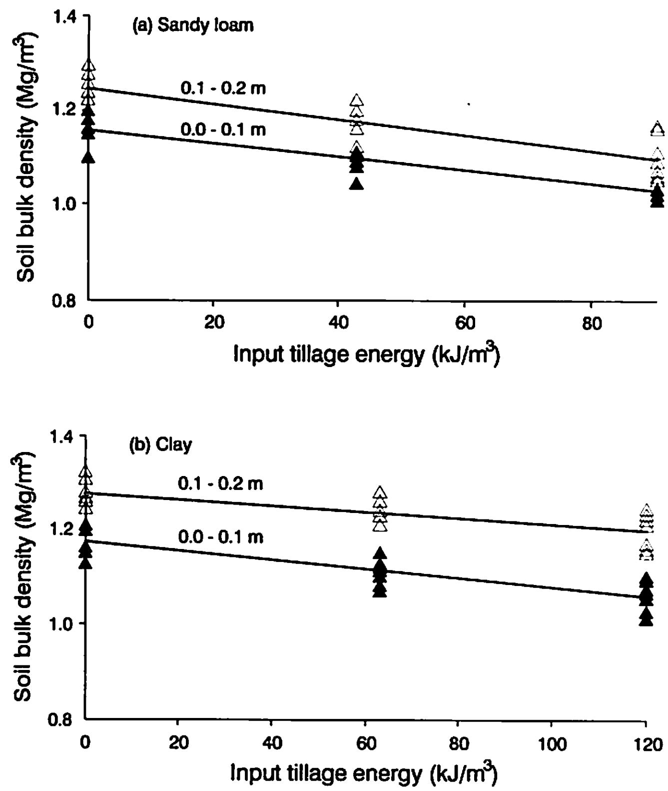


**Fig. 1. Initial soil bulk density at two depths versus specific tillage energy for the seedbed preparation for both experimental sites.** Tillage energy of 0, 62, and 120 kJ/m$^3$ (clay soil) represent zero, reduced, and conventional tillage, respectively.

## RESULTS AND DISCUSSION

### Initial soil bulk density and input tillage energy

Fertilizer treatment had no effect ($p = 0.05$) on the experimental values of soil resistance. Thus, the measured values of the implement forces for the two fertilizer treatments were pooled and the values shown in Table I are the tillage treatment averages. The specific tillage energy for each tillage system was calculated from Eq. 1 and all of the tillage operations for seedbed preparation were included. For instance, the input tillage energy of the conventional tillage treatment is the summation of the energy for one moldboard plow and two diskings. The measured values of initial soil bulk density are plotted with those of energy, $E$, corresponding to the three tillage practices in Fig. 1. Initial soil bulk density refers to the density just after seedbed preparation. A linear relationship between initial soil bulk density and tillage energy was found. The value of initial bulk density decreased with increase in tillage energy. The rate of decrease was greater in the sandy loam than in the clay soil. Further, the slope of the increase of initial soil bulk density with depth was greater in the clay soil than in the sandy loam. However, this analysis was based on a limited data set. It must be remembered that the moldboard plow and disk have different geometries, apply energy to soil in different ways, and therefore their effects on resultant soil bulk density can not be compared directly.

### Soil bulk density during the growing season ($\gamma_b$)

Soil density varies over the growing season (Gantzer and Blake 1978; Weill et al. 1990). Adding to the influence of depth, the soil bulk density, $\gamma_b$, over the growing season can be expressed as

$$\gamma_b = \gamma_{b0} + \beta_1 d + \beta_2 D + \beta_3 dD \qquad (2)$$

**Table II*. Regression parameters (Eq. 2) of the soil bulk density varying over the season and depth under different tillage treatments.** Data are from 36 observations for each soil, tillage, and fertilizer treatment in 1990.

| Treatment | $\gamma_{bo}$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $R^2$ | SE** |
|---|---|---|---|---|---|---|
| Clay | | | | | | |
| CM | 0.97 | 1.20 | 0.0033 | -0.0083 | 0.94 | 0.03 |
| RM | 1.05 | 1.20 | 0.0015 | NS | 0.87 | 0.04 |
| ZM | 1.17 | 0.94 | 0.0017 | NS | 0.80 | 0.05 |
| CI | 1.09 | 0.98 | 0.0009 | NS | 0.79 | 0.05 |
| RI | 1.10 | 0.99 | NS | NS | 0.86 | 0.04 |
| ZI | 1.14 | 0.80 | 0.0010 | NS | 0.94 | 0.02 |
| Sandy loam | | | | | | |
| CM | 0.97 | 0.86 | 0.0010 | NS | 0.97 | 0.02 |
| RM | 1.01 | 0.87 | 0.0008 | NS | 0.92 | 0.02 |
| ZM | 1.07 | 0.80 | 0.0008 | NS | 0.63 | 0.06 |
| CI | 1.02 | 0.75 | 0.0012 | NS | 0.96 | 0.02 |
| RI | 1.03 | 0.99 | 0.0013 | NS | 0.92 | 0.03 |
| ZI | 1.12 | 0.94 | 0.0014 | -0.0068 | 0.91 | 0.02 |

*All independent variables are significant at the $\alpha = 0.01$ level.
NS= Not significant; C = Conventional tillage; R = Reduced tillage; Z = Zero tillage; M = manure; I = Inorganic fertilizer.
**Standard error of the model.

where:

$\gamma_{b0}$ = initial soil bulk density (Mg/m$^3$),
$d$ = soil depth (m),
$D$ = number of days after seedbed preparation, and
$\beta_i$ = regression coefficient.

The analysis of variance indicated that not only the tillage practice, but also the type of fertilizer, affected the soil bulk density. Therefore, empirical regression analysis was performed for each tillage and fertilizer treatment. The regression coefficients, $\beta_i$, are listed in Table II. Soil bulk density generally was a linear function of depth and time. The term for the interaction, $\beta_3 dD$, was only significant in the clay with the CM treatment and in the sandy loam with the ZI treatment. Soil bulk density increased with increasing depth for all treatments. Hill (1990) reported similar results for no-till soils, but he indicated that this pattern was not evident for the conventionally tilled soils. The clay soil under conventional tillage combined with manure fertilizer was most susceptible to recompaction. The rate of density change over the season in the reduced tillage with inorganic fertilizer was not significant in the clay. The relationships in Table II show that the soil density increased more slowly with depth in the sandy loam than in the clay soil as indicated by the coefficient, $\beta_1$. For the RM treatment, the rate of increase in bulk density from 50 to 300 mm at $D$=20 days was 6% greater in the clay site than in the sandy loam site (Fig. 2). The results of $\beta_2$ show that inorganic fertilizer preserves the soil density in the clay soil. Figure 3 shows that the slope of the density increase with time for zero tillage is 1.6 times greater in the manure treatment than in the inorganic treatment.

To perform a preliminary validation of the relationship presented by Eq. 2, bulk density variations during 1991 were compared to those calculated from the regression equations arising from the 1990 season on the same fields. Three sampling dates were used for this purpose. For each sampling date, the measured values were averaged over the plots and the replications. Good fit ($R^2$=0.93 on average) of these data is demonstrated with the proposed relationships (Fig. 4).

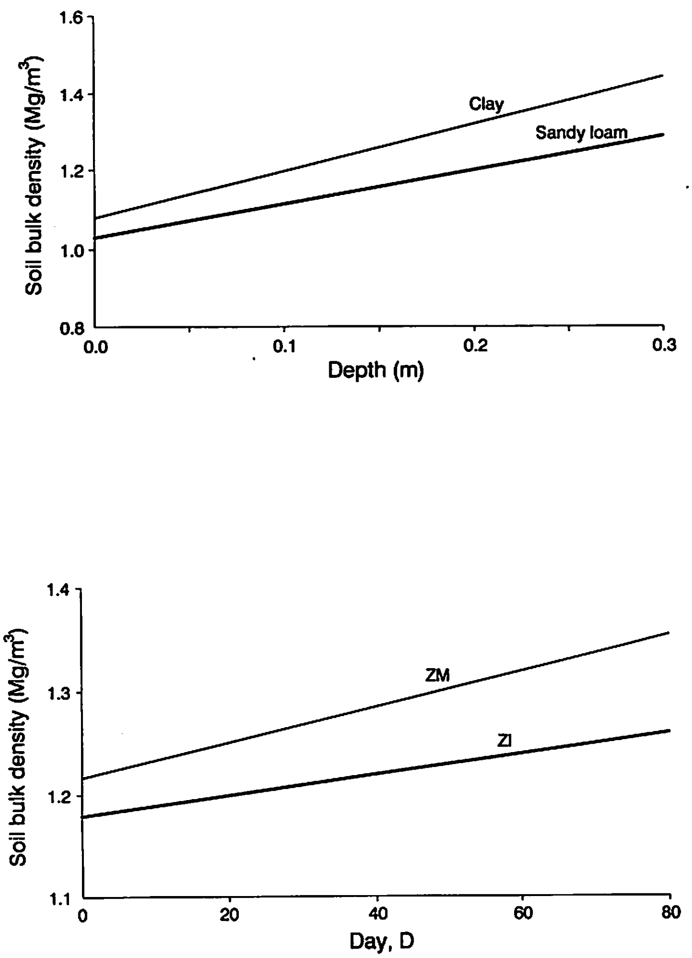


**Fig. 3. The predicted values of soil bulk density versus the number of days after the tillage operations for seedbed preparation for two treatments: zero tillage with inorganic fertilizer (ZI) and manure (ZM), respectively; for clay, at 50 mm depth.**

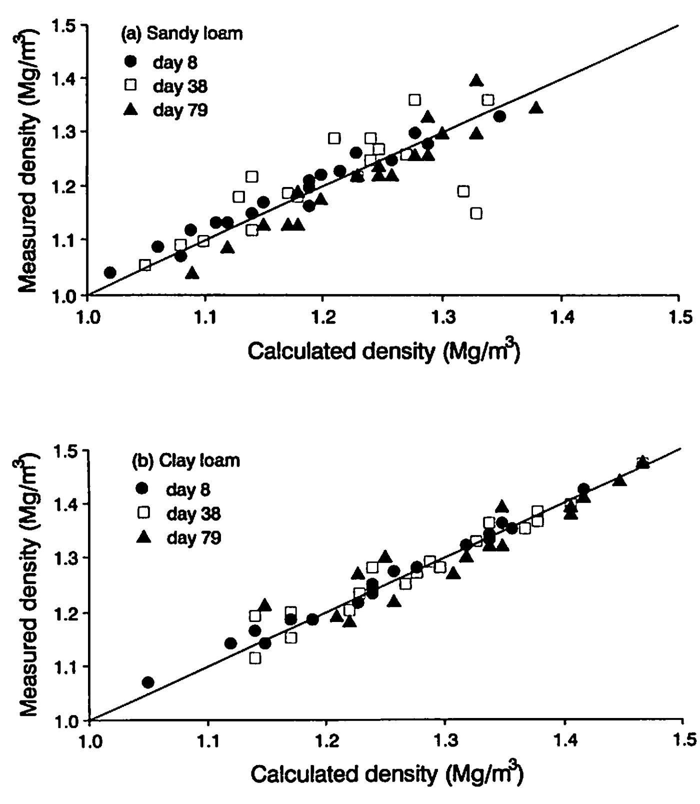


**Fig. 4. Comparison between measured and calculated soil bulk density for three sampling dates during the growing season of 1991.** Each symbol in the graph represents the mean of nine individual samples within a treatment (3 samples per plot x 3 replications).

## CONCLUSIONS

This study provides preliminary information on how soil bulk density is affected by tillage energy input to the soil. Soil bulk density was found to decrease linearly with an increase of input tillage energy over the range of this study. The reconsolidation of soil, as indicated by soil bulk density, over the growing season varied with soil type, tillage, and fertilizer treatments. Slower increase of soil bulk density with time was found in the inorganic treatment compared to the manure treatment in the clay soil. Among the tillage treatments, conventional tillage with manure fertilizer at the clay site lead to fastest reconsolidation. The models are based on a limited data set, two soil types (clay and sandy loam), and two tillage implements (moldboard plow and disk). Further research is required to determine if the relationship holds for a wider range of soil type and implements.

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