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Evaluation of Soil Compactibility Using Micromorphological Characteristics and Mercury Intrusion Porosimetry Data

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THE CURRENT investigation was couducted to evaluate soil compactibility using micromorphological characteristics and mercury intrusion porosimetry. The micromorphological description reveals that there are marked differences in morphology, size and distribution of pores in the compacted and uncompacted soils. The microstructure of compacted soils is platy, whereas it shows a granular structure in the uncompacted ones. The increase in planar and fissure pores on compaction produces a platy microstructure and a strongly horizontal preferred orientation. The structure of uncompacted soils shows a weakly preferred and random orientation .Mercury intrusion porosimetry data show that total porosity was significantly lower at all sampling times in compacted soils and the proportion of pores ranging from 0.2 to 100 um, which are considered the most important criteria in soil-water-plant retionships and in maintaining a good soil structure. The compacted soils have higher area compared to uncompacted ones due to the destruction of soil aggregates induced by heavy agricultural machinery and the rearrangement of particles which are more closely associated to soil compaction. These values could be used to predict water movement and give a better information about transmission and storage pores.

Keywords: Soil compactiblity, Micromorphology, Mercury intrusion porosimetry.

Soil compaction has a great economical beariong on the national economy through its adverse effect on crop production. Jongerius (1970) mentioned that there are three types ol soil compaction induced by heavy agricultural machinery; namely mecapedocompaction, desti-pedo-compaction and vibropedocompaction. Abo-Habaga (1989) reported that soil compaction has two forms; the first is aitifical and the second is natural. He showed that compaction is affected by different factors such as soil type, moisture content, weight of machines and number of passes on the field. The quantity of pores in a soil and their size distribution are useful indicators of the physical condition of soils. However, pore characteristics changes during seasons as well as within a croppin season are not readily quantifiable in their influence on crop productivity. Murphy *et al.* (1977) have shown that the alveolar structure in the top soil was changed to coarse lenticular by the action of tractor wheels. while compaction due to harrowing has been reported by Jongerius (1973). El-Araby *et al.* (1992) reported that tilled soils are subjected to greater compaction than untilled ones at the same moisture content through increasing the number of wheel traffic passes. Raghavan, *et al.* (1978) indicated that machinery traffic has an effect on crop yields by increasing the soil bulk density which decreases the ease of root penetration into the soil, reduces oxygen availability and decreases water infiltration into the soil.

Kozak and Pezda (1995) and Pachepsky *et al.* (1995) reported that mercury intrusion porosimetry is one of the most popular methods used for the determination of pore size distribution of porous materials. From the standpoint of agricultural production. The Salhiya project on Cairo Ismailiya road is one of the present trends in Egyptain agricultural policy to use highly mechanized crop production system. However, the adequancy of tillage. planting, irrigation and harvesting systems may vary greatly from year to year; depending on the available form machinery. Tractors, machines and equipments have been successively increased in terms of number of passes across the field. This condition leads to changes on both physical and micromorphological soil characteristics.

Material and Methods

The current study has been carried out to evaluate soil compactibility using micromorphological characteristics and mercury intrusion porosimetry data. To identify the main differences in characteristics of compacted and uncompacted soils, the area at Salhiya project is considered as one of the promising area.

Four foil profiles were chosen, the first two soil profiles representing the compacted soils (induced by different types of heavy agricultural machinery....*i.e.*

* John Deere 4040 tractor.

* Transpoit pluvi-mulcher disk harrow.

* Roller harrow

* Potato planter

* Pivot center system

The other two soil profiles representing the uncompacted soils. The different layers of the four profiles were morphologically described according to FAO (1990).

Disturbed and undisturbed soil samples were collected for physical and chemical characteristics. Mechanical and chemical analyses of the soil samples were carried out according to Piper (1950), Jackson(1958) and De Leenheer and De Boodt (1965).

For the micromorphological study, undisturbed oriented samples were taken in kubiëna boxes from each compacted and uncompacted layers for the preparation of soil thin sections. The samples were air dried at room temperature. Impregnation was preformed using Epofix resin in vaccum. The small thin sections were prepared according to Murphy (1986) and examined under the petrological and phase contrast microscopes. Soil voids were stained by methylene blue dye (Bouma *el al.*, (1979). The terminology proposed by Bullock *et al.* (1985) was used for the micromorphological description of the thin sections.

Mercury intrusion porosimetry is the most extensively method used in the field of micromorphology for measuring both porosity and pore size distribution. This technique is based on the fact that mercury is a non wetting liquid towards most substances, a pressure must be applied to force it into the pores of the soil: and this pressure is inversely related to the pore size. By measuring the volume of mercury intruded at each increment of pressure, the pore size distribution can be obtained, (Klock *et al.*, 1969). Total porosity, pore size, particle size distributions, surface area and bulk density were determined by the mercury intrusion porosimetry (Porosimetry 2000 series, Carls Frba Instruments). Precise measurement of changes in the volume of mercury as the pressure is increased provides a measure of the volume of pores in a given size range.

Results and Discussion

Mechanical and mineralogical compositions, morphological description and chemical characteristics of the studied soil profiles have been published in a previous paper, (Khadr, 1998).

Micromorphological observations show that there are marked differences in the morphology, size and distribution of voids in the compacted and uncompacted soils. The microstructure of the top soil of the compacted soils is platy, partially being massive and that of the uncompacted ones is granular, photos (1 and 2). This is a result of cultivation, addition of organic materials and biological activity as evidenced by droppings and formation of microaggregates resistant to compaction. Examination of the thin sections of the compacted soils shows that the voids have a more or less bimodal distribution, relatively large planar and fissure voids in contrast to very fine and more or less rounded voids within the platy structural units. The voids in the uncompacted samples have a more random arrangement and weakly preferred orientation and more unimodel distribution. The pore system may be used as a good criterion for explaining the compaction characteristics. The compacted soils have well developed structure associated with poorly physical properties denoting a dominance of planar and fissure voids. The main effect of soil compactibility appears to be the creation of large planar voids (blue colour in pore space) apparently on the expense of vughs, compound packing voids and vesicles as well as a decrease in size of the small voids; hence the size range of the voids increases on compaction. However, as the large voids are horizontally plane, the depth to which roots could explore the soil is likely to be less. The increase in planar and fissure voids on compaction produces a platy microstructure and a strong horizontal preferred orientation in contrast to the uncompacted soils. This indicates that the greater the pressure induced by heavy agricultural machinery is the more significant the planar and fissures occurr.

In respect to the basic organic components. existed in the uncompacted soils, plant remnants in various stages of decomposition, occurring in both discretely and embedded within the soil matrix. In the compacted ones. however, patches of highly humified organic materials and small fragments of dark amorphous organic materials are observed in the top soil, photos (3 and 4). As the organic material content increases, it encourages the formation of microaggregates which is resistant to compaction. Data in Table1 indicate that the bulk density of the uncompacted top soil was (1.40 and 1.56 cm^3/g) compared to (1.68 and 1.74 cm^3/g) for the compacted top soil. The total porosity of the uncompacted top soil was (47.2 and 41.1%), compared to (36.6 and 34.3%) for the compacted ones. This is due to the increase in density of soil as a result of applied .pressure and the reductional in the fractional air volume. Values showed that the studied compacted samples are almost impermeable. Such low porosity and permeability may by attributed mainly to the effect of passes of heavy agricultural machinery and/or the migration of line clay particles and their deposition as clay coatings by the effect of intensive irrigation system through pivot center system.

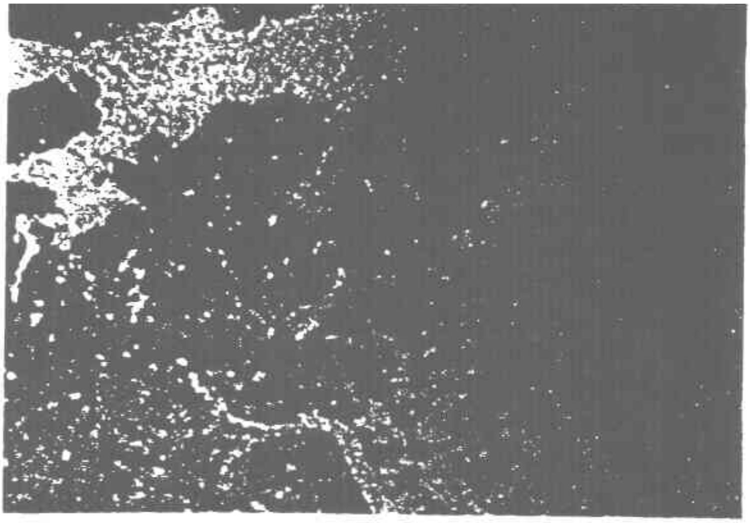

Photo 1. Granular structure. Granules are separated by compound packing voids, no accommodation each other. Uncompacted soils. Phase contrast (0-30cm) layer, profile (3), 135 X.

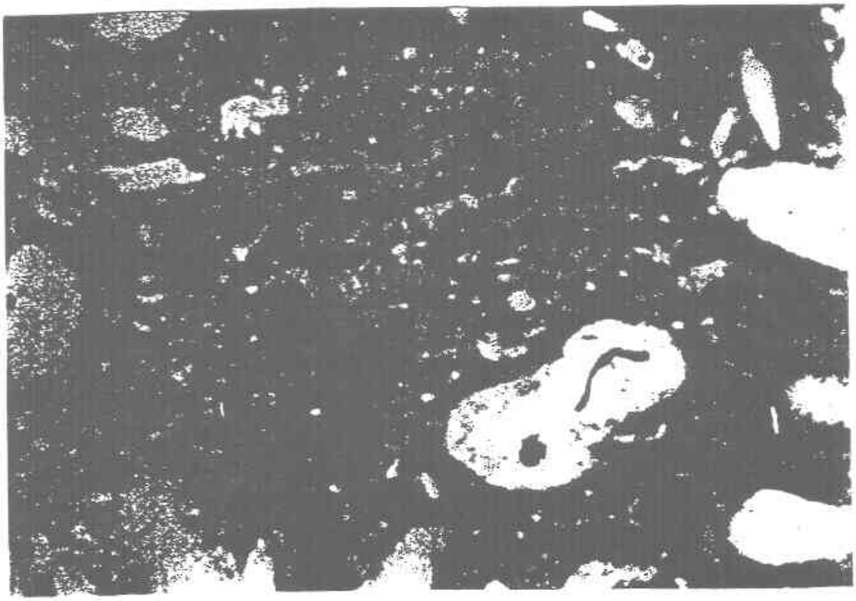

Photo 2. Platy structure. Stacks of aggregates generally horizontally elongated and separated by planar and fissure voids. Compacted soils. Phase contrast, (0-30 cm) layer of profile (1), 135 X Note: blue colour is apore space.

TABLE 1. Some parameters of the compacted and uncompacted soils.

Profile No.	Soil	Depth/cm	Bulk density cm3/g	Total/ porosity%	Permeability(k) cm/hr
1	compacted	0-30	1.68	36.60	0.032
		30.60	1.79	32.45	0.030
		60-90	1.80	32.03	0.028
		90-120	1.82	31.32	0.018
2		0-30	1.69	36. 23	0.028
		30.60	1.72	35.09	0.019
		60-90	1.76	33.58	0.014
		90-120	1.84	30.57	0.012
3	uncompacted	0-30	1.40	47.17	0.512
		30-60	1.45	45.28	0.423
		60-90	1.48	44.15	0.328
		90-120	1.60	39.62	0.048
4		0-30	1.40	47.17	0.518
		30-60	1.42	46.42	0.438
		60-120	1.45	45.28	0.432

Pore size distribution

Greenland(1977) classified pores less than 50 µm in diameter (storage pores) are considered important as reservoir for plant and microorganisms in the soil and pores ranging from 50 to 500 µm (transmission pores) are for transmission of air and water.

The patterns of pore size distribution and pore diameter distribution of compacted and uncompacted soils are reported in Fig. 1. pore Size distributions of samples of uncompacted soils showed a great variation in respect to those of compacted soils at both sampling times. In the former, the proportion of pores ranging from 0.2 to 100 µm was higher than in the latter. Thus, increasing the percentages of transmission and storage pores can be regarded as a clear symptom of improved soil structure. On the other hand, the proportion of pores less than 0.2 µm of samples ot compacted soils was high reaching 90.1% indicating that soil structure isbetter in the uncompacted soils. The highest proportion of pores less than 0.2 µm in compacted soils was induced by the effect of heavy traffic machinery. Figure 2 shows the cumulative percentages of pore size distribution in both compacted and uncompacted soils as a function of pore space. Cumulative values indicate that pores less than 0.2 µm are higher in samples of compacted soils (69.2%) compared to (49.4%) in uncompated ones. This result in an increase of bulk density as well as a decrease in the proportion of larger pores.

Photo 3. Slightly decomposed organic residues, uncompacted soils, phase contrast, (0-30 cm) layer of profile (1), 135 X.

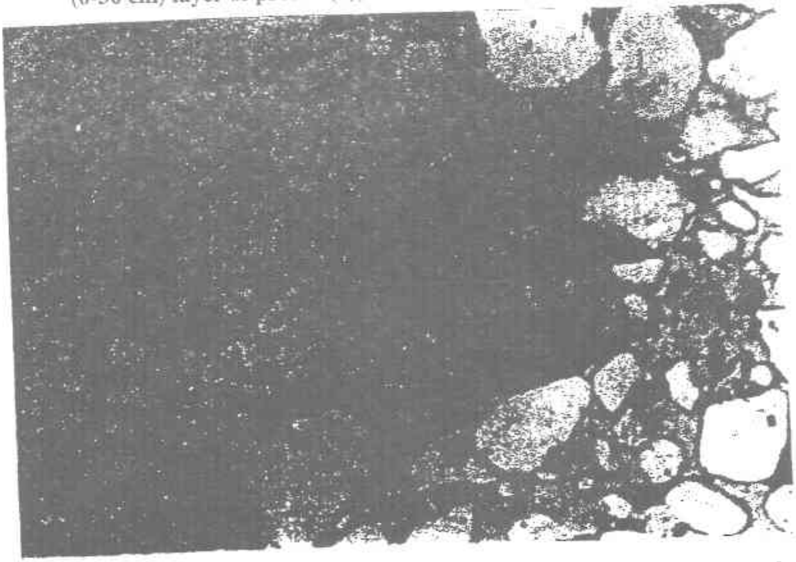

Photo 4. Small fragments of dark amorphous organic residues, compacted soils, phase contrast, (0-30 cm) layer of profile (3), 135 X.

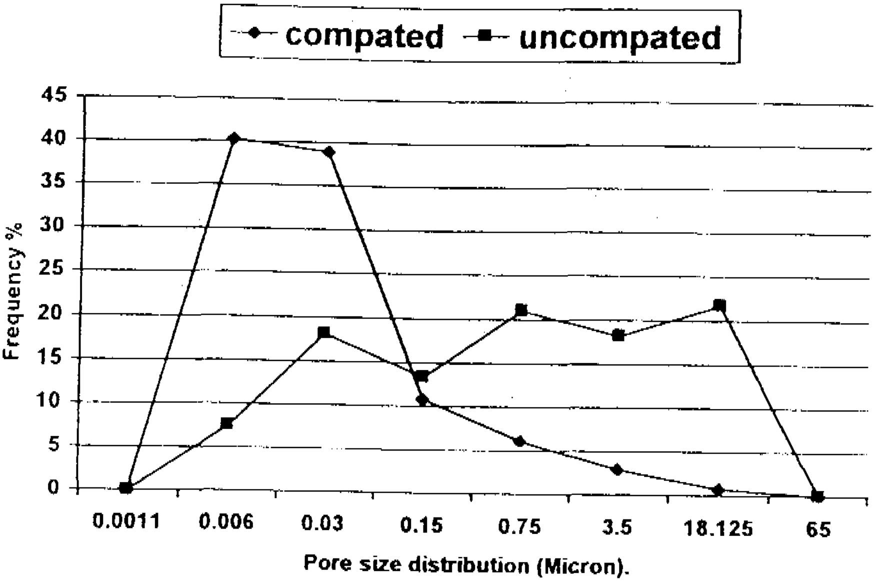

Fig. 1. Frequency percentage of pore size distribution in compacted and uncompacted soils.

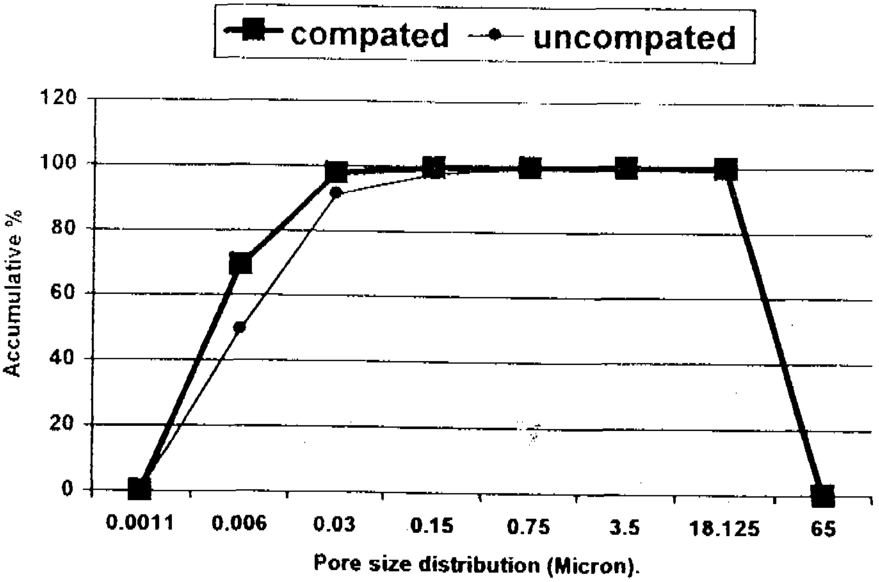

Fig. 2. Accumulative percentage of pore size distribution in compacted and uncompacted soils.

In respect to the high percentage of pores larger than 0.2 µm in uncompacted soils gives a useful indication to the better physical conditions of soils; namly, aeration, water movement and root penetration in soils (Landon,1991).

Figure 3 indicated that pores less than 0.2 µm in the samples of compacted soils had surface area of about 61527.4 cm^2/g compared to those of uncompacted ones of 45441.2 cm^2/g. This is due to the severe compaction induced by heavy agricultural machinery and high content ot swelling clay. These conditions lead to the rearrangement of particles to form compacted layers. Also the high surface area of pores ranging between 0.2 and 100 µm in the uncompacted soils indicates a rather homogenous particle distribution within the clay fraction (Hamdi *et al.*, 1972). It could be concluded that the low values of pores in the compacted soils is certainly due to the compaction of soil particles and their rearrangement creating more micropores, which, in turn, have their reflection on soil water and air conductivity (Boodman and Constantin, 1962).

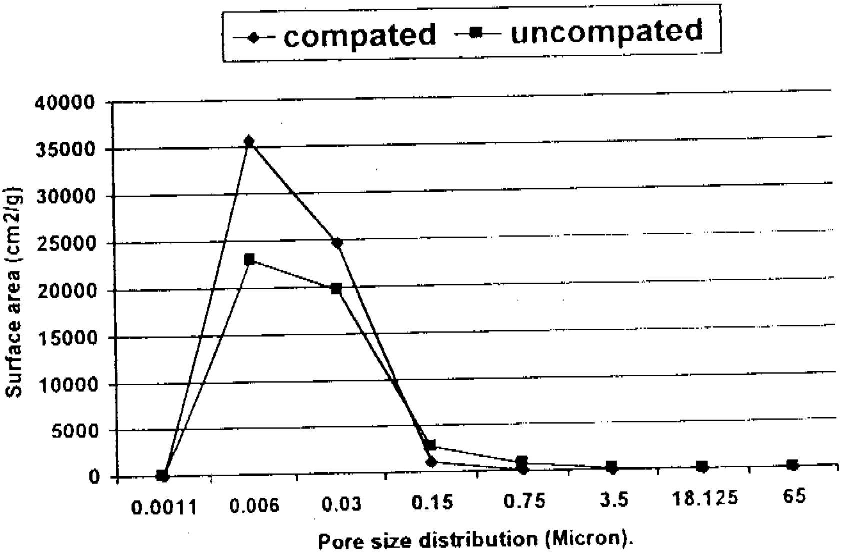

Fig. 3. The relationship between surface area (cm^2/g) and pore size distribution for compacted and uncompacted soils.

Particle size distribution

The particle size distribution in compacted and uncompacted soils which is reported in Fig. 4 and 5 showed that the clay; fine and medium silt contents in the compacted soils are higher than in the uncompacted ones. However, the coarse silt has its major amount in the uncompacted soils in respect to those of compacted ones. Values indicate that the fine particles is the principle constituent of the cementing material in the compacted soils. This is due to the agricultural practices adopted in Egypt by ploughing the top soil at the same depth for many years.

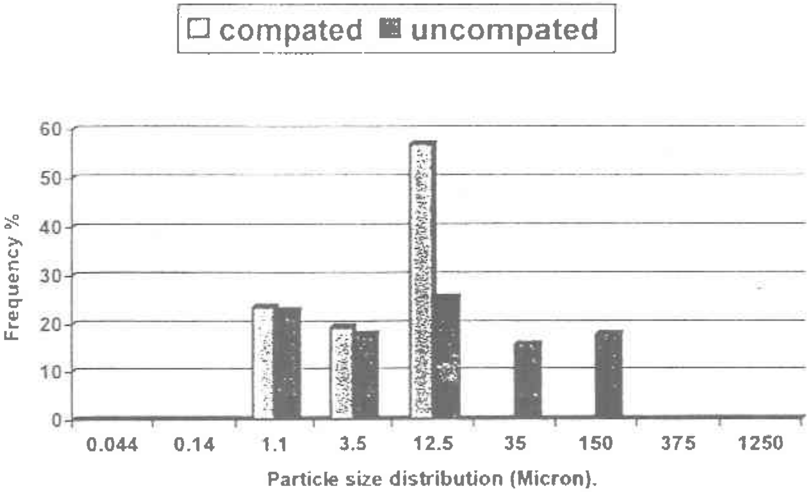

Fig. 4. Frequency percentage of particle size distribution in compacted and uncompacted soils.

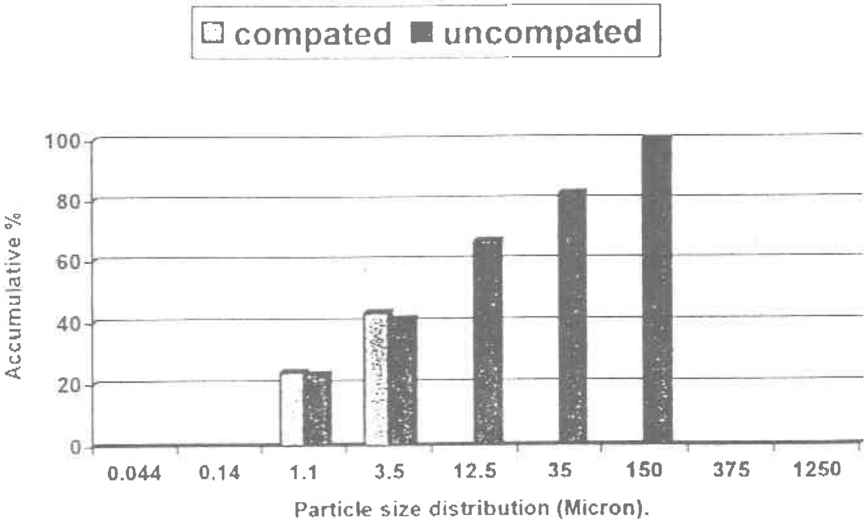

Fig. 5. Accumaltive percentage of particle size distribution in compacted and uncompacted soils.

In respect to the relationship between particle size distribution and surface area in both compacted and uncompacted soils, values show that the coarse clay, fine and medium silt contents in the compacted soils had specific area higher than that of uncompacted ones. These results stood in a good agreement with particle size distribution and other physical and micromorphological characteristics. The compacted soils had specific area of about 1223.1 cm^2/g, while the uncompacted ones had only specific area of about 91.0 cm^2/g (Fig. 6.)

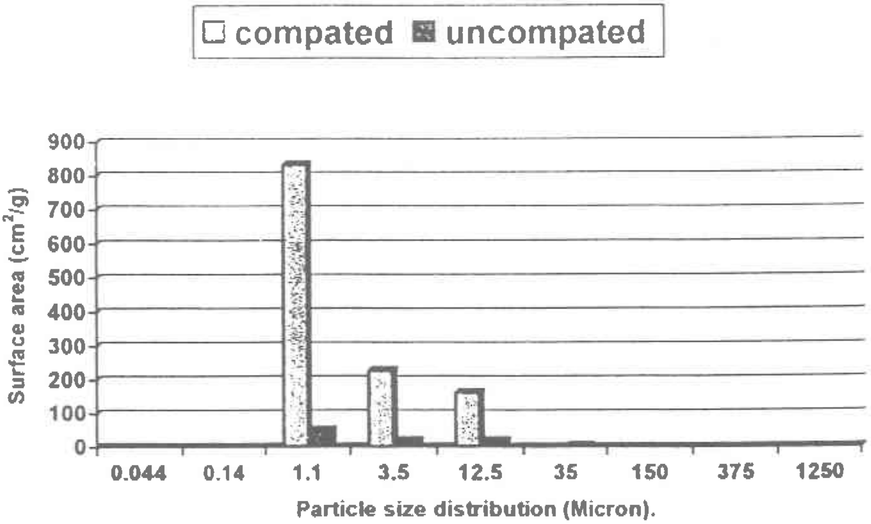

Fig. 6. The relationship between surface area (cm^2/g) and particle size distribution for compacted and uncompacted soils.

It could be concluded that surface area is generally affected by particle size and shape, dominant clay minerals, although both compacted and uncompacted soils exhibit similarity in their parent materials.

Conclusions

Micromorphological characteristics and mercury intrusion porosimetry have been applied to the measurement and characterization of voids in both compacted and uncompacted soils. The micromorphological description of the voids in compacted soils shows that changes of voids have been undergone during compaction. Lateral movement of plant roots is favoured by larger planar voids but downward movement is restricted by the small size of the voids in the platy units, thus inhibiting their search for moisture and nutrients.

From the present study, it can be said that soil compaction should be avoided for a sustainable agricultural development.

Caution is required during field operation by taking into consideration that special design should be adopted for agricultural machinery to minimize the unit pressure imposed on the soil. By increasing intensity of heavy agricultural machinery, the soil porosity and pore size decreased. Also, organic manures addition enhances both soil porosity and pore size distribution and plays an important role in preventing soil compatibility enhancing the formation of granular structure.

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تقييم إندماج الأراضي بإستخدام الخصائص الميكرومورفولوجية وبيانات جهاز قياس المسامية الزئبقي

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أجريت هذه الدراسة بهدف تقييم إندماج الأراضي بإستخدام الخصائص الميكرومورفولوجية وبيانات جهاز قياس المسامية الزئبقي.

وقد أظهرت نتائج الخصائص الميكرومورفولوجية أن هناك إختلافاً جوهرياً في الشكل المورفولوجي وحجم وتوزيع المسام في كلا النوعين من الأراضي المندمجة وغير المندمجة. فالبناء الأرضي الدقيق في الأراضي المندمجة من النوع الطبقي، بينما في الأراضي غير المندمجة يسود النوع الحبيبي نتيجة تكوين التجمعات الدقيقة التي تقاوم الإندماج.

وإتضح أيضاً من الوصف الميكرومورفولوجي إلى سيادة أسطح الإنفصال والشقوق في الأراضي المندمجة مما يساعد على تكوين البناء الطبقي ويكون نظام توزيع المسام أفقياً، بينما في الأراضي غير المندمجة يكون نظام الترتيب عشوائياً.

وقد أوضحت نتائج جهاز قياس المسامية الزئبقي إنخفاض المسامية الكلية في الأراضي المندمجة، وإن نسبة الفراغات (المسام) التي تتراوح بين ٢و٠-١٠٠ ميكرون والتي تعتبر ذات أهمية بالغة في علاقة الأرض بالماء والنبات والتي تحافظ على البناء الأرضي الجيد تكون أيضاً عالية. كما إتضح أن الأراضي المندمجة ذات سطح نوعي مرتفع إذا ما قورنت بالأراضي الغير مندمجة نتيجة هدم الحبيات بإستخدام الآت الخدمة الزراعية الثقيلة وإعادة ترتيب الحبيبات مما يسبب الإندماج.

وهذه النتائج تعتبر ذات أهمية كبيرة في مدى التنبؤ بحركة الماء والهواء وتعطي فكرة جيدة عن كل من المسام الناقلة للماء والهواء أو التي يخزن فيها الماء.