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Experimental Characterization of Physio-chemical, Hydrdynamic and Mechanical Properties of Two Typical Egyptian Soils

Dr. Ahmed Saleh El-Khodre[*]
Dr. Mohamed Naguib Abdel-Azim Bedaiwy[**]

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☐ ABSTRACT ☐

In this research work, conducted in Egypt between December 2006 and April 2007, physiochemical, hydrodynamic and mechanical characteristics were evaluated for two prominent Egyptian agricultural soils. These are the ancient delta clayey soil (Itai El Baroud, western Nile Delta) and the newly reclaimed sandy soil of the Egyptian desert (West Nubaria). They represent the most important agricultural soil types in the country. Results showed major discrepancies between the two soils. Nubaria soils contained merely about 1.0% clay, whereas the Delta soil had about 54% clay. This was reflected in the moisture-retention characteristic curves, as well as the hydrodynamic functions, soil porosity, hydraulic conductivity, susceptibility to densification and compression,. Also, the two soils displayed wide differences in their chemical properties

Keywords: soil properties, physiochemical, hydrodynamic, mechanical properties.

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[*] **Professor, Dept. of Soils and land Reclamation- Faculty of Agriculture, Tishreen University. Syria.**
[**] **Associate Professor, Dept. of Soil and Water Sciences, Faculty of Agriculture, University of Alexandria, Alexandria, Egypt.**

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((دراسة تجريبية للخصائص الفيزياكيميائية والهيدروديناميكية والميكانيكية لتربتين نمطيتين من أترية جمهورية مصر العربية))

الدكتور أحمد صالح الخضر [*]
الدكتور محمد نجيب عبد العظيم بديوي [**]

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☐ الملخّص ☐

أنجز هذا البحث في جمهورية مصر العربية بين شهر كانون الأول 2006م وشهر آذار2007م حيث تمّ فيه تحديد الخواص الفيزياكيميائية والهيدروديناميكية والميكانيكية لتربتين واسعتي الانتشارمن الأترية الزراعية المصرية هما الأترية الطينية القديمة للدلتا (منطقة إيتاي البارود في دلتا النيل الغربية)، و الأترية الرملية المستصلحة حديثا من الرمال المصرية (غربي منطقة النوبرية)،و اللتان تمثلان أهم الأترية النمطية الزراعية في مصر. لقد بينت النتائج تباينا واسعا جدا بين النوعين من التربة ،حيث تميزت تربة النوبرية بنسبة ضعيفة جدا من الطين بحدود 1% ،في حين وصلت نسبة الطين في تربة الدلتا إلى حوالي 54% . لقد انعكس هذا التباين على مواصفات منحنيات الشد الرطوبي ، وعلى التوابع الهيدروديناميكية للتربة ، وكذلك على مسامية التربة وتوصيلها الهيدروليكي وقابليتها للتكثف وللانضغاط . كذلك فقد أبدت التربتان تباينا واسعا في خصائصهما الكيميائية .

الكلمات المفتاحية :خواص التربة ، فيزياكيميائية ، هيدروديناميكية ،ميكانيكية .

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[*] أستاذ – قسم التربة واستصلاح الأراضي – كلية الزراعة – جامعة تشرين – اللاذقية – سورية .

[**] أستاذ مساعد – قسم علوم الأراضي والمياه – كلية الزراعة – جامعة الإسكندرية – مصر .

Introduction:

The study of physiochemical, hydrodynamic and mechanical characteristics of the Delta and Nubaria soils and their changes under external natural elements, particularly water, or man-induced causes have represented a prime interest for researches and occupied a good number of research works. The ultimate objective has always been to identify and evaluate the suitability of a given soil as a complex, multi-phase medium for water flow into it, and thought it to plant roots, in order to provide plants with their need of water and nutrients essential for growth and yield development (Heller, 1977; Heller, 1978; Durand, 1983, El-Khodre 1986; El-Khodre and Kenjo, 2001). Research work is often directed at identifying the patterns of soil aggregation and aggregate stability, and their susceptibility or resistance to the adverse effect of water impact of rainfall or runoff over agricultural lands (Hillel, 1982, Poirée and Ollier, 1978). On another side, numerous works targeted the possible patterns of changes of the soil's adsorption complexes under the influence of water, as it passes through the root zone (Serres, 1980; Durand, 1983; El-Khodre, 1989; El-Khodre et al., 1996).

The two hydrodynamic functions describing the relationship between soil moisture content (θ) and soil moisture tension (ψ), i.e. $\psi=f(\theta)$, and those describing the relationship between soil moisture content and capillary conductivity (K), i.e. $K=f(\theta)$ are among the most important soil-water characteristics. They reflect a much wider array of soil properties, namely, soil formation, development, clay content and mineralogy, particle sizes and gradations, particle and bulk densities, porosity, plasticity, structure and aggregate stability, compactness, swelling, and susceptibility to the formation of surface seals or crusts, in addition to its salinity and types of prevailing salts (Jumikis, 1967; Guerif et al., 1994; Barzegar et al., 1996; Fox and le Bissonnais, 1998; El-Sheemy, 2003). Hence, the improvement of physio-chemical, hydrodynamic, and mechanical properties of the soil, and consequently raising its productivity in case of soils like the two studied here can only be accomplished through reclamation processes (El-Sheemy, 1999; Balba, 1999;). Despite the many new reclamation techniques, we suggest that the use of organic matter could be the most fruitful in such cases, as it provides the sought improvement of soil characteristics while maintaining an "environmentally-clean" agricultural production (Balba, 1999; Mokabel, 2005; Ali and Bedaiwy, 2005).

Importance of Research:

The importance of the work presented in this article comes from the fact that it provides a comprehensive characterization of the two most prevailing soil types in Egypt. These are the ancient Delta soil with its old history of richness and fertility, and current agricultural production privileges and problems; and the new, quite infertile, agricultural sandy soil, that has been, only in recent few decades, put under reclamation programs for agronomic production. The main characteristics of these two soils should be looked at as the foundation for any reclamation processes, irrigation and drainage system design and implementation, and soil agricultural and agronomic practices (irrigation methods, irrigation water quantities and timing, irrigation stream limitations and possible impacts, irrigation durations, irrigation farm unit, drain types, sizes depths and spacing, plowing techniques.. etc.) The ultimate objective must remain focused all the time on how to preserve the soil against possible deterioration, and how to boost its productivity, given all other available factors and limiting conditions.

Material and Experimental Methods:

The experimental work of this research was accomplished between December 2006 and April 2007 at two scientific research facilities in Alexandria, Egypt; Soil physics laboratory, at the Department of Soil and Water Sciences, The Faculty of Agriculture, University of Alexandria, and the Soils laboratory at the Soil, Water and Environment Research Institute, Agriculture Research Centre.

1. Soils

Soils were obtained from two regions in Egypt: 1) Itai El-Baroud, located in the western part of the Nile Delta, and 2) West Nubaria, located in the desert areas to the west of the Delta, nearly midway between Cairo and Alexandria. Soil of Itai-El Baroud (Delta) area is formed of ancient Nile sediments and has been put under agricultural activities for thousands of years. The soil is clayey (clay content > 54%). Soil of the Nubaria area is principally new and has been put under reclamation programs only in the recent few decades. The soil texture of this region is sandy with sand content over 96%. Samples were collected from the top soil layer (0-30 cm) of both soils, transferred to the laboratory, air dried, ground, and sieved through different mesh sizes according to test type.

2. Pedological and Morphological Description of the Experiment Soils

Pedological and morphological description of the sampled regions and soil profiles was conducted. General information about the soil, namely; region, exact geographic coordinates, parent material, land use, water table, average annual temperature, and average annual precipitation, were collected. Detailed profile description was conducted. Description covered specific characteristics such as horizon identification and naming, horizon color, consistency and firmness, characterizing features (e.g. cracks, nodules, roots. etc.). Soils were taxonomically identified and appropriate taxonomic names were designated.

3. Soil Physical and Hydrodynamic Characteristics

Physical and hydrodynamic characteristics determined included the following:

3.1. Soil Moisture-Tension Characteristic Curves

Soil moisture-tension characteristics were determined by means of three approaches:

i) The porous cup (porous plate) method. This was used to determine the $\psi(\theta)$ or $\psi= f(\theta)$ hydrodynamic functions for the lowest range of soil moisture-tensions (< 10.0 centibars) for both soils.

ii) Tensiometers, where $\psi(\theta)$ function was determined at relatively low values of soil moisture-tensions (< 0.8 bar) for each of the two soils.

iii) Pressure-membrane technique, where a pressure-membrane apparatus was used to determine the characteristic relation between soil matric-suction (ψ) and its moisture content (θ) at suction values ranging between 0.2 and 14.0 bars. The use of the pressure-membrane moisture-tension apparatus facilitated the construction of a complete *p*F curve for each of the two soils.

3.2. Density and Soil Densification

The bulk density (D_b) of the Delta clayey soil was determined by means of i) soil cores, constant volume technique, with the use of metal cylinders (5 cm inside diameter, 7 cm high for laboratory determinations, and 8 cm inside diameter, 10 cm high for in-situ field sampling), and ii) the clod method (paraffin wax method) using a tri-beam balance. For the sandy soil, constant volume technique was used, where the loose soil was packed into metal cylinders, 8 cm inside diameter and 7 cm high. Cylinders were tapped 3-times to allow particles to rearrange in a near-natural packing mode. Samples were dried at 105°C for 24 hours and the oven-dry weight was determined. Soil bulk volume was taken as the net inside volume of the metal cylinders.

Soil susceptibility to densification was determined through monitoring the change of density with varying rates of wetting. This was performed by packing deep metal trays, 30 cm inside diameter and 10 cm high with each of the two soils, saturating the soils, draining the gravitational (free) water. Soils were then dried successively, and samples were taken at each moisture level by means of sampling, 5-cm diameter, 7-cm high metal cores. Soil moisture was determined in the tray soil. In the same soil trays, tensiometers were installed for soil-moisture-tension measurements. Also, soil surface strength (resistance to penetration by a spring penetrometer) was measured. It was possible, thus, to obtain simultaneous measurements of soil moisture content, moisture-tension, bulk density and soil surface mechanical resistance.

Real (Particle or solid) Density (D_s) of each of the two soils was determined by means of the pycnometer method.

3.3. Soil Porosity

Total, micro- and macro-porosities were determined for both soils.

i. **Total porosity (P_t):** This porosity parameter comprises the sum of the micro- (capillary) and macro- (air) porosities. Capillary pores (diameters ≤ 8μ or ≤ 10μ in some classifications, e.g. Soltner, 1978) are ideally filled with water when the soil is at field capacity. Macro pores (diameters > 8μ, or > 10μ depending on classification system) are those filled with air when the soil is at field capacity. Naturally, fine-textured soils are characterized by high total- and micro-porosities and low macro-porosity. The opposite is true for coarse-textured soils; i.e. they have low total- and micro-porosity and high macro-porosity.

Total porosity was determined through two different approaches:

■ Mathematical (calculated); based on the bulk density, D_b, and the particle density, D_s, where:

$$P_t\% = 100\,(1 - D_b/D_s) \qquad [1]$$

■ Gravitational (weighing) method; This was done by saturating covered soil samples from below by capillarity to avoid the formation of pockets of entrapped air within soil sample. Samples were covered to prevent evaporation of water and were saturated for 48 hours. This was performed in soil cylinders with perforated bottoms. Saturation moisture content was then determined by drying the soil samples in the oven at 105°C for 24 hours, until no further weight change occurs. Total porosity was then determined as the percent of total volume (in cm^3) of saturation water, which numerically equals its weight (in g), to total soil volume.

ii. **Microporosity (capillary porosity P_c)** Microporosity was determined gravimetrically by saturation and drainage of gravitational water. The soil was saturated then left with its surface covered for 48 h to dry by draining its gravitational (free) water. The remaining water is defined as the capillary water (Hansen et al, 1980). Samples were dried in the oven at 105°C for 24 h and the weight of the capillary water, and hence its volume was determined. This volume (in cm^3) is equal to total micropore volume. Porosity is then determined as the percentage of micropore volume to total soil volume.

iii. **Macroporosity (air porosity P_a)** Macroporosity was determined as the calculated difference between the total and the capillary porosities. i.e.

$$P_a\% = P_t\% - P_c\% \qquad [2]$$

iv. **Specific yield, S (drainable porosity, P_d)** Specific yield is defined as the volume of water released from a known volume of saturated soil under the force of gravity and the inherent soil tensions. It is determined by subjecting saturated soil to some additional suction (usually about 70 cm of water) to enhance equilibrium under gravitational force. Specific yield is expressed as a percentage of the total volume of saturated soil:

$$\text{Specific yield, } S \text{ or Drainable porosity } P_d = \frac{\text{volume of water drained}}{\text{total volume of saturated soil}} \times 100 \qquad [3]$$

3.4. Soil Moisture Contents (θ)

Soil moisture content was determined by drying the soil samples in an oven at 105°C until the soil mass was unchanged. Soil moisture was measured at saturation, field capacity, and at several intermediate values, as well as at contents lower than field capacity, to monitor the impact of different soil moisture levels on various pertinent properties.

3.5. Capillary/Hydraulic Conductivity (K)

The capillary/hydraulic conductivity of the two soils was determined in two cases; at complete saturation and below saturation.

i. Saturated hydraulic conductivity (K_s): This determination was performed according to Darcy's Law in two laboratory settings on soil samples that were initially saturated by capillarity at room temperature (18°C). The first determination was done under a constant head, where a constant head of water (5 cm) was maintained over the soil sample in 10-cm diameter, 10-cm high brass cylinders. The second was done under a falling head starting at 5 cm and ending when the water head vanishes. An average head of 2.5 cm was thus considered in this case. The soil used for the hydraulic conductivity determinations had been passed through a 2-mm sieve.

ii. Unsaturated capillary conductivity (K) and conductivity of saturated soil under no pressure head: The soil used in this determination had been passed through 2-mm sieves. Two experiments were performed on each of the two soils to evaluate: i) The hydraulic conductivity for initially air-dry soil samples, and, ii) the hydraulic conductivity for soil samples that were pre-saturated by capillarity, at different stages of drying by simultaneous evaporation and drainage. In both cases, measurements were done according to Darcy’s law. In the first case (air-dry soil), the moisture content of the soil rose gradually during the experiment. The top soil (about 2 cm) reached saturation. The rest of the soil column had a moisture content somewhat below saturation, following closely the Bodman and Coleman model (1944) and forming a transitional zone through the rest of the soil depth. In the initially-saturated soil, no pressure head was applied. The purpose of this was to simulate non-ponding field situations, associated with irrigation techniques such as sprinkle and drip, where short irrigation intervals are followed. These two sets of conductivity determinations were done using soil cylinders, 10-cm high and 7.5-cm in diameter.

iii. In situ infiltration rate, *IR*

Field determination of infiltration rate, *IR*, was performed to assess the influence of field conditions (management and agronomic services) on the infiltrability of field soil to water. For both soils, infiltration rate was determined in soils exposed to surface irrigation (Delta) where the soil is subjected to occasional flooding, or drip irrigation (Nubaria soil), as well as in fallow soils. Double ring infltrometers were used under a constant head of water provided by means of special feeding tubes (Withers and Vipond, 1980).

4. Soil Mechanical Properties

Determined soil mechanical properties included the following characteristics:

4.1. Soil Texture

Soil texture was determined using the pipette method at laboratory temperature of 18°C. The soil samples used were finer than 2 mm. Coarse sand was separated using sieves according to Richards (1954).

4.2. Soil Mechanical Resistance to Penetration

Soil resistance to penetration was determined by means of a spring penetrometer (SoilTest inc.–Model CI-700). Resistance was monitored while initially-saturated soil, packed into deep soil trays was left in open air to dry under normal laboratory conditions. Soil packing was done at D_b values comparable as closely as possible to those under field conditions. The strength-moisture content patterns and relations were thus evaluated for both soils.

4.3 Soil Plasticity

Soil plasticity was evaluated through the following parameters (Casagrande, 1932, El-Khodre, 2006):

- Lower plastic limit
- Viscosity point (stickiness point).
- Upper plastic limit (or lower liquid limit), and
- Plasticity range

These limits, known as Atterberg limits, were determined by progressive mixing of soil and water under controlled conditions in porcelain dishes. Liquid limit was determined by Casagrande apparatus (SoilTest–Model CI- 207, Casagrande, 1932).

5. Chemical Properties

The chemical analysis of the two soils was done following methodologies described by Jackson (1958). Soil paste was prepared of sifted soil (< 2 mm), saturated for 24 hours. Saturation moisture percent was determined. All determinations were performed at laboratory temperature (18° C). Determinations included:

□ Basic chemical characteristics; namely: pH, $CaCO_3$, OM, CEC and EC.
□ Soluble cations: Na^+, K^+, Ca^{++}, and Mg^{++}.
□ Soluble anions: SO_4^{--}, Cl^-, HCO_3^-, and CO_3^{--}

The following methods and/or instruments were used,

- pH: pH-meter;
- $CaCO_3$: calcimeter apparatus,
- O.M. : potassium Di-cromate + ammonium ferrous sulfates method,
- EC: electric conductivity salinity meter,
- CEC: sodium chloride and barium chloride solutions,
- Na^+ and K^+: flame photometer ,
- Ca^{++} and Mg^{++}: versenate (EDTA) titration,
- SO_4^{--}: Barium chloride,
- Cl^-: silver nitrate titration
- HCO_3^-, and CO_3^{--}: sulfuric acid method

Results and Discussions:

1. Data Processing and Analysis

Collected data were processed and analyzed using standard computer data processing programs such as Statgraph 5.0 and Excell 2003.

2. Pedological and Morphological Description of the Experiment Soils

2.1. Delta Soil: The Delta region represented in this work is located near Itai El-Baroud, about 84 km to the south-east of the city of Alexandria, on the agricultural road bound to Cairo, at 30° 40′ north and 30° 52′ east. This soil represents the western region of the Nile Delta. The parent material is Holocene Nile alluvium deposits (Abdel-Kader and Abdel-Hamid, 1974). The land in the area is predominantly agricultural, where agronomic activities represent the principal occupation for the inhabitants of the region. Crops are various, including field crops, vegetables, and orchards. Farms are generally small in area and individually owned. Depth to ground water in a typical farm is about 120 cm. Average annual air temperature is approximately 21.0°C and average rainfall is about 100.0 mm. The taxonomic name of the soil is *Typic Pellusterts*. A typical soil profile consists of two horizons:

Ap (0-30 cm): Plowed surface layer; very dark gray (10YR 3/1) clay; strong coarse angular blocky to cloddy structure; sticky and very plastic wet, firm moist, slightly hard dry ; common continuous vertical cracks dry; many fine black nodules; many medium roots, gradual boundary to next horizon.

Ba (30-100 cm): Structural subsurface horizon; very dark grayish brown (10YR 3/2) clay; strong very coarse angular blocky structure; sticky and very plastic wet, firm moist, hard dry; many slickensides moist; many continuous vertical cracks dry; many fine to coarse black nodules; few medium roots.

2.2. Nubaria Soil: Nubaria is located in the western desert to the west of the Nile Delta. Region represented here is located at 30° 47′ north and 30° 25′ east . Parent material is Pleistocene sandy deposits of the deltaic stage of river terraces. The area has been put under reclamation and agriculture in the recent few decades. A Variety of crops are grown in the area; field crops, such as wheat, barley and maize, a wide variety of vegetables and fruits as well as citrus and fruit trees orchards. Depth of water table ranges between 6-8 m. Average annual air temperature approximately 20.0°C and average annual rainfall is about 23.0 mm. The taxonomic name of the soil is: *Typic quartzipsamments*. Four horizons can be distinguished in a typical profile.

Aw (0-10 cm): Weak humus horizon; brown (10YR 4/3) coarse sand; single grain; very friable moist, soft dry; many fine roots; abrupt boundary to the next horizon.

C_1 (10-30 cm): Yellowish brown (10YR 5/4) coarse sand; single grain; very friable moist, loose dry; a abrupt boundary to the horizon below.

IIC_2 (30-90 cm): Brown (10YR 4/3) very find sand; single grain; friable moist, soft dry; gradual wavy boundary to the horizon below.

$IIIC_3$ (90-120): Yellowish brown (10YR 5/4) fine sand; single grain; friable moist, soft dry; many coarse soft spherical clay segregations

3. Hydro-physical Properties

3.1. Basic Moisture Relations and Effects on Density, Tension, and Mechanical Resistance

Table 1 displays results obtained concurrently for bulk density (D_b), weight-based soil moisture content (θ_w), soil moisture tension (ψ) as measured by soil tensiometers, and mechanical resistance to penetration (R_m).

Table 1. Bulk density (D_b), weight-based soil moisture content (θ_w), soil moisture tension (ψ) and mechanical resistance to penetration (R_m) for Delta and Nubaria soils.

Delta soil				**Nubaria soil**			
D_b, g cm^{-3}	θ_w%	ψ, centibar	R_m, kg cm^{-2}	D_b, g cm^{-3}	θ_w%	ψ, centibar	R_m, kg cm^{-2}
1.152	46.645	5.00	0.10	1.792	17.768	1.00	0.00
1.186	43.876	12.00	0.15	1.772	16.425	4.00	0.00
1.216	41.513	23.00	0.40	1.746	14.795	7.00	0.10
1.212	34.062	29.00	0.50	1.701	11.610	9.00	0.15
1.276	29.610	38.00	0.75	1.708	7.904	11.00	0.15
1.286	26.958	44.00	1.25	1.701	6.440	13.00	0.15

Results shown in the above Table indicate the following:

- As expected, the Nubaria soil has very low water holding capacity in comparison with the Delta soil. Obviously, this is a result of the domination of macropores in sand which make the soil looses water by gravity much more easily in contrast with finer texture soils that have predominantly micro (capillary)- pores.

- The Delta soil displayed much greater soil moisture tension in contrast with the Nubaria soil even when the moisture content in the former is several folds greater than that in the latter. This is attributed to the much higher capillary porosity in the Delta clay. Both soils suffered high moisture tension at low soil moisture content, as larger pores were emptied, with tension values consistently greater in the Delta soil. Clayey soils are known to have most of their porosity in the form of micropores. At the permanent wilting point, pores filled with water in clay are as small as 0.2µ or smaller (C.T.G.R.E.F, 1979).

- Mechanical resistance to penetration was greater in the Delta clay than in the Nubaria sand, apparently due to the high content of the clay fraction with montmorillonite minerals constituting the major part of it in the Delta soil (50-60%, Kishk et. al, 2003). Upon wetting, clay aggregates slake and disintegrate into small single soil particles that rearrange and form interlocked seal or skin of denser packing (Bedaiwy and Rolston, 1993). As a result, higher mechanical resistance is observed. Mechanical resistance was seen to increase with decreased soil moisture in both soils. This increase was more evident, however, in the Delta soil. This is attributed both to the increased densification of the formed skin or crust (Rolston et. al, 1991) in clay, and the over all increased bulk density associated with soil drying, particularly in clay where shrinkage is more pronounced.

- Greater bulk density, D_b, in the Nubaria soil as compared with the Delta soil; this is caused principally by i) smaller total porosity of the Nubaria sand on one hand, and ii) higher specific gravity of quartz which constitutes the main mineral of sand, on the other hand.

- Increasing bulk density of the Delta clay with desiccation, partly due to shrinkage, while the sand's density did not show marked increase with decreasing wetness. On the contrary, the Nubaria soil displayed occasional slight decrease in D_b with dryness, as gaseous component increased at the account of the denser liquid phase. Soil solutions could also play a role in enhancing soil bonding in coarser soils, which is reflected in slightly higher density. Figure 1 shows the above described trends. Strong correlations were seen for moisture-tension (θ-ψ) and moisture-resistance (θ-R_m) relationships in both soils, emphasizing the very significant role of soil moisture. Second order polynomial equations of the form $y=ax^2+bx+c$ described θ-ψ relationship, where y is soil moisture tension, x is the moisture content, and a, b, and c are constants. Correlations were significant ($P < 0.01$, determination coefficients, R^2, were 0.96 and 0.97, for the Delta and Nubaria soils, respectively). The θ-R_m functions were described by a logarithmic equation (for Delta) of the form $y = a \ln x + b$ and a second order polynomial equation (for Nubaria) of the form $y=ax^2+bx+c$, where y is mechanical resistance, x is soil moisture content and a, b, c are constants. Relations were statistically significant ($P < 0.05$ and < 0.01 for the Delta and Nubaria soils, respectively)

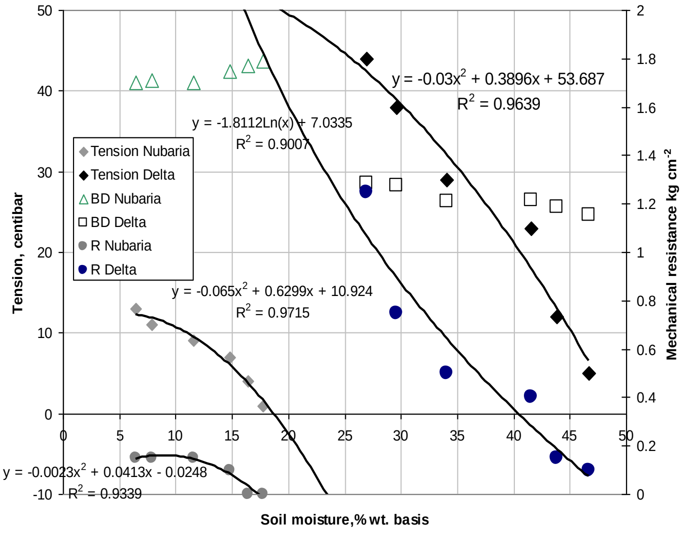

Fig. 1. Bulk density, tension (range < 1.0 bar) and mechanical resistance to penetration as influenced by soil wetness in the Delta and Nubaria Soils.

Figure 2a displays the relationship between gravitational moisture content (θ_w%) and soil moisture tension (ψ) over tension range < 10.0 centibar, as determined by the porous cup technique (Marshal and Holmes, 1988) for the two soils. As the graph shows, soil moisture tension increases with dryness for both soils. Typical texture effects on the moisture-tension trends are seen over the determined range. Much greater soil moisture is retained in the Delta clayey soil at any given value of tension, as discussed earlier. This has an important significance in irrigation and water availability to plant roots. Most water in a sandy soil is available to plant uptake and is readily used, whereas in a clayey soil most of the soil water is held tightly to the soil matrix by forces of adsorption (surface forces) and capillary forces. Obtained data fitted exponential equations of the form $y = a e^{bx}$, where y is soil moisture content, x is soil moisture tension, and a, b are constants. Both functions were statistically significant ($P < 0.01$), Determination coefficients (R^2) were > 0.96 and > 0.99 for the Delta and Nubaria soils, respectively.

For larger values and a wider range of soil tensions, moisture-tension relations were examined by means of a pressure plate apparatus setup. A range of 0.2- 14.0 bar of suction was applied and the obtained results are displayed in Fig. 2b. Trends were expressed by a power function (Delta soil) of the form $y = a x^b$, and a *log* function (Nubaria soil) of the form $y = a \ln x + b$ of where y is soil moisture content, x is soil moisture tension, and a, b are constants, both with determination coefficients exceeding 0.96 in highly significant relationships ($P < 0.01$).

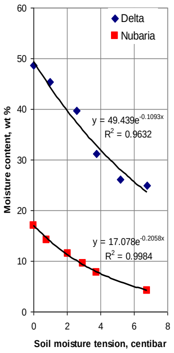

Fig. 2a. Soil moisture-tension curves over low-range of tension (< 10.0 centibars), determined by the porous cup technique for the Delta and Nubaria soils.

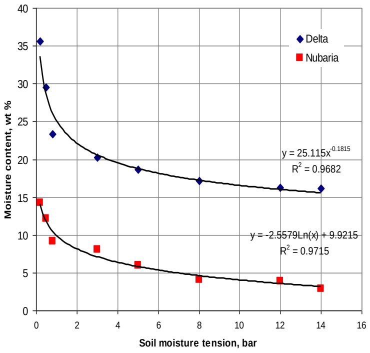

Fig. 2b. Soil moisture-tension curves for Delta and Nubaria soils over a wide range of moisture tension as determined by pressure plate technique.

Results shown in Fig. 2b illustrate trends similar in general to those described earlier of low suction ranges. The Delta soil had, consistently, higher moisture contents at any given value of soil tension due to its high clay content. Some important moisture characteristic values (moisture constants) can be concluded from the θ-ψ data. The field capacity (*FC*) moisture content of the Delta soil falls apparently between 35.58% and 29.51%, which are the moisture contents corresponding to tension values of 0.2 and 0.5 bars, respectively. This gives an average *FC* of approximately 32.55%. For the Nubaria soil, corresponding values are 14.22 and 12.16%, with an average of 13.19%. The permanent wilting point (*PWP*) falls in the vicinity of the 14-bar suction, i.e. 16.11% for the Delta soil and 2.91 for the Nubaria soil. These values yield an available water percentage of approximately 16.44% and 10.28% for the Delta and Nubaria soils, respectively. This means that the Delta soil has about 6.16% more available water for plant use than the Nubaria soil. The readily available water (*AW*) in the Nubaria sandy soil would, however, represent a higher portion of the available water than in the delta clayey soil due to the much greater capillary pores in clay where water is held more tightly and is much more difficult to release. It is noticeable here that *FC* moisture content, and hence *AW*, in the Nubaria soil is rather high for a sandy-textured soil. This may be a result of the fact that more than half (51.5%) of the sand fraction of this oil is formed of fine sand (200-20µ). Domination of fine sand in a sandy soil is reflected in better water holding capacity. Texture description of the two soils is discussed in a subsequent section (section 4.3.3). On the other hand, the Delta soil reflects relatively lower-than-expected values both for *FC* and *PWP*. Typically, clayey soils would usually have *FC* and *PWP* values in the approximate vicinity of 40% and 25% (Withers and Vipond, 1980). A possible explanation for this may have to do with the markedly high percentage of the very highly swelling montmorillonite in this Delta clay. Montmorillonitic clays absorb significant amounts of water and render it into a difficult to extract form, which may result in such relatively lower values.

Other moisture parameters determined included saturation moisture percentage (θ_{sat}%) for the two soils. These were 46.06% and 17.29% for the Delta and Nubaria soils, respectively. The *FC* was determined also for the two soils by gravitational drainage to ensure consistency of results. Obtained values were 32.49 % and 13.65% for the Delta and the Nubaria soils, respectively. These numbers are very comparable with those deduced from the *p*F (moisture-tension) curves referred to in the above paragraph (32.55% and 13.19% for the two soils in the same order).

Soil Porosities: Total and capillary porosities of the two soils were determined. Calculated total porosities (P_t) were 56.19% and 30.04% for Delta and Nubaria soils, respectively. Capillary porosities (P_c) of the two soils were calculated, based on *FC* values, as 39.64 and 23.71% for the two soils, in the same order. Accordingly, the macroporosity (or air-porosity, P_a) are determined as 16.56% and 6.33% for the Delta and Nubaria soils. These determined values are typical values for the respective soil textures of the two soils.

Specific yield, *S*, (Drainable porosity), P_d

Determined specific yield produced results that were more consistent in Nubaria soil than in Delta soil. Values of *S* in Nubaria soil ranged between 7.48 and 8.22%. These values are somewhat lower than expected for a sandy-textured soil. Typical sandy soil with comparable saturated hydraulic conductivity values (K_s = 41.78 – 47.33 mm h^{-1} , Table 2) fall between approximately 12 and 14% This may be attributed to the high percent of fine sand fraction in this soil. In general, these determined *S* values reflect good soil aeration and drainage but poor water holding capacity. For the Delta soil, the obtained results were highly inconsistent and variable, where a wide a range of 1.92 to 5.81% was measured. Typical *S* values, based on K_s (K_s = 2.15-2.50 mm h^{-1}, Table 2) are below 2%. Generally, these low *S* values indicate, to the contrary of the Nubaria soil, a high water holding capacity and very poor aeration and drainage capability.

3.2. Hydraulic/capillary conductivity and infiltration

Hydraulic conductivity (K_s) results are shown in Table 2. As one would expect, the saturated hydraulic conductivity in the Nubaria soil was markedly greater than that of the Delta soil, based mainly on their difference in texture.

Table 2. Hydraulic conductivity of the Delta and Nubaria soils, determined under falling and constant water heads.

Delta soil		Nubaria soil	
Falling head mm h^{-1}	Constant head mm h^{-1}	Falling head mm h^{-1}	Constant head mm h^{-1}
2.15	2.50	41.78	47.33

Other determinations performed on non-saturated soils, i.e., initially air-dry soils and soils that had been subjected to saturation then left to drain and evaporate freely, included measuring the infiltration rate (*IR*) and the capillary conductivity (*K*) under those specific conditions. Water flow was maintained under no pressure head (water height above soil surface = 0). Apparent infiltration rate IR_a, was approximated by the rate of advance of the wetting front over a distance *x* in time *t*, where

$$IR_a = x/t \qquad [4]$$

Capillary conductivity (*K*) was calculated according to Darcy's Law

$$K = QL/(AHt), \qquad [5]$$

where:

K: hydraulic conductivity, cm s^{-1},

Q: volume of water passing through the soil column (cm^3),

L: length of soil column, cm,

A: cross section area of soil column, cm^2

H: total height of soil column and pressure (water) head, cm, and

t: time over which the outflow (Q) was collected, s.

Since the pressure head in these determinations was equal to zero, equation [5] reduces to the simple relation: $K = Q/At$. Measurements were taken in two replications for each soil. The average of replications for each soil is given in Table 3. Results are those of 6 sets of measurements taken at 30 min intervals, and extending over an interval of 180 min.

i. Initailly air-dry soil samples

Table 3. Apparent infiltration rate (IR_a) and hydraulic conductivity (K) of the Delta and Nubaria soils taken every 30 min for a total of 180 min. Subscripts refer to time intervals.

Soil	IR_a, cm s^{-1}	K_{30} cm s^{-1}	K_{60} cm s^{-1}	K_{90} cm s^{-1}	K_{120} cm s^{-1}	K_{150} cm s^{-1}	K_{180} cm s^{-1}
Delta	7.8×10^{-3}	2.466×10^{-4}	1.919×10^{-4}	1.535×10^{-4}	1.453×10^{-4}	1.359×10^{-4}	1.271×10^{-4}
Nubaria	2.33×10^{-1}	1.474×10^{-3}	1.571×10^{-3}	1.570×10^{-3}	1.571×10^{-3}	1.571×10^{-3}	1.572×10^{-3}

It was noticed that for both soils, IR_a replications were identical, and equaled 7.8×10^{-3} and 2.33×10^{-1} cm s^{-1} for the Delta and Nubaria soils, respectively. Variations of K with time were very minor for the Nubaria sand, and all K determinations were in the vicinity of 1.55 $\times10^{-3}$ cm s^{-1} on average basis. For the Delta soil, however, K values decreased gradually with time, with an overall average of about 1.66×10^{-4} cm s^{-1}. The Delta soil had markedly much lower infiltration rate and hydraulic conductivity in comparison with the Nubaria soil. Obviously, differences are principally a direct result of texture differences. Besides, the Delta soil displayed a monotonic decrease in conductivity with time (this was consistent in the two replications). The decrease in K with time is apparently associated with two mechanisms:

i) A continuous slaking and rearrangement of particles, which results in more closely-packed soil system with time (le Bissonnais, 1990, Bradford and Huang, 1991),

ii) The swelling of the montmorellonitic clay, which dominates the the Delta clayey soil.

The Nubaria sandy soil, on the other hand, displayed virtually no change in conductivity with time. Slaking in sand is almost non-existing, since its content of cementing agents and organic matter is nearly zero, and hence no significant aggregation occurs. Rearrangement and close-packing of soil particles is also minimal due to the sizes, shapes, and gradation of sand particles. Also, the lack of swelling minerals or any clay fractions result in very insignificant- if at all- alterations in volume or shape.

The high values of K in the Nubaria soil reflect its high permeability to water. In practice, this is very important, as it emphasizes the need for special irrigation techniques, such as drip or sprinkle irrigation, depending on salinity conditions, especially sodium bicarbonates content in irrigation water. Controlled, low input, high frequency irrigation systems usually provide better efficiency both in irrigation and water distribution. Surface irrigation is obviously no appropriate option for such soils.

ii. Zero water head on saturated soil, and saturated soil subjected to drainage and evaporation

In this case also, infiltration rate and hydraulic conductivity were determined immediately after the soil was saturated by capillarity while being covered for 24 h ($IR_{a\ s\text{-}}$

$_{24}$, $K_{s\text{-}24}$). Then, determined again after the soil was left to freely drain and evaporate for 24 h ($IR_{a\ d\text{-}24}$, $K_{d\text{-}24}$), and after the soil was left to drain and evaporate more, for 48 h ($IR_{a\ d\text{-}48}$, $K_{d\text{-}48}$), and finally after 96 h. The purpose of this set of treatments was to simulate the flow in soils irrigated at intervals ranging between one day and 4 days. Results are shown in Table 4.

Table 4. Apparent infiltration rate (IR_a) and hydraulic/capillary conductivity (K) for the Delta and Nubaria soils under saturation, and saturation-and-drying conditions, and associated moisture contents (shown moisture contents apply both to IR and K measurements).

	Infiltration rate, IR_a cm s^{-1}				Hydraulic conductivity, K cm s^{-1}			
	$IR_{a\ s\text{-}24}$	$IR_{a\ d\text{-}24}$	$IR_{a\ d\text{-}48}$	$IR_{a\ d\text{-}96}$	$K_{s\text{-}24}$	$K_{d\text{-}24}$	$K_{d\text{-}48}$	$K_{d\text{-}96}$
Delta	0.165	0.148	0.038	0.0075	7.548×10^{-5}	6.417×10^{-5}	5.536×10^{-5}	2.611×10^{-5}
Nubaria	3.5	2.567	2.333	0.788	1.473×10^{-3}	1.145×10^{-3}	1.101×10^{-3}	1.057×10^{-3}
	$\theta_{s\text{-}24}$	$\theta_{d\text{-}24}$	$\theta_{d\text{-}48}$	$\theta_{d\text{-}96}$				
Delta	47.33	44.739	38.596	30.216				
Nubaria	18.7	15.730	15.445	14.248				

Results shown in Table 4 reflect the markedly lower infiltration rate IR_a and conductivity in the Delta soil in comparison with the Nubaria soil in all cases. Also, a pattern of falling infiltration rates and conductivity with drying is apparent for both soils (Fig. 3), where the fall is steeper in the case of Nubaria soil. The falling pattern of both IR_a and K is attributed to the increased presence of soil air at the account of water, and the subsequent blocking caused by air in soil voids. This disruption of soil solution continuum caused by air entry leads to slow water flow through the soil porous medium (Hillel, 1982). This mechanism appears to play the major role in the Nubaria sandy soil and to lead to that steep fall. Two other reasons are added in the case of the Delta clayey soil; i) the swelling effect of clay minerals, particularly montmorillonite, and the resulting reduction in larger pores, and, ii) the formation of a dense sealed skin or crust on the soil surface as a result of wetting, and the subsequent slaking, rearrangement, and resettling of loose particles in dense, interlocked impermeable formations (Bedaiwy and Rolston, 1993). Generally, and for the above reasons among many others, clayey soils have infiltration and conductivity rates that are tens- to hundreds of folds lower than those of sand, which is obvious in the above results.

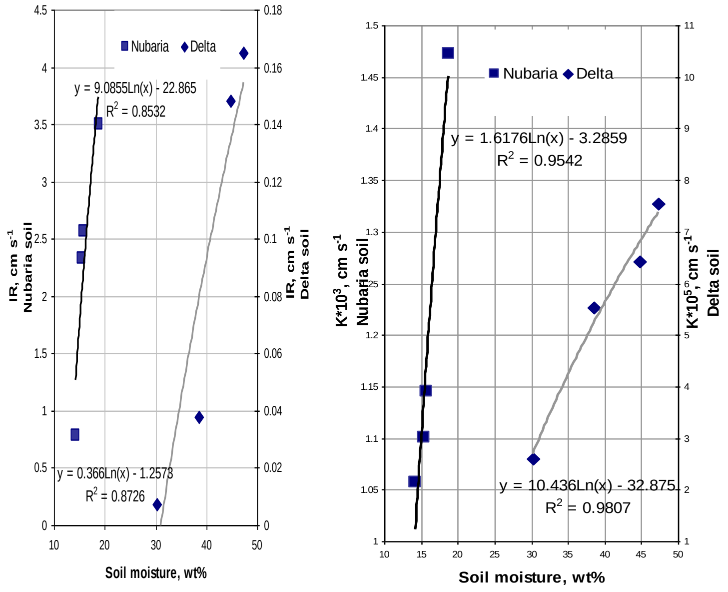

Fig. 3. Effect of moisture content at saturation and after drying to various levels on infiltration rate, *IR,* (left) and hydraulic/capillary conductivity, *K,* (right) for Delta and Nubaria soils.

iii) In situ infiltration Rate

In situ infiltration rate was determined in the field for both soils. Double cylinder technique (Withers and Vipond, 1980) was used. Delta soil in-situ infiltration was determined in sites where soil was exposed to frequent or occasional flooding under irrigation, as well as in fallow soils. Values varied significantly, depending on soil condition. Much lower *IR* was measured in areas subjected to surface irrigation or flooding. In some cases, an *IR* of virtually 0.00 mm h^{-1} mm was observed. Soils subjected to flooding/ponding are reported to undergo mechanical and structure alterations . Aggregates are likely to disintegrate under frequent flooding or wetting. Loose particles move with water and migrate into larger voids, resulting in surface crusting, or, at least, the formation of a denser surface layer that is less permeable than the rest of the soil. Fallow soils and soils exposed to limited infrequent irrigation showed, generally, higher *IR*, where values ranging between 2.94×10^{-5} and 1.77×10^{-4} cm s^{-1} were obtained. Overall, for the Delta soil, determined infiltration rates ranged between approximately 4.64×10^{-8} cm s^{-1} in areas subjected to surface irrigation and occasional flooding, and 1.77×10^{-4} cm s^{-1} for more open, fallow soil. The Delta soil represented in Fig. 4 was subjected to a single surface irrigation, and has a basic (steady state) *IR* of 1.28×10^{-4} cm s^{-1}. For Nubaria soil, determinations were performed in 5 different villages in the area. Determined rates varied slightly, ranging between 3.8×10^{-3} and 6.08×10^{-3} cm s^{-1}. An average, basic (steady state, final) infiltration rate was calculated as 4.85×10^{-3} cm s^{-1} (4.19 m day^{-1}). This rate falls within typical values for coarse-textured soils (Withers and Vipond, 1980; FAO, 1973). Fig. 4 displays the obtained infiltration curve for an intermediate, typical case where *IR* = 4.67×10^{-3} cm s^{-1}.

Comparing the above field-determined basic *IR* values with those determined in the laboratory (IR_a and *K*) for disturbed samples of the two soils, it is seen that, for the Delta soil, field values were smaller than IR_a laboratory values (Tables 3 and 4) by at least one order of magnitude, but was very comparable with the K values determined after extended time intervals (e.g. K_{180}, Table 3). This could be explained by the fact that after such long durations of infiltration, soil swelling on one hand, and swelling on the other, would have reached their peak and the soil is as closely packed as it may exist in the field. Additionally it is obvious that approximating *IR* by the advance rate of water as not accurate and would yield greater-than-real rates. Comparing with the case where the soil was pre-saturated (Table 4), it seems that all field IR values are significantly lower than IR_a values but are somewhat comparable to *K* values. The Nubaria soil showed rather similar trend, where field *IR* measurements were notably lower than those determined in the laboratory for disturbed samples. Field *IR* values were here also more comparable with *K* values. It is known that steady-state (basic) infiltration rate can, in general, be well approximated by the soil's hydraulic conductivity (Hillel, 1974; Marshal and Holmes, 1988).

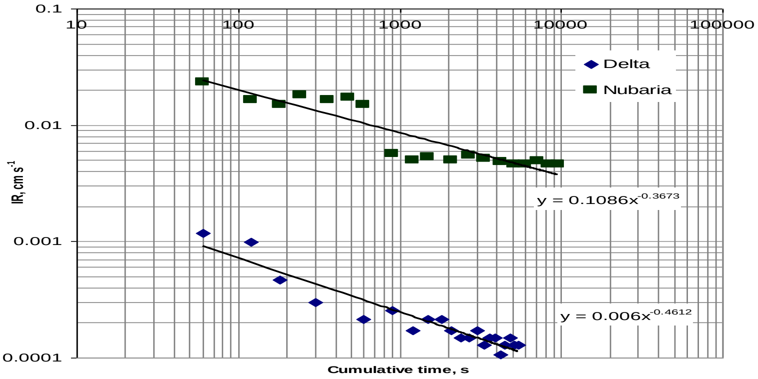

Fig. 4. In-situ infiltration rate for the Delta and Nubaria soils.

3.3. Particle-Size and Granulometric Soil Analyses

Texture and density results reveal that the two studied soils are extremely different, a heavy clayey Delta soil and a sandy Nubaria soil poor in clay content and organic matter (OM), (OM content will be discussed in Section 4.4). Both bulk and particle densities appear within normal ranges for these two soil types, although the bulk density of the Delta soil appear slightly higher, and that of the Nubaria soil slightly lower, than expected. Table 5 displays the mechanical analysis of the two examined soils, as well as soil densities as experimentally determined

T **Table 5. Mechanical analysis, texture class[1], and soil densities of the two examined soils.**

	% fraction				**Texture**	**D_b, g cm^{-3}**	**D_p, g cm^{-3}**
	C. sand	**F. sand**	**Silt**	**Clay**			
Delta	5.10	10.10	30.20	54.60	Clay	1.220 (field core sample) 1.376 (clod)	2.667
Nubaria	44.80	51.50	2.60	1.10	Sand	1.730	2.710

[1] **class determined based on the International Society of Soil Science (ISSS) classification.**

the viscosity limit (stickiness point, **($\theta_{V.L}$)** =34.41% (Table 6). The stickiness point moisture content approximates the moisture content near the soil's field capacity. This value is quite close to the one previously determined by gravitational drainage of 32.49%. The practical implication of this is related to field agronomic activities. Any agronomic practices involving applying pressures or manipulation of the soil, such as plowing, machinery and individuals' traffic, etc., must be avoided at moisture contents near this $\theta_{V.L}$ for the Delta soil. Extensive pressure around this moisture content is likely to lead to extreme densification and to the loss of favorable tilth through the formation of massive, structureless soil layers. Consequent results are typically, very poor infiltration, excessive water loss by surface runoff, and difficulty in germination and seedling emergence, in addition to poor soil manageability.

3.4. Density, Soil Densification, and Resistance to Penetration

Mechanical resistance to penetration was greater in the Delta clay than in the Nubaria sand, apparently due to the high content of clay, and the domination of montmorillonite, which constitutes 50-60% of it (Kishk et. al, 2003). Upon wetting, clay and clay-rich aggregates slake and disintegrate into small single soil particles that rearrange and form interlocked seal or skin of denser packing (Bedaiwy and Rolston, 1993). As a result, higher mechanical resistance is observed. Mechanical resistance was seen to increase with decreased soil moisture in both soils. This increase was more evident, however, in the Delta soil. This is attributed both to the increased densification of the formed skin or crust (Rolston et. al, 1991) in clay, and the overall increased bulk density associated with soil drying, particularly in clay, where shrinkage, and hence apparent density increase, are more pronounced. Soil mechanical resistance to penetration (R_m), as well as effect of soil moisture (θ_w%) on mechanical resistance are discussed in section 4.3.1. Results are shown in Table 1, and the θ_w-R_m function is plotted in Fig. 1.

3.5. Soil Consistency, Consistency Limits (Atterberge Plasticity and Liquid Limits)

Plastic and liquid limit determinations were performed exclusively on the Delta clayey soil. Sandy soils do not qualify for these tests due to their loose structure (Jumikis, 1967). Soil samples (50.0 g, oven dry, passing through 2.0 mm sieves) were placed in porcelain dishes and water was added slowly from a graduated burette. Soil-water mix was stirred continuously with a glass rod (El-Khodre, 2006). Also, the Casagrande liquid limit apparatus was used (Jumikis, 1967). Results (two replications) were as follows:

Volume of water needed to reach lower plastic limit (L_p) = 21 $cm^{3,}$

Volume of water needed to reach viscous limit (L_V) = 28 cm^3

Volume of water needed to reach upper plastic limit (liquid limit) (L_L) = 43.5 cm^3

Number of blows (beatings) needed by the Casagrande apparatus as well as the moisture content corresponding to the different limits (L_p, L_V and L_L) are shown in Table 6

Table6. Soil moisture content, and number of Casagrande blows needed to reach different Atterberg limits.

Atterberg Limit	Mass, g			No. of blows on Casagrande apparatus
	Wet soil	Dry soil	Water content,%	
Lower plastic limit, L_P ($\theta_{P.L}$) - observed	35.75	27.80	28.60	50
Viscous limit, L_V ($\theta_{V.L}$) - observed	34.88	25.95	34.41	35
Liquid limit – L_L ($\theta_{L.L}$) - observed	35.77	24.00	49.04	27
Liquid limit – L_L ($\theta_{L.L}$) - determined graphically from 'flow curve'			42.0	25
Liquid state			51.0	13
Liquid state			54.0	6

As seen in Table 6, some marked difference exists between observed value of **($\theta_{L.L}$)** and the value determined graphically on a flow curve (Fig. 6). Observed value was

49.04%, while that determined was approximately 42.0%. Swelling of the soil and the high capacity of the montmorillonite clay may alter plasticity and liquid behavior depending on equilibration time, and could therefore result in marked variation. Typical values of ($\theta_{L.L}$) for a clayey is generally > both observed and graphically determined values obtained here, and could reach moisture contents as high 70%. This particular point appears to require more investigation on this Delta soil.

Taking an average value, we have: ($\theta_{L.L\text{- }average}$) = (49.04% + 42.0%)/2 = 45.52%

i. Plasticity Index (*PI*) From Table 7, the plasticity index (*PI*%) can be calculated as:

$$PI\% = \theta_{L.L} - \theta_{P.L} \qquad [8]$$

$$= 16.92 \text{ or} \approx 17.00\%.$$

This *PI*% is considerably high. According to the plasticity index classes (ASTM, 1964), a soil having *PI* > 17% is a highly plastic soil, and typically has a clay texture. A soil having a *PI*% of 7-17 % is medium plastic and is generally of silty clay or clayey silt texture. But since this Delta soil has a plasticity index that lies virtually on the borderline between medium plasticity and high plasticity, and also, since we know that the texture class of this soil is clay. We can conclude that this Delta soil is one of medium-high to high plasticity. According the ASTM classification, 1964 both classes including soils of *PI* > 17% or 7-17% (i.e. both medium plastic and high plastic soils) are cohesive soil. Therefore, this delta soil is also classified as cohesive.

i. State of consistency at *FC*

This soil has a *FC* of 32.49 (refer to section 4.3.1 on moisture constants). The soi's D_b and D_s are 1.22 (taking core density) and 2.667 g cm^{-3}, respectively. The soil's total porosity, P_t (determined based on densities) is hence:

P_t% = (1-1.22/2.667)100 or 54.26%

It should be noted here that porosity determined based on saturation water content (section 4.3.1) was: P_t = 56.19%, which is fairly comparable.

Saturation moisture content (θ_{sat}, calculated) = $P_t/D_s(1-P_t)$ or 47.25%

Saturation moisture content (θ_{sat}, determined, section 4.3.1) = 46.06%

Again, theses two values (density-based and experimentally-determined) compare reasonably well. Taking the average value for θ_{sat}, ($\theta_{sat\text{-}average}$) = 46.66%), the degree of saturation, *S*, at *FC* is thus:

S = 32.49/46.66, or,

= 0.696. Here,

i) Since 28.60 < (*FC*%) < 45.52, where *FC* = 32.49%, the soil at its field capacity moisture content is in the plastic state.

ii) Examining obtained values of θ_{sat} and $\theta_{L.L,}$, we notice that θ_{sat} (both density-based calculated and experimentally-determined values) are > $\theta_{L.L\text{- }average}$ by a slight difference of 1.14%. But if observed $\theta_{L.L}$ of 49.04% is considered, then θ_{sat} is < $\theta_{L.L,}$by 49.04% - 46.66% or by 2.38%. This shows that the moisture content of the examined Delta soil at saturation is very close to the soil liquid limit, and the soil is most likely at its highest point in the plastic state (closest to liquid limit or approaching that limit). This, once again, indicates high soil consistency and cohesiveness induced principally by clay content and clay mineral types. The flow curve of the Delta soil is shown in Fig. 7. Obtained data points are best-fitted to a logarithmic equation of the form $y = a \ln x + b$, where, *y* is moisture content, *x* is number of blows on the Casagrande apparatus, and *a*, *b* are constants, *a* being negative.

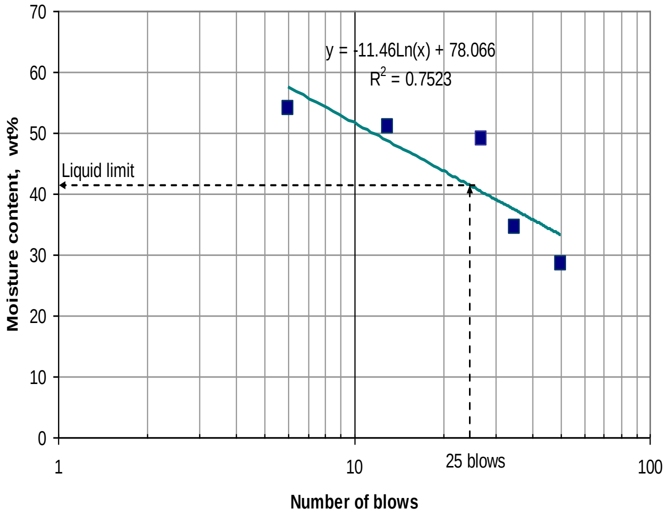

Fig.5. Flow curve of the Delta soil. $\theta_{L.L}$ is determined graphically as the moisture content corresponding to 25

The viscosity limit (stickiness point, **($\theta_{V.L}$)** =34.41% (Table 7). The stickiness point moisture content approximates the moisture content near the soil's field capacity. This value is quite close to the one previously determined by gravitational drainage of 32.49%. The practical implication of this is related to field agronomic activities. Any agronomic practices involving applying pressures or manipulation of the soil, such as plowing, machinery and individuals' traffic, etc., must be avoided at moisture contents near this $\theta_{V.L}$ for the Delta soil. Extensive pressure around this moisture content is likely to lead to extreme densification and to the loss of favorable tilth through the formation of massive, structureless soil layers. Consequent results are typically, very poor infiltration, excessive water loss by surface runoff, and difficulty in germination and seedling emergence, in addition to poor soil manageability.

4. Chemical Analysis and Properties

Results of chemical analyses of the two examined soils are shown in Table 7a. Analyses were done on soil extracts (Jackson, 1958)

Table 7a. Results of chemical analyses of the Delta and Nubaria soils

	Analysis												
						Concentration of soluble cations and anions, meq/100 g							
						Cations				Anions			
	pH	$CaCO_3$ %	OM %	CEC	EC dS m^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	SO_4^{--}	Cl^-	HCO_3^-	CO_3^{--}
Delta	8.06	1.024	1.39	39.6	1.6	0.22	0.01	1.83	1.02	0.41	1.8	1.0	0
Nubaria	7.8	2.88	0.02	3.4	0.9	0.11	0.01	0.31	0.13	0.34	0.11	0.11	0

Taking into account the saturation percentage for each of the two soils, on weight basis, and examining the concentrations in Table 7a, concentrations in meq/liter would be as shown in Table 7b.

Table 7b. Concentration of soluble cations and anions, meq / liter, for the Delta and Nubaria soils.

	Concentration of soluble cations and anions, meq / liter							
	Cations				**Anions**			
	Na^+	**K^+**	**Ca^{++}**	**Mg^{++}**	**SO_4^{--}**	**Cl^-**	**HCO_3^-**	**CO_3^{--}**
Delta	4.876	0.222	40.567	22.611	9.089	39.902	22.168	0
Nubaria	2.438	0.223	6.872	2.882	7.537	2.438	2.438	0

As seen in Table 11a, the pH of both soils is rather high, especially in the Delta soil, reflecting moderate alkalinity despite the low concentration of total and active $CaCO_3$ in both soils. This relatively high pH is most likely attributed to the high Na^+ concentration in both soils, particularly in the form of $NaHCO_3$. Organic matter is virtually zero in the Nubaria soil, whereas in the Delta soil it is of a moderate concentration. The cation exchange capacity is very low in the Nubaria soil, while high to very high in the Delta soil. Soil salinity, expressed as electric conductivity, EC, is low and so is the sodium adsorption ratio, SAR, which is 1.104 for the Nubaria sandy soil and 0.868 for the Delta clayey soil.

Conclusions:

The research work presented in this manuscript deals in details with physiochemical, hydrodynamic and mechanical characteristics of two predominant, and economically important soils in Egypt. It draws the attention to the important characteristics of each of them and the implication of these characteristics in practical agriculture. It is obvious that each of the two tested soils requires particular management programs with regard to cropping systems, crop rotations, agronomic practices, irrigation, drainage, water management and fertilization, depending on their respective particular properties, potentialities, or problems. While the Delta soil may suffer of depleted fertility due to extensive cropping over the centuries, and of physical problems associated with high susceptibility to densification, as well as water penetration problems, the Nubaria soil has more limitations and problems. Poor water holding capacity is a major problem of the Nubaria sandy soil, which makes the addition of organic or chemical amendments and conditioners a must. Mechanical properties reflected the high susceptibility of the Delta soil to crusting and densification. It became clear that great attention must be given to managing the soil at various moisture contents, and that particular management practices and/or manipulations that may lead to alteration of the soil beyond a certain moisture limit must be avoided. In general, many approaches could be considered to deal with the limitations and problems of these two soils. We focus here on some of the options: The first option is to use composted organic matter which is expected to markedly boost most of the soil's physiochemical, hydrodynamic and mechanical properties. This is more important in the case of the Nubaria sandy soil, which has virtually neither organic matter, nor a good physical structure. Composted organic matter is also apt to enhance the biological activity in the soil via boosting biological cycles. This may be useful in two ways; on one hand it limits the need for the use of expensive chemical fertilizers, and hence reduces financial costs of agricultural production, and on the other, it saves the environment of potential pollution. Therefore it could be favorable both economically and ecologically. The use of chemical fertilizer (e.g. nitrate fertilizers) has shown very adverse effects on the environment and the health of both man and animals. A second possibility lies in mixing the two types of soils, in proportions that depend on their respective properties, based on researches like the one presented here, with or without the application of organic amendments (compost.. etc.), and fertilizers. This option is obviously less expensive than the first, especially when it involves cases where the two types of soils are located in adjacent areas or at relatively short distances, like in this case. One problem that results from such mixing is the migration of smaller soil particles of clayey soil down the profile, and the subsequent formation of dense impermeable pans, sometimes at critical depths, resulting in water logging and root penetration problems. Mixing was practiced for some time in Tahrir region, Egypt, in the 1960s and was then stopped when the formation of hard pans and the consequent rise of water table became a problem. Some specific field services can limit such hazards if planned and executed properly. Disking and subsurface plowing are some of the practices that may reduce the problem. More research on soil mixing seems to be needed. A third possibility may involve mixing the two soils with yet a third soil type, that is the calcareous soil that dominates the northern coastal areas of Egypt, and has been partly and discretely put under cultivation for long times. Calcareous soils in Egypt have moderate texture class between the Delta and the desert soils, and the resulting mixed soil may overcome a number of their problems, especially those having to do with water holding. Organic matter may be added in this case for amending the mixed soil. Although we did not include calcareous soils in this research work, the reason we suggest it as a mixing option is the fact that in both studied soil we noticed that the content of calcium carbonates, both total and active, was markedly low. In order to put some of those above proposed ideas to practice, we started a new research project on the first two options, that is adding composted OM, and mixing clayey and sandy soils. An experiment is currently set-up, where the effect of adding composted organic matter and mixing Delta and Nubaria soils on physical properties and plat growth is currently underway and should be the subject of a subsequent article.

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