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CONSIDERATIONS OF VARIOUS SOIL PROPERTIES FOR THE IRRIGATION MANAGEMENT OF VERTISOLS

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ABSTRACT

Most of the irrigated soils on the Nile River Delta are classified by the U. S. Soil Taxonomy as Vertisols. For proper irrigation management, the extensive cracking exhibited by the soils upon drying requires an understanding of how crack formations effect, among others, infiltration, internal drainage, salt and sodium movement, root growth, and evaporation. Other considerations more specific to the Delta region with respect to the effect of textural stratification on various soil properties important in irrigation management are also addressed. Discussion of these considerations is based on pertinent findings reported in the literature.

33 Pages - 2 Tables

مستخلص

تم تصنيف الترب الزراعية في دلتا وادي النيل بمعرفة هيئة تاكسونومي الأمريكية على أنها ترب خصبة من نوع الفيرتيزول . ولتطوير استخدام طرق الري ، ينبغي أن يكون هناك فهم كامل لطبيعة تشقق الترب الناتج عن حالة الجفاف مما يتطلب معرفة تأثير هذه الشروخ على كل من تسرب المياه في الترب ، والصرف المغطى ، وحركة الأملاح والصوديوم ، ونمو الجذور وكذلك البخر . وقد تم أيضا عرض الاعتبارات الأخرى بمنطقة الدلتا والخاصة بتأثير تركيب طبقات الترب على خواص الترب المختلفة والتي لها أهمية في نظام تطوير الري ، وقد بنيت هذه الاعتبارات على دراسات تفصيلية سابقة .

٣٣ صفحة - ٢ جدول

EGYPT WATER USE AND MANAGEMENT PROJECT

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CONSIDERATIONS OF VARIOUS SOIL PROPERTIES FOR THE IRRIGATION MANAGEMENT OF VERTISOLS

INTRODUCTION

Most of the irrigated soils in Egypt are classified by the U. S. Soil Taxonomy as Vertisols. Vertisols are characterized by having a depth of at least 50cm, 30 percent or more clay in all horizons, and cracks at least 1cm wide at a depth of 50 cm during part of most years (Soil Survey Staff, 1975). The clay mineralogy of Egypt's Vertisols has been determined to be predominately montmorillonitic (El Shimi, 1979). This explanding-lattice clay mineral strongly contributes to the high shrink-swell potential of these soils. Extensive shrinking upon drying of Vertisols promotes the formation of cracks. These cracks may exceed 7.5cm in width and 100 cm in depth. Cracks are an important mechanism controlling water infiltration, serve as avenues for evaporation and oxidation (thus weathering), and may promote vertical root extension but hamper horizontal root development through root pruning (Hardy and Derraugh, 1947; Selim and Kirkham, 1970; White and Lewis, 1969). Other characterisitics of Vertisols often include wedge-shaped structural aggregates, gilgai microrelief, and polished ped faces called slickensides. These three features apparently result from the internal pressures produced within the soil profile during the swelling phase of the shrink-swell cycle. An additional characteristic of Vertisols is the homogenization or self-churning of the profile, which is caused by the additions of surface material into the cracks through the actions of wind, water, cultivation, and/or animals. These additions may in turn effect the expandable volume/internal pressure relationship and thus the development of slickensides, wedge-shaped structure, and gilgai.

The Vertisols in Egypt are found along the Nile River flood-plain and in the Nile Delta. These soils have formed from alluvium from the deposition of suspended matter during annual flooding of the river prior to flood control.

Since the main thrust of this paper deals with the Vertisols located on the delta region, a brief note on delta formation is desirable. Perhaps the most improtant concept to understand for purposes of this paper is that deltaic channels shift their positions during the natural course of delta formation.

Although the river itself may be confined to its valley, the many anastomosing branches on the delta may undergo drastic changes. Some branches may capture one another, leaving other channels relatively higher in elevation. At a later time, these channels may become either rejuvenated or filled in by sediments. Streambed deposition may proceed in any of these channels until a threshold slope is attained and a surge of sediment is released further downstream.

This release of sediment may be viewed as a lowering of the localized base level, thereby causing an upstream migration of scouring (Schumm, 1977). Although only two deltaic channels are readily observed on the Nile Delta today (Damietta Branch, Rosetta Branch), many fossil branches have been recognized by Wendorf and Schild (1976). Therefore, even though most of the soils on the Nile Delta are classified as Vertisols, the implication here is that these alluvial soils should be expected to possess differing soil properties due to the complexity of the processes by which the delta has formed. Data in this report will reflect the nature and degree of difference of these soil properties.

Irrigation management of Vertisols seems to have been only scarcely addressed in the literature. It is therefore the objective of this paper to discuss the questions and considerations of importance for the irrigation of Vertisols, in general, and then to specifically focus on those considerations of importance for the irrigation management of the Nile Delta Vertisols. Since first-hand knowledge on these subjects is limited, the discussion will primarily consist of what is available from the literature. While acknowledging the policy of the United States Bureau of Reclamation to refrain from establishing minimum levels of infiltration rates, hydraulic conductivity, etc. in the determination of irrigation suitability, a secondary objective of this paper is to offer suggestions for the refinement of the criteria utilized by the Bureau of Reclamation in order that they may more closely accommondate Vertisols.

GENERAL CONSIDERATIONS FOR THE IRRIGATION MANAGEMENT OF VERTISOLS

As previously mentioned, the presence of cracks at some time of the year is one of the characteristics common to Vertisols. Although only a brief note pertaining to the effect of cracking on infiltration is provided by the Bureau of

Reclamation, it appears that cracking should be a main concern in the irrigation management of Vertisols. Similarly, the relatively low permeability of these heavy clay soils suggests that other factors which may alter this permeability, such as soil structure, may be important in the management of these soils. Specific factors of importance are the effects of cracking and soil structure on infiltration, internal drainage, salt movement, root development, and evaporation. The following is a brief discussion of each of these factors.

Infiltration

Stirk (1954) investigaged the shrinkage and infiltration rates of four cracking soils in Australia. As compared to relatively higher moisture contents, he found infiltration rates to be increased only slightly at moisture contents greater than wilting point. Mainly fine cracks were observed above this moisture content, and these apparently did not significantly contribute to water entry into the soil. However, a rapid increase in infiltration rate was seen at moisture contents below wilting point, which corresponded to the formation of large cracks. Since large cracks were rarely observed above wilting point, Stirk (1954) concluded that cracks could not be relied upon for increasing permeability and aeration under continuous irrigation practices where moisture contents are generally kept above wilting point.

In the Riverine area of the Netherlands, Hoogmoed and Bouma (1980) developed a simulation model for predicting infiltration into a heavy clay soil classified as a very fine clayey, illitic, mesic Typic Fluvaquent. The model included vertical infiltration into the upper surface of the peds, downward flow into the cracks, and horizontal absorption from the cracks into the peds. The preferential movement of water along large pores and cracks ("short-circuiting") was predicted well by the model. However, the experiments were not conducted for a sufficient length of time to allow closure of the vertical cracks. Staining techniques described by Bouma and Dekker (1978) for determing infiltration patterns along ped faces suggested that "short-circuiting" was due not only to low horizontal absorption rates, but also to a low number of pathways for flow along vertical ped faces.

Blake et.al. (1973) used tritium as a tracer for following water movement in a Vertic Eutrochrept. Higher concentrations of tritium on the walls of shrinkage cracks than within the soil peds indicated that most of the infiltrating water flowed down these cracks.

Talsma and Van der Lelij (1976) investigated infiltration and water movement during the ponding of an Australian Vertisol. Even in the absence of cracks, they observed infiltration to be relatively rapid during the initital stage of water application. They felt that this rapid initial movement of water occurred along preferential flow paths noted in their profile descriptions which included slickensides, former crack faces, and intrusions of the less dense surface soil into the denser subsoil through previous cracks. However, subsequent infiltration was seen to proceed much slower.

On a dense clay soil in South Dakota, Rauzi and Kuhlman (1961) reported the infiltration rate of a soil exhibiting "severe cracking" to be 5cm/hr during the first 15 minutes and 1.0cm/hr during the fourth 15 minute observation period. In a heavy clay soil in Australia, Quirk and Blackmore (1955) reported that 70 percent of the total amount of water which entered the soil over a 4 hour period occurred in the first 10 minutes. Similar results were reported on a Vertisol in Sudan by Fadl and Ali (1977).

A number of conclusions may be made based on these findings. Most obvious is the repeated observaton that cracks provide an important mechanism for water infiltration. Although lateral absorption is slow, it should be expected to proceed once the cracks are filled, as has been shown by Fadl and Ali (1977). Not so obvious is the answer concerning the moisture content at which crack formation becomes an appreciable mechanism for infiltration. Stirk (1954) reported that large cracks do not develop at moisture contents above wilting point and that cracking could therefore not be used to promote infiltration under continuous irrigation practices. However, Johnson et.al. (1962) recommended the practice of variable row spacing and skip seeding of wheat as a means of inducing controlled soil cracking for the promotion of deeper and more rapid water penetration. It is probable that the contradictory findings may be explained by differing soil properties studied by these authors, because the extent of cracking is highly dependent on the amount of clay, the type of clay mineral, and the saturating ion. Vertisols which predominately possess highly expansive 2:1 clay minerals, such as montmorillonite, would be expected to crack extensively before wilting point is reached. In these situations it would appear feasible that additions of water may be based on crack volume measurements. Methodologies for calculating crack volumes on an area basis are available from Zein el Abedine and Robinson (1971) and Novak (1976).

Internal Drainage

A basic theory and application of that theory pertaining to water movement in swelling soils has been presented by Philip (1969a, 1969b) and Philip and Smiles (1969). This theory which is based on the whole soil and not just the macro-aggregates (i.e., crack volume is accounted for as void space) has undergone little testing in the literature. Favorable methodologies designed to test certain phases of this theory have been presented by Smiles and Colombera (1975). An approach which replaced Philip's (1969a, 1969b) concept of overburden potential with an experimentally measurable overburden pressure was introduced by Miller (1975) with the purpose of allowing the quantities employed to be measurable in situ.

Bouma et.al. (1977) investigated the application of modern morphometric techniques and methylene blue as a tracer for characterizing different types of macropores and their function in the saturated hydraulic conductivity of swelling soils. By use of porosity photograms, voids were classified into three shapes, namely, channels, vughs, and planar voids. From this study, Bouma et.al. (1977) concluded that all three types of macropores corresponded with differences among measured conductivity values, and the distinction between "smooth" and "rough" ped surfaces may be physically meaningful. Bouma et. al. (1977) felt that "rough" surfaces do not allow complete closure of the planes upon swelling; whereas, "smooth" surfaces would provide better contact upon swelling, thereby reducing conductivity to a greater degree.

Bouma and Wosten (1979) later substantiated this importance between "rough" and "smooth" ped surfaces by showing that a decrease in "effective" pore size distribution and an associated decrease in conductivity upon swelling was greater for those soils exhibiting "smooth" ped surfaces than those characterized by "rough" ped surfaces. In addition, Bouma and Dekker (1978) found soils with strongly developed prisms to exhibit deeper infiltration than those with moderately developed prisms.

Ritchie et.al. (1972) examined water movement during steady-state saturated flow in a Texas Vertisol. Hydraulic conductivities were measured in field basins, in 73cm and 21cm undisturbed cores, and in 17cm disturbed cores. Conductivities of the largest undisturbed cores were about seven times lower than those of the field basins. Conductivities of the 21cm undisturbed cores were even lower, and those of the disturbed cores were the lowest of all. Upon examination of the soil profiles continuous intersecting slickensides were revealed, suggesting that water movement in the field basins was greatly controlled by these structural units and their associated macropores. The lower conductivities of the smaller diameter undisturbed cores substantiated this implication because the larger undisturbed cores would have a greater probability of containing the macropores. Therefore, Ritchie et.al. (1972) concluded that water flow around the structural units controlled the flow process to a much greater degree than that water contained within the structural units. Furthermore, hydraulic conductivities of these swelling soils were most appropriately determined by field methods.

Bouma and Anderson (1973) utilized the concept of soil structure introduced by Brewer (1954) to investigate its relationship with hydraulic conductivity. This concept stresses the importance of pore type, abundance, and especially continuity. Very detailed field descriptions of soil structure were merged with pore studies from thin sections and soil peels along with conductivity values measured in situ. The study results not only emphasized the importance of a careful evaluation of soil structure in soil-water movement relationships, but also the strong effect of planar voids and channels on hydraulic conductivity.

These findings reported in the literature suggest that even though cracks are an important mechanism for the conduction of water, their significance may be replaced upon crack closure by the physical structure of the soil and the associated macropores. Not only may the grade (distinctness) and type of structure be important, but the distinction between rough and smooth ped surfaces may also provide a significant indication of the soil's conductivity. Likewise, field description of soil pores and channels, if carefully conducted, should provide a valuable contribution to an understanding of the soil's internal drainage characteristics. Finally, the report by Ritchie et.al. (1972) emphasizes the importance of maintaining the perspective that we should consider the complete soil system when dealing with Vertisols. Point observations made on a single component of this system may eventually lead to gross errors in our interpretations.

Salt and Sodium Movement

While conducting a study on water movement through a dry saline-sodic Vertisol in Sudan, Fadl and Ali (1977) suggested that wetting and drying cycles which induce cracking should enhance both water penetration and salt movement. Continued investigations at this same site by Ali and Fadl (1977) produced a reduction in exchangeable sodium percentage of the surface 30cm from above 50 to below 10 after 40 months of irrigation. After two floodings, salinity (EC_e) in the surface 45cm was reduced from over 20 mmho/cm to approximately 9 mmho/cm, but accumlations of salts were observed below this depth throughout the 40 month period.

Hardy and Derraugh (1947) cited Mosseri and Bey (1923) as having found that the cracks which form during fallow periods on Egyptian Vertisols allow salts to be leached below the root zone. However, this report is presently unavailable to the authors.

These research findings, although few in number, suggest that cracking and other mechanisms of improved Vertisol permeability (i.e., strong structure, worm channels, etc.) should aid in the leaching of salts from the root zone. However, a seemingly important question arises in this regard which is not consistently answered in the literature (De Vos and Virgo, 1969). Namely, do these cracks reopen in the same place? If not, then the salinity level in the surface soil may be, on an area basis, in "equilibrium" with the environment and management practices because opening of the cracks in different locations would allow leaching of salts at those locations. Thus leaching of soil salts may be realized for an entire field over a period of time. However, if the cracks do reappear at the same places, then only those specific locations would receive the benefit of leaching, and the soil matrix between cracks would remain relatively saline.

Root Growth

There is some confusion regarding the effect of cracking on the development of the root system. On the Grumusols (Vertisols) of Australia, Fox (1964) observed large cracks to be located in the middle of crop rows in cultivated areas and to surround grass tussocks in a circular nature in virgin grassland areas but to never intersect the plants. Similiar observations have been reported by Johnston and Hill (1944) and Johnson et.al. (1962). However, DeVos and Virgo (1969) reported that cultivated plants in Sudan often grow from the sides of cracks. Similarly, Bouma and Dekker (1978) reported grass roots to be mostly concentrated in the upper 40cm of a heavy clay with deeper roots following vertical prism faces to depths greater than 90cm. Rauzi and

Kuhlman (1961) and White and Lewis (1969) observed soil shrinkage and its accompanying crack formation to break or prune lateral roots.

The effect of cracking on the root system therefore appears to be dependent upon the type of root system (i.e., plant species) involved. Plant species which develop tap roots would not be expected to be seriously affected by root pruning, whereas a species that develops a lateral root system may be appreciably affected. In situations where root pruning may be a problem, a key question is at what soil moisture content do cracks of critical width develop. This subject has not been addressed in the literature. As previously mentioned, the shrink-swell potential (and its associated cracking) is highly dependent upon the type of clay mineral, the percent clay content, and the saturating ion. Therefore, root investigations must be preceded by an examination of these particular factors. In addition, the plant roots themselves may have a modifying effect on soil cracking. Each situation should therefore be evaluated on an individual basis, and extrapolations from one soil to another should be critically approached.

Evaporation

Another subject of importance is the effect of cracking on evaporation. Adams and Hanks (1964) suspended moist soil samples ("soil atmometers") at different depths in the shrinkage cracks of a Texas Vertisol. The atmometers suspended at depths of 30cm or less were reduced from 55 percent moisture to less than 17 percent moisture in 44 hours. During the first 19 hours, the rate of evaporation from the atmometers suspended 60cm below the surface was from 53 to 60 percent of the evaporation rate from the soil surface. Surface area measurements showed there was from 2.9 to 4.6 times more surface exposed on the crack walls than on the surface soil. From these observations, Adams and Hanks (1964) noted that if one assumed the evaporation rate in the cracks to be 50 percent of that of the surface soil, the water loss from the larger surface area crack walls would be 1.5 to 2.3 times more than from the surface soil.

Adams et.al. (1969) constructed a simulated shrinkage crack with its walls lined with porous ceramic plates. Total evaporation was shown to increase with an increase in crack width, crack depth, and/or windspeed. The circulation of air within the crack was found to be the major factor affecting evaporation from the crack walls. The data also indicated that soil water may be evaporated from the crack walls to depths of 60cm and deeper at higher windspeeds.

Johnston and Hill (1944) showed a decrease in the soil moisture content from a lateral distance of about 7.5cm on each side of a Vertisol crack at a depth of 45cm. Ritchie and Adams (1974) showed similar results at a depth of 30cm.

Selim and Kirkham (1970) found artificially induced cracks of 0.64cm wide and 1.91cm wide increased evaporation from bare soil by 12-16 percent and 30 percent, respectively. Increased evaporation from the crack walls caused considerable lateral movement of water from the soil matrix to the crack walls.

Under natural conditions in a Texas Vertisol, Ritchie and Adams (1974) showed a low horizontal soil water flux in the liquid phase to a crack wall, which suggested that most of the evaporation measured was a result of vapor transport in the soil pores at some distance to the crack walls.

These findings consistently state that soil cracks have a considerable impact on the total evaporation from Vertisols. This increased evaporation may be largely related to the increased total surface area provided by the crack walls. Circulation of air within the cracks has been identified, and windspeed has been shown to influence evaporation rate. In addition, depletion of moisture from the soil matrix adjacent to crack walls has been demonstrated. Therefore, these considerations must be taken into account when measurements of evapotranspiration are made. Evaporation may be seen to steadily increase between irrigations of Vertisols even within a given season, because crack width and depth should also increase. Other factors which may play an important role include the effect of shading by plants and the modifying effect of plant species on cracking patterns.

CONSIDERATIONS FOR THE IRRIGATION MANAGEMENT OF THE NILE DELTA VERTISOLS

The importance of cracking on the irrigation management of Vertisols, in general, has already been discussed. However, unpublished soil survey data collected in the Kafr el-Sheikh Governorate of the Nile Delta suggests that an additional soil property, textural stratification, should be considered in the management of these Vertisols. Selected data from this survey are presented in Table 1.

Some of the soil survey data has shown a relatively constant particle size distribution for a given profile; however, a considerable number of profiles show a rather abrupt textural change, as exemplified by profiles 10 and 20 in Table 1. However, others show a definite layering or textural stratification, as found in profiles 35, 43, and 44. Upon reviewing our rather complex description of delta formation, it appears that the shifting, abandonment, and rejuvenation of deltaic channels along with the associated scouring and depositional processes have produced a textural maze on this landform. Therefore, irrigation management on these deltaic Vertisols should not only be concerned with the effects of cracking, but also the effects of textural stratification. With these considerations in mind, several specific questions have surfaced which may be thought of collectively as an effort to determine if textural stratification and cracking or their interrelationships are important to the irrigation management of Nile Delta Vertisols.

How Does Textural Stratification Affect Water Movement?

Miller and Gardner (1962) studied the effects of textural stratification on the rate of infiltration into a silt loam soil. They found that a layer of fine-textured soil initially had a high infiltration rate because of the great attraction of the fine pores for water. However, further advance of the wetting front was dramatically slowed because the fine pores required for water transport were filled. Thus the decrease in infiltration rate observed in soils possessing a fine-textured layer is directly due to the lower saturated permeability of that layer. This also suggests that the swelling exhibited by Vertisols may further reduce the size of the transmitting pores and thus the rate of infiltration.

On the other hand, a relatively fine-textured soil possessing a coarse-textured layer also exhibits a reduced infiltration rate but for a different reason. Before the wetting front in a fine-textured soil can advance into the coarse-textured layer, the moisture tension at the wetting front must be reduced until it is low enough to allow the larger pores of the coarse-textured layer to fill with water. The water content in the finer-textured soil will therefore continue to rise until the tension by which the water is held becomes low enough that the larger pores of the underlying coarse-textured layer can fill. At this point the infiltration rate is rapidly increased, but not to that which would have existed in the absence of the coarse-textured layer (Miller and Gardner, 1962).

Table 1 Particle Size Distribution of Selected Soil Profiles From The North-Central Nile Delta Region (Abu Raya Soil Survey)

Profile #	Depth (cm)	Clay (%)	Silt (%)	Sand (%)
10	0-25	56.7	16.1	26.6
	25-80	50.1	20.1	29.1
	80-100	33.2	25.4	38.1
20	0-30	60.0	8.6	28.2
	30-80	47.6	24.3	27.0
35	0-25	58.0	12.0	27.8
	25-55	35.4	15.4	45.4
	55-80	44.5	30.5	21.4
43	0-20	44.1	21.5	33.1
	20-60	34.9	24.3	40.4
	60-150	50.5	26.1	22.3
44	0-20	41.3	19.9	18.5
	20-70	34.4	20.7	43.3
	70-150	47.4	33.1	17.0

The presence of textural stratification in these delta soils would therefore be expected to reduce the rate of internal water movement. A soil such as profile number 20 in Table 1 would be expected to have a decreased infiltration rate upon advancement of the wetting front to the 30cm depth. However, after a certain period of time, the infiltration rate would probably increase but not to its initial value. A soil like profile number 35 would probably exhibit a more dramatic overall reduction in infiltration rate because both of the effects described by Miller and Gardner (1962) would apply. These same concepts should also be considered as a possible cause of perched water tables. Future experimentation along these lines should include particle size data for those horizons both within and below the perched water table zone.

How Does Textural Stratification Affect Cracking?

Although this question has apparently never been addressed in the literature, an attempt can be made to do so by incorporating the work reported on the affect of varying clay concentrations on soil shrinkage. DeJong and Warkentin (1965) reported that for a given clay mineral and for soils containing more than 30 percent clay, shrinkage of soil increased approximately linearly with an increase in clay concentration. Similar results were reported by Franzmeier and Ross (1968).

It can be speculated that a soil like profile number 36 in Table 1 which possesses a more coarse-textured layer would have a lower cracking potential than the overlying horizon and would therefore crack very little. Furthermore, since crack widths generally decrease with depth, the crack may not extend into this layer except under very dry conditions. However, the effect of an underlying finer-textured horizon is especially questionable. This horizon may reside deep enough in the profile that sufficient moisture would prevent crack development, or allow cracking to proceed only to that width attained in the overlying coarser-textured horizon. It is certainly difficult to envision a crack which is wide in the upper horizon, relatively narrow or non-existent in the middle horizon, and then relatively wide again in the third horizon. Johnston and Hill (1944) have observed cracks to be closed at the surface but open at lower depths; however, this was caused by a slow, gentle rainfall which caused the cracks to seal at the surface.

How Does Textural Stratification Affect Salt and Sodium Movement?

Again, no studies on Vertisols are known to have been conducted with regard to this question, and again, a need for research on this topic seems to exist. However, it would be expected that the movement of salts and sodium in stratified soils would closely resemble the movement of water previously described. An additional effect may be an accumulation of salts and sodium along the boundaries of these layers where the rate of water movement is reduced. If appreciable quantities of sodium are involved with relatively low electrolyte concentrations, the soil may become dispersed in which case pore clogging may result and/or clay swelling may be intensified. In either case, the rate of water movement would be lessened and accumulation of salts and/or sodium may result.

What Are the Interactions of Cracking, Stratification and Water Movement?

A number of possible interactions among these three variables may exist. A soil like profile number 35 in Table 1 may possess a crack which extends to a depth of 25cm, thus allowing direct water application into the more coarse-textured layer. Based on the concepts of Miller and Gardner (1962), the wetting front may advance through the more coarse-textured layer and into the underlying finer-textured horizon for a relatively short period of time due to the lower saturated permeability of this finer-textured horizon. If water application was ceased at this time, the end result may be a soil profile which has sufficient moisture at lower depths, but whose surface horizon remains relatively dry and probably still cracked. However, continued water application at this time would seemingly cause an upward advance of the wetting front in the soil matrix due to the relatively larger amounts of water in the second and third horizons. Thus upward advance (i.e., from the top of the more coarse-textured layer to the top of the finer-textured surface horizon) would probably be slow because of the lower permeability of the surface horizon and the downward force of gravity. A deleterious effect of this process, if it does in fact occur, may be the upward movement of salts to the root zone.

Many other conjectural examples may be hypothesized because the interactions of these three factors would appear to be both complex and conditional. However, one basic fact remains. These factors do effect water behavior. Therefore, experimental investigations of these interactions may vastly improve our ability to realize a sound irrigation management scheme.

How Do We Sample And Characterize These Soils In Terms of Irrigation Management?

The sampling and characterization of these soils should be based on those factors which the literature and our experience tells us are the most important for proper irrigation management. A fairly intensive soil survey should be the first step so that the presence and relative amounts of soils which exhibit differing soil properties (e.g., stratified vs. nonstratified) may be determined.

In general terms of irrigation management, sampling should be conducted in those areas exhibiting these differing soil properties. The specific methods used in sampling each area would, of course, depend on the research objectives. For example, if the major objective is to determine the cause of a perched water table, sampling should not terminate at the top of that water table, as is commonly done. Soil samples should be collected within and below the zone of water table development, as aggregate dispersion and/or textural stratification may be the cause of this development.

Another example is the case of sampling for hydraulic conductivity measurements. Although the use of field basins is suggested (Ritchie et.al. 1972), situations requiring the use of sample cores should use only undisturbed cores of sufficient diameter to contain complete peds and of sufficient length to consider large vertical pore continuity (Bouma, 1980). The added effect of textural stratification should also be considered in determining the sample core length.

One of the most common measurements made for all irrigated soils is that of porosity. From determinations of porosity, the amount of water to be added to bring the soil to "field capacity" may be calculated. Probably the main question regarding the porosity determination of Vertisols is whether sampling should be done in the soil matrix between cracks or if sampling should include crack volumes. Since soil cracking provides such an important mechanism for infiltration in these soils, and since water transport through pores in the soil matrix should also occur, it appears that evaluation of the soil's porosity should include both crack volume and the soil matrix. Additions of water may then be based on how much water is required to fill the cracks plus how much water is required to fill the pores. This approach may provide only an estimate of the water additions required because other factors such as pore continuity, textural stratification, and the presence of slickensides may effect this determination. However, if a detailed morphological description is conducted, some of these factors may be accounted for, at least qualitatively, and adjustments can be made. In short, the selection of sampling procedures should be based on both the research objectives and the morphological properties of the soils.

Chemical, physical, and morphological characterization of Vertisols for irrigation management should include those factors which influence water movement and plant growth. Discussion has already been aimed at two broad factors, namely, cracking and textural stratification. However, more specific parameters for characterization must be addressed in order to detect the variables most important for interpretive purposes. While the emphasis here is on the morphological characterization of these soils, it should be noted that the relationship among various chemical and physical soil properties with the morphological properties must first be determined. The following example illustrates this point.

Particle size distribution was determined for 20 Vertisol profiles on the Nile Delta. Fourteen of these profiles exhibited a difference in clay percentage of 8% or more at some depth within a given profile. Nine of these profiles (57%) exhibited mottling. The data presented in Table 2 show that for every soil profile which exhibited mottling and for which particle size data are available some degree of textural stratification was present. Furthermore, data not presented here have disclosed that 42 percent of the profiles having an exchangeable sodium percentage (ESP) of 15 or greater were found to be mottled. This suggests a possible interaction among textural stratification, mottling, and a high ESP; however, since determinations of particle size and ESP were only conducted on a small number of profiles this relationship could not be tested statistically. Similarly, the data presented in Table 2 are also limited in their statistical implications due to the small number of particle size determinations made; however, since mottling generally suggests poor drainage (reducing conditions), the data do infer that the concepts of Miller and Gardner (1962) previously presented pertaining to water movement in stratified soils may be applicable in stratified Vertisols. Therefore, characterization of these soils should include determinations of ESP, particle size distribution, and the presence of mottles.

Other parameters important for the characterization of these soils may include the determination of salinity levels, bulk density, clay percentage, horizon thickness, soil structure, and the presence of slickensides. Salinity levels should be examined for each horizon so that the relationship between textural stratification and salinity can be examined. Bulk density may be determined as a means of obtaining the soil's porosity. The percent porosity may then be coupled with crack volume measurements to determine how much water should be added to bring the soil to "field capacity". However, since bulk density in swelling soils is dependent upon both depth and moisture content, these factors must be taken into account (Berndt and Coughlan, 1977). Clay percentage and horizon thickness should be measured and related to the extent and depth of cracking at known moisture contents of the soil matrix. For a given clay mineral and saturating ion, this relationship may then provide an understanding of proper irrigation timing based on clay percentage and horizon thickness.

The grade, size class, and type of soil structure should be carefully examined and noted in the morphological description, along with the distinction between rough and smooth ped surfaces, as these morphological observations have been shown to be important indicators of water movement in Vertisols. Finally, the presence of slickensides should be noted, because this may related to the depth of cracking. Since slickensides are formed by the internal forces of swelling, they are not commonly found in zones of cracking because the development of cracks renders the swelling stresses ineffective in slickenside formation (Yaalon and Kalmar, 1978). In addition, slickensides may be an important pathway for water movement (Ritchie et.al. 1972).

CONCLUSIONS

Irrigation management of Vertisols, in general, would appear to be largely dependent upon the effect of cracking on infiltration, internal drainage, salt and sodium movement, root growth, and evaporation. Management of the Nile Delta Vertisols; however, must consider another important factor, namely,

TABLE 2 Particle Size Distributions Available From Those Soils Which Exhibit Mottling On The Nile Delta (Abu Raya Soil Survey)

Profile #	Depth (cm)	Clay (%)	Silt (%)	Fine Sand (%)
1	0-25	45.0	32.0	20.5
	25-60	56.7	22.8	18.7
	60-100*	59.9	25.6	13.1
4	0-20	56.5	20.4	20.9
	20-70*	64.7	15.0	18.7
	70-150	60.0	14.5	22.8
8	0-20	60.5	16.5	20.4
	20-70*	61.3	13.9	21.5
	70-150*	40.6	10.4	47.8
10	0-25	56.7	16.1	26.4
	25-80*	50.1	20.1	28.5
	80-100	33.2	25.4	37.3
20	0-30	60.0	8.6	27.8
	30-80	47.6	24.3	26.7
	80-110*	--	--	--
35	0-25	58.0	12.0	27.1
	25-55	35.4	15.4	45.3
	55-80*	44.5	30.5	20.5
51	0-25	52.5	21.0	22.7
	25-60	40.8	27.8	29.3
	60-150*	41.5	31.4	21.9
93	0-20	67.0	24.9	4.5
	20-100*	63.0	29.6	4.2
	100-130	30.0	39.6	27.6

*Horizons which exhibit mottling.

textural stratification. The interactions among cracking, textural stratification, water movement, and plant growth may be highly variable due to the differing soil properties, management practices, and plant species found on the Delta. Identification of those areas exhibiting different soil properties should be the first step in the investigation of the above interactions. Once these areas have been identified, field studies in representative areas should be conducted to determine the relationships between textural stratification and water movement, cracking and water movement, textural stratification and cracking, textural stratification and salt/sodium movement, and cracking and salt/sodium movement. Each of these field studies should include determinations of crack volumes, bulk density, infiltration rate, moisture contents at various depths, particle size distribution, ESP, and salinity. In addition, a very detailed morphological description should be conducted at each experimental site to include the grade, class, and type of soil structure; the smoothness of ped faces; the presence of old crack faces, root channels, and other macropores; the presence, size, and grade of slickensides, and the presence of mottles.

Determination of the relationships among these characteristics should allow for the development of criteria to be used in the classification of these soils in terms of irrigation management. Once these relationships have been established it may become possible to utilize mostly morphological criteria (i.e., mottling, slickensides, horizon thickness, etc.) as a field guide for the delineation of areas which require differing irrigation management practices.

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AMERICAN EQUIVALENTS OF EGYPTIAN ARABIC TERMS AND MEASURES COMMONLY USED IN IRRIGATION WORK

LAND AREA	IN SQ METERS	IN ACRES	IN FEDDANS	IN HECTARES
1 acre	4,046.856	1.000	0.963	0.405
1 *feddan*	4,200.833	1.038	1.000	0.420
1 hectare (ha)	10,000.000	2.471	2.380	1.000
1 sq. kilometer	100×10^4	247.105	238.048	100.000
1 sq. mile	259×10^6	640.000	616.400	259.000

WATER MEASUREMENTS	FEDDAN-CM	ACRE-FEET	ACRE-INCHES
1 billion m^3	23,809,000.000	810,710.000	
1,000 m^3	23.809	0.811	9.728
1,000 m^3 /*Feddan* (= 238 mm rainfall)	23.809	0.781	9.372
420 m^3 /*Feddan* (= 100 mm rainfall)	10.00	0.328	3.936

OTHER CONVERSION		METRIC	U.S.
1 *ardab*	=	198 liters	5.62 bushels
1 *ardab*/*feddan*	=		5.41 bushels/acre
1 *kg*/*feddan*	=		2.12 lb/acre
1 donkey load	=	100 kg	
1 camel load	=	250 kg	
1 donkey load of manure	=	0.1 m^3	
1 camel load of manure	=	0.25 m^3	

EGYPTIAN UNITS OF FIELD CROPS

CROP	EG. UNIT	IN KG	IN LBS	IN BUSHELS
Lentils	*ardeb*	160.0	352.42	5.87
Clover	*ardeb*	157.0	345.81	5.76
Broadbeans	*ardeb*	155.0	341.41	6.10
Wheat	*ardeb*	150.0	330.40	5.51
Maize, Sorghum	*ardeb*	140.0	308.37	5.51
Barley	*ardeb*	120.0	264.32	5.51
Cottonseed	*ardeb*	120.0	264.32	8.26
Sesame	*ardeb*	120.0	264.32	
Groundnut	*ardeb*	75.0	165.20	7.51
Rice	*dariba*	945.0	2081.50	46.26
Chick-peas	*ardeb*	150.0	330.40	
Lupine	*ardeb*	150.0	330.40	
Linseed	*ardeb*	122.0	268.72	
Fenugreek	*ardeb*	155.0	341.41	
Cotton (unginned)	*metric qintar*	157.5	346.92	
Cotton (lint or ginned)	*metric qintar*	50.0	110.13	

EGYPTIAN FARMING AND IRRIGATION TERMS

fara = branch

marwa = small distributer, irrigation ditch

masraf = field drain

mesqa = small canal feeding from 10 to 40 farms

qirat = cf. English "karat", A land measure of 1/24 *feddan*, 175.03 m^2

qaria = village

sahm = 1/24th of a qirat, 7.29 m^2

saqia = animal powered water wheel

sarf = drain (vb.), or drainage. See also *masraf*, (n.)

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