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EWUP TECHNICAL REPORT #64

# INFLUENCE OF SOIL PROPERTIES ON IRRIGATION MANAGEMENT IN EGYPT

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EGYPT WATER USE AND MANAGEMENT PROJECT

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## ABSTRACT

On three of the four distributary canals studied by EWUP, the soils were mostly alluvial clay soil (Vertisols) or a Vertic Subgroup of the Entisols. The remaining distributary canal was all sandy Entisols.

Vertisols are a soil order composed of heavy, clay soils that contain large quantities of clay minerals which expand when wet and contract when dry. Irrigating these soil requires recognizing that the root penetration and measureable soil water changes are restricted to the top 40 cm. This limits the operational available water to 5 to 7 cm. The water infiltration rate during an irrigation can have a hundred fold decline during a 2 hour irrigation, ending with almost sealed conditions. This allows highly uniform application over a large area almost independent of available flow rate. However, the soil sealing does require a potential for surface drainage to prevent crop suffication. After an in irrigation, redistribution tends to be very slow, with the possibility in winter of it requiring 15 days for a wetting fringe to drain 30 cm. Some overirrigation occurs that can contribute to high watertables, and make subsurface drainage desirable. Although the capillary potential from the watertable may exceed 2 m. or more, the rate of flow is so slow that a watertable below 1.25 m may contribute less then 10% of the potential ET. The physical heaving of the soil may make compaction difficult to maintain, and may require a continous compacting force or synthetic stabilization methods in raised ditches or canals. Compaction may be possible by encouraging traffic patterns on the canal banks. Failure to keep the banks compacted may result in significant conveyance losses through seepage.

The high infiltration rates in the sandy soils make them basically unsuited for surface irrigation. It is therefore difficult, if not impossible, to surface irrigate them efficiently. High watertables occur with large volumes of subsurface water flow. A de facto sub-irrigation system results in which farmers applying water to their field sub-irrigate their neighbors and visa-versa. Some farmers, far from the water source, actually receive more water than their crops required.

## نبذة

أوضحت الدراسة التى أجراها معهد بحوث المائية المصرى على أربع من قنوات توزيع المياة أن معظم أنواع التربة من النوع الطمى الخصب وعلى قنوات التوزيع الأخرى فإن التربة من النوع الرملى وإن التربة الطينية الطميية الخصبة تكون حاملة للمعادن مما يسبب تمددها بالمياة وانكماشها بالجفاف وإن رى هذة الأنواع من التربة يكون على أساس أن منسوب المياة فى التربة محدد بمنطقة أختراق الجذور أى فى حدود ٤٠ سم. كما تكون كمية مياة الرى فى حدود ٥ - ٧ سم وتستغرق عملية تشرب المياة الى التربة ساعتين من زمن الرى وفى النهاية تتسرب هذة المياة إلى باطن التربة ويؤدى ذلك الى رفع كفاءة الرى دون أن يعتمد ذلك على كمية المياة المتوفرة للرى وإن التربة التى لها هذة الخاصية يتم ريها بنظام الرى السطحى مما يوفر للنبات الحماية من الزبول.

بعد الرى تقل عمليات أعادة التوزيع للمياة فى التربة وقد تستغرق عملية تبخر مياة التربة بواسطة ذرات الهواء الحاملة للمياة الى مدة ١٥ يوما وذلك لتبخير ١٥ سم من المياة فى فصل الشتاء. أن الرى بأستخدام كميات أكثر من المطلوب من المياة يؤدى الى أرتفاع منسوب المياة الجوفية وفى هذة الحالة يكون الصرف المغطى مستحبا.

ومع أن منسوب المياة في باطن التربة قد يصل الى مترين أو أكثر إلا أن صغر معدل مياة الري يؤدي إلى تقليل نسبة البخر بمقدار ١٠ ٪ في حالة ما يكون منسوب المياة في التربة ١,٥٠ مترا.

أن الخواص الطبيعية للتربة تجعل من الصعوبة أن تحتفظ التربة بتماسكها حتى لو تم كبسها ولذلك يتطلب الأمر أستمرار عمليات كبس التربة ويمكن عمل ذلك بتجميع المرور على أجناب الترع لأن عدم تماسك الأجناب قد يؤدي الى فقد كميات كبيرة من المياة بواسطة الرشح.

إن أنواع التربة الرملية لا يصلح لها نظام الري السطحي وذلك لأرتفاع معدل الرشح فيها مما يؤدي الى فقد كميات كبيرة من المياة ويظهر ذلك بوضوح عندما يستخدم الفلاحين الري السطحي في هذه الأراضي وتتسرب كميات كبيرة من المياة الى الحقول المجاورة أو العكس وقد يصل الأمر أن يصل للأراضي البعيدة عن مصادر المياة كميات من المياة تزيد عن حاجتها

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# INFLUENCE OF SOIL PROPERTIES ON IRRIGATION MANAGEMENT IN EGYPT[1]

A.T.A. Moustafa & R.L. Tinsley[2]

## I. INTRODUCTION

The Egypt Water Use and Management Project (EWUP) is a joint technical assistance program between the Egyptian Ministries of Irrigation (MOI) and Agriculture (MOA) in cooperation with USAID. The Project is an on-farm research project that has been operating for 6 years. Its major objective has been to determine ways in which improved water management can contribute to improving the economic well being of the small farmers of Egypt. EWUP's efforts have concentrated at the farm level and the lower portions of the delivery system, starting with the distributary canals. The Project has restricted its efforts to the "Old Lands" of the Nile Valley and Delta, where the irrigation system has been established for 100 years or more. Most of the Project's work has sought means for increasing water use efficiency, increasing the farmers returns per unit of water applied, and saving water for the horizontal expansion of the irrigated area into the "New lands" currently being reclaimed from the desert. The irrigation system used in the "old lands" is almost exclusively surface irrigation with emphasis on lifting water at the farm level.

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1. This Technical Report is the final report for EWUP Task Group 8 on Soil Characterization. The Report contains the results of the EWUP soil interpretation evaluation. The paper was presented at the EWUP Workshop May 30 to June 2, 1983, Cairo, Egypt.

2. Senior Agronomist & Discipline Leader, and Senior Agronomist, EWUP, Cairo.

The Project has worked on four distributary canals in three pilot field areas. These are the Mansouria area in Giza Governorate near the Ancient Pyramids of Giza and at the edge of the Metropolitan Cairo area. The Mansouria area is subdivided into two parts, Beni Magdul and El-Hammami. The other two locations are Abu Raya in Kafr El-Sheikh Governorate in the North Central Delta approximately 100 km North of Cairo and Abyuha in El-Minya Governorate in the Nile Valley approximately 300 km South of Cairo.

In each of the EWUP study areas, one of the first activities was to conduct a soil survey of the area. The results of these surveys has been reported in EWUP PTR Nos. 2, 33 and 34 for Mansouria, Abyuha and Abu Raya, respectively. These soil surveys showed, that with the exception of El-Hammami, the soils in all areas were alluvial clays classified in either the Vertisols Soil Order or a Vertic Sub-group of the Entisol Soil Order. The soils in El-Hammami were loose sandy Entisols. The objective of this paper is to review the properties of these soils and, based on EWUP experience and other available information, illustrate how the soil type can influence the design, and operation of Egypt's irrigation system.

The paper will concentrate on the old land alluvial clay soils (Vertisols), because they are both the most extensive soils, and they have the greatest influence on irrigation. Less attention will be given to the sandy soils.

## II. PROPERTIES OF ALLUVIAL CLAY SOILS

The majority of the clay alluvial soils in Egypt are Vertisols. Vertisols are one of the 10 soil orders identified in the Soil Taxonomy classification system (Soil Survey Staff, 1976). They are defined as "Mineral soil that have 30% or more clay, deep cracks when dry, and either a natural gilgai[3] micro-relief, intersecting slickenslides, or

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3. Gilgai refers to a naturally occurring micro-relief pattern consisting of small basins and knolls approximately 1 $m^2$ and up to 1 m high.

wedge shaped structural aggregates tilted at an angle from the horizontal" (SSSA, 1978). The large percentage of clay and the formation of cracks are what make these soils physically the most difficult of the 10 soil orders to manage, and cause the greatest problems in irrigating them. The cracking and sluffing of soil into the cracks etc. results in the natural continuous mixing of the soil making for relatively uniform and generally dark colored profiles.

In Egypt Vertisols are the most common of the alluvial soils deposited in the Nile Valley and Delta (Figure 1) and extend south well into Sudan. Most of the Vertisols in the EWUP study sites were defined into the Sub-order and Great Soil Group of Typic Torrerts (Soil Survey Staff, 1976). This is an incompletely defined Soil Group that only indicates the natural conditions of a hot dry climate. It does not take into consideration the irrigated conditions of all agricultural soils in Egypt, or the chemical properties of salinity and sodicity, all of which are important in Egypt.

A. Soil Texture and Mineralogy

The soil profiles sampled from the EWUP study sites had clay contents that varied from 40 to 60%. This was nearly uniformly distributed with depth, as expected with Vertisols (Table 1). Various clay mineralogy studies on Egyptian alluvial soils have shown that 51% of the less than 0.002 mm fraction is a form of Montmorillonite, i.e. an abnormal dioctahedral iron-rich Smecite. Other clay fraction minerals include kaolinite (31%), mica (11%), quartz (14%), and feldspar (2%) (Elgabaly & Khadr, 1962; Heakal, 1968, 1973; and Mikhail, 1975). Montmorillonite is a family of layer silicate minerals characterized by the ability to absorb water between successive layers of the crystal structure. The adsorption of this "interlayer water" pushes the clay layers apart, only to contract again upon drying. The loss of the interlayer water causes the large cracks characteristic of the Vertisol Soil Order and makes for extensive soil movement. Under laboratory conditions the interlayer expansion has been measured to be from 80 to 100 percent of the thickness of the dry clay crystal. Since the clay

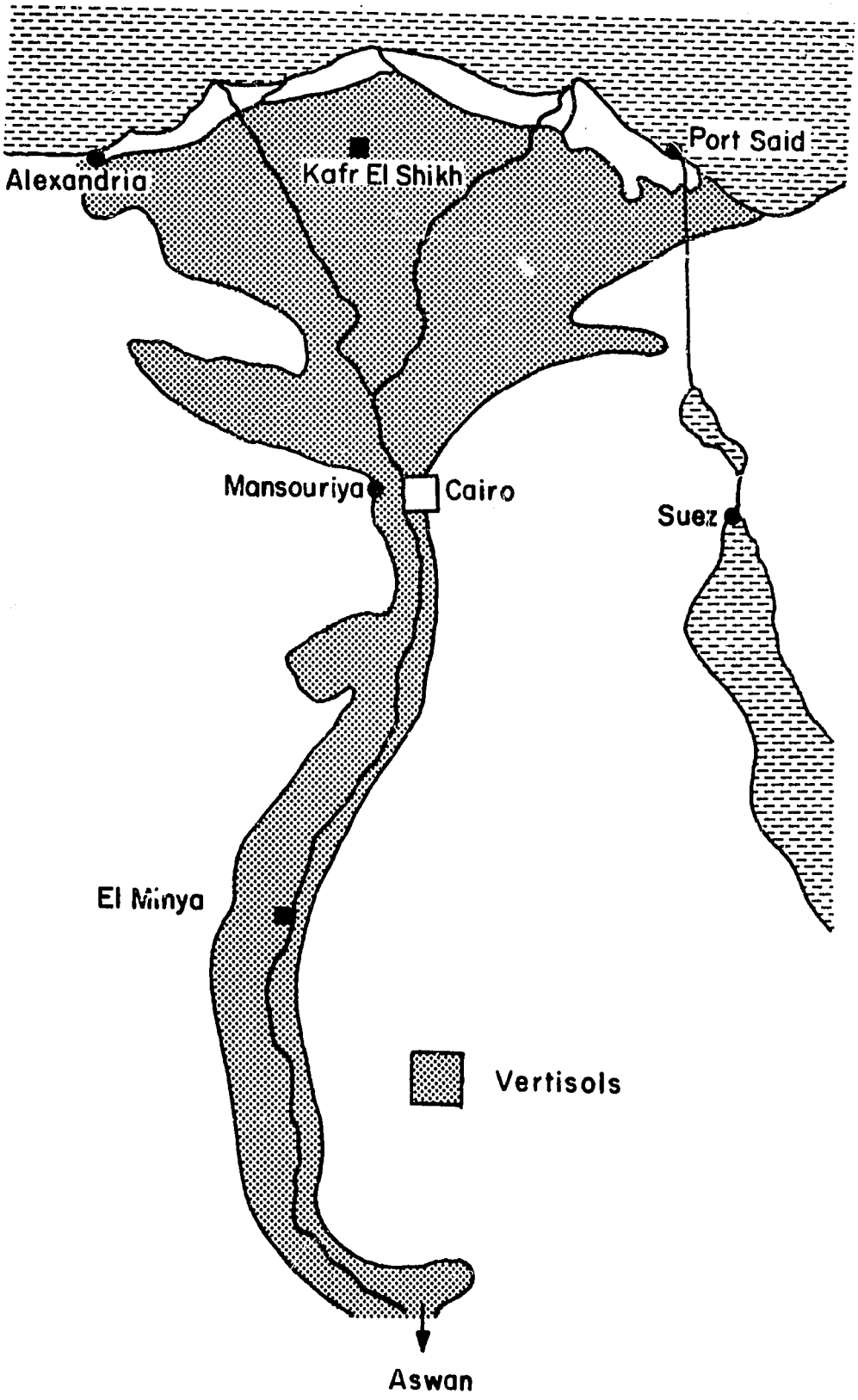


Figure 1. Distribution of clay alluvial soils (Vertisol) in Egypt and location of EWUP study locations.

Table 1. Particle size distribution for Vertisols in EWUP areas.[a/]

| Location | Profile No. | Depth | Clay | Silt | Sand |
|---|---|---|---|---|---|
| | | --cm-- | ----------%--------- | | |
| Beni Magdul | 12 | 0- 15 | 44.8 | 8.4 | 41.8 |
| | | 15- 50 | 55.7 | 15.8 | 28.6 |
| | | 50-150 | 51.3 | 7.4 | 41.3 |
| | 37 | 0- 25 | 39.8 | 24.1 | 36.1 |
| | | 25- 80 | 57.5 | 23.9 | 18.5 |
| | | 80-150 | 50.7 | 30.4 | 18.9 |
| | 48 | 0- 20 | 47.0 | 18.2 | 34.8 |
| | | 20- 75 | 45.7 | 21.4 | 32.8 |
| | | 75-150 | 52.0 | 23.8 | 24.1 |
| Kafr El-Sheikh | 4 | 0- 20 | 56.5 | 20.4 | 21.4 |
| | | 20- 70 | 64.7 | 15.0 | 19.3 |
| | | 70-150 | 60.0 | 14.5 | 23.3 |
| | 33 | 0- 30 | 47.5 | 32.5 | 27.4 |
| | | 30- 80 | 27.0 | 33.7 | 38.4 |
| | | 80-140 | 49.0 | 21.8 | 28.2 |
| | 72 | 0- 30 | 51.0 | 21.1 | 21.7 |
| | | 30- 65 | 51.6 | 24.7 | 24.4 |
| | | 65-150 | 51.7 | 23.9 | 24.3 |
| El-Minya | 1 | 0- 20 | 50.4 | 25.3 | 23.1 |
| | | 70-150 | 60.2 | 19.5 | 20.0 |
| | 45 | 0- 25 | 67.4 | 16.1 | 16.3 |
| | | 25- 65 | 63.2 | 10.0 | 26.7 |
| | | 65-150 | 68.5 | 18.2 | 13.1 |
| | 81 | 0- 30 | 40.0 | 14.0 | 44.7 |
| | | 30- 90 | 63.0 | 27.4 | 7.8 |
| | | 90-150 | 62.0 | 35.1 | 1.1 |

a/ Adapted from EWUP PTR No. 2, 33, 34 for Beni Magdul, El-Minya and Kafr El-Sheikh, respectively.

expansion results in particle movement, there is a redistribution of micropores which could effect water movement, root penetration, and aeration.

B. Soil Moisture

Montmorillonites are concentrated in the fine clay fraction of the clay size range. This results in a large surface area for the adsorption of matrix water. Combining the matrix water with the interlayer water provides a very large soil water content. Laboratory analysis of soils from EWUP study sites have shown changes in volumetric soil water contents of 30% as the soil tension increased from 0.1 to 15.0 Atm. (Table 2). Although in each location the difference between 0.1 and 15.0 Atm was similar, the actual values varied substantially between locations. El-Minya had the relatively wettest range, going from 67 to 32% while Mansouria had the dryer range from 50 to 22%. Kafr El-Sheikh was between them but closer to the El-Minya range then the Mansouria range. These differences in range probably is only a reflection of the difference in clay percentage between the areas. The soil moisture range was similar for both surface and subsurface soils. This would be expected considering the uniformity of the profile. For the soil moisture tension range of 0.33 to 15.0 Atm., that are usually associated with available water, the change in volumetric water is approximately 20%. This would imply a computed available water of 18 cm for the 90 cm soil depth EWUP used in evaluating irrigation applications.

When the available soil moisture was plotted as a pF curve most of the soil water was retained between 0.1 and 3.0 Atm. (Figure 2). The retained water includes both matrix and interlayer water. The tensions at which the two types of water are removed and how this affects crack formation, plant root development, actual available water and irrigation practices may need further study. Observations at EWUP study sites have shown cracks 1 to 2 cm wide occurring at a 15 cm depth and a soil moisture tension of 15 centibars. Cracks as wide as 5 cm have also been observed when fields have not been irrigated for periods of 2 weeks or less.

Table 2. Soil moisture characteristics for Vertisols in EWUP areas[a/]

| Location (texture) | Depth | Moisture Content at Atm. Tension 0.10 | 0.33 | 3.00 | 15.00 | Avail H2O .33-15 atm |
|---|---|---|---|---|---|---|
| | --cm-- | ----------% volume---------- | | | | --cm.-- |
| Beni Magdul (clay loam) | 0- 20 | 49.0 | 42.2 | 35.4 | 22.8 | 3.9 |
| | 20- 40 | 54.5 | 44.9 | 38.3 | 23.8 | 4.2 |
| | 40- 60 | 49.5 | 39.1 | 35.7 | 22.1 | 8.5[b/] |
| | | | | | Total | 16.6 |
| Kafr El-Sheikh (clay) | 0- 20 | 61.3 | 48.7 | 45.4 | 30.2 | 3.8 |
| | 20- 40 | 60.9 | 49.1 | 48.0 | 29.9 | 3.8 |
| | 40- 60 | 64.1 | 51.1 | 35.6 | 30.3 | 10.4 |
| | | | | | Total | 17.9 |
| El-Minya (clay) | 0- 30 | 67.2 | 55.6 | 40.7 | 31.7 | 7.2 |
| | 30-120 | 67.2 | 59.7 | 45.0 | 33.7 | 15.6 |
| | | | | | Total | 22.8 |

a/ Adapted from EWUP Staff Paper No. 33 and 60. The latter was presented to session S-1, ASA meeting, Aug. 1979, Fort Collins, Co.

b/ Available water from 0-90 cm. The lowest value was extended or truncated to accomodate the 90 cm limit.

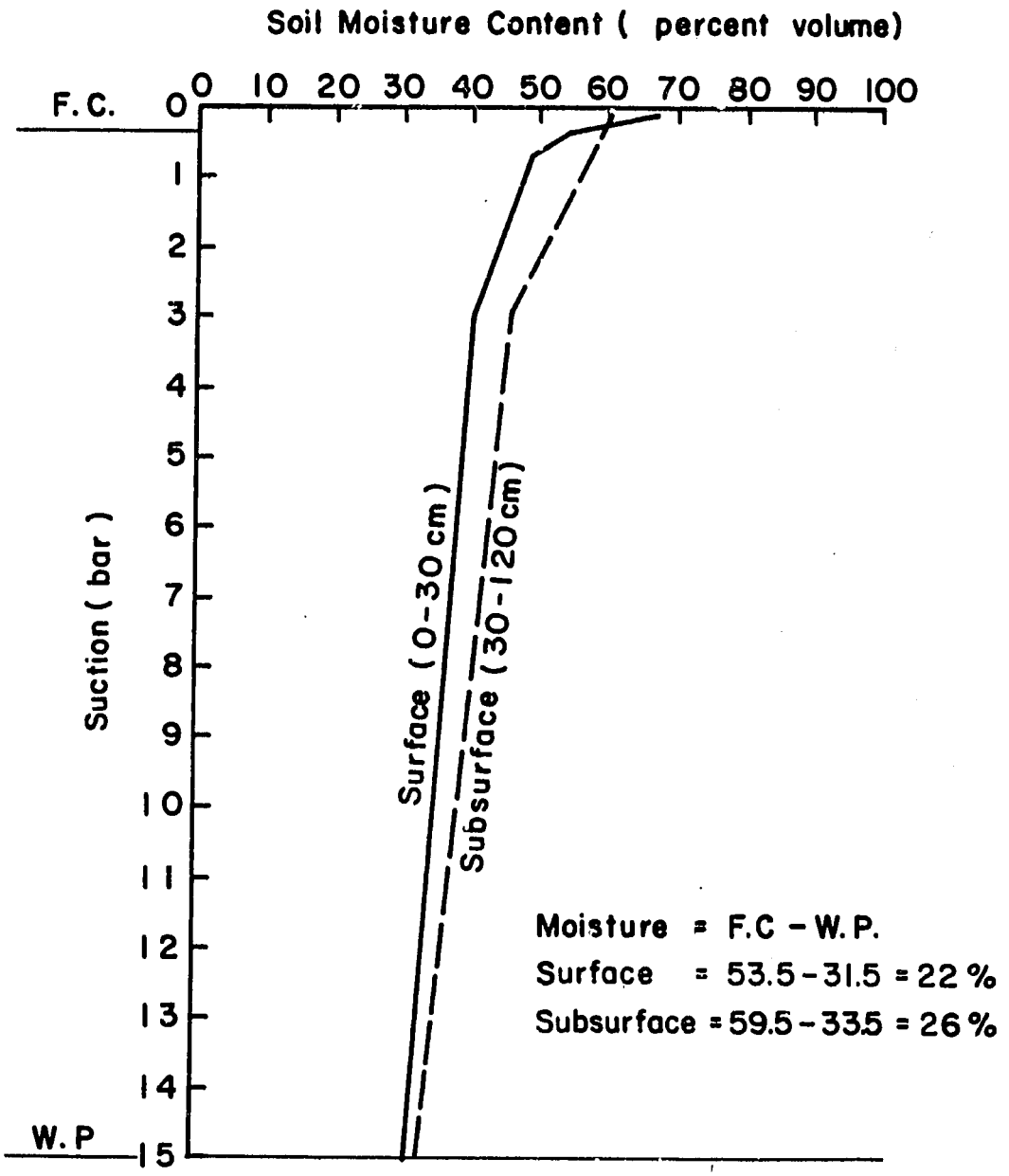


Figure 2. Soil moisture vs. tension pF curves for Vertisols. From EWUP Study Areas.

## C. Salinity and Alkalinity

The two chemical properties that mostly affect the irrigation of alluvial soils in Egypt are the salinity and alkalinity. Neither of these conditions are part of the classification for Vertisols, because various management practices could rapidly change their values. However, both parameters directly affect the available water for plants, the soil aggregation, water infiltration rate, and other soil moisture characteristics, as well as having a potential toxic effect on crops.

In the EWUP project sites the salinity and alkalinity levels are generally low to moderate, but both tended to increase with depth (Table 3). The most severe salinity problems are in Kafr El-Sheikh, while the most severe alkalinity problems are in the El-Minya subsoils. Both salinity and alkalinity problems can be very localized, occurring in highly variable isolated spots.

## D. Shrink/Swell

The most distinguishing feature of Vertisols is their shrinking/swelling activities with wetting and drying cycles. This is most noticeable from the vertical cracks formed by the horizontal contraction. The shrinking/swelling activity also occurs vertically. Under natural conditions the gilgai micro-relief pattern is a clearly visible and dramatic expression of the vertical movement. However the vertical movement usually is not seen under cultivated conditions, but could create problems in maintaining precision levelled fields.

The vertical expansion for various Egyptian soil has been evaluated. The extent of expansion for every 1% absorbed water during the 1st irrigation is 0.314 and 0.140 mm for clay and clay loam soils, respectively (Salib, 1981). Upon initial wetting, the rate of accumulated vertical expansion has been calculated to be 0.24 and 0.18 mm/min for the 2 soil types, respectively. This rate of expansion decreases with both subsequent irrigations and depth, at least down to 15 cm (Figure 3). The decrease with depth could be attributed to either a reduction in the change in soil moisture content as reviewed later, or the downward force of the over-lying soil, or both. In a similar manner

Table 3. Salinity and alkalinity values for Vertisols in EWUP areas a/

| Location | Profile No | Depth | E.C. | pH | SAR |
|---|---|---|---|---|---|
| | | --cm- | mmohs/cm | | |
| Beni Magdul | 12 | 0- 15 | 10.5 | 7.5 | 14.8 |
| | | 15- 50 | 5.9 | 7.4 | 12.2 |
| | | 50-150 | 7.5 | 7.4 | 9.4 |
| | 37 | 0- 25 | 1.2 | 7.4 | 3.4 |
| | | 25- 80 | 1.2 | 7.4 | 7.7 |
| | | 80-150 | 1.4 | 7.8 | 5.6 |
| | 48 | 0- 20 | 5.5 | 8.0 | 8.1 |
| | | 20- 75 | 5.8 | 7.7 | 8.4 |
| | | 75-150 | 2.8 | 7.9 | 5.6 |
| Kafr El-Sheikh | 4 | 0- 20 | 4.1 | 7.7 | 5.4 |
| | | 20- 70 | 7.8 | 7.6 | 18.9 |
| | | 70-150 | 5.7 | 8.1 | 12.5 |
| | 33 | 0- 30 | 4.0 | 7.4 | 6.7 |
| | | 30- 80 | 3.6 | 8.0 | 17.2 |
| | | 80-140 | 2.7 | 8.3 | 27.4 |
| | 72 | 0- 30 | 1.7 | 8.0 | 4.8 |
| | | 30- 65 | 4.0 | 8.0 | 10.9 |
| | | 65-150 | 5.9 | 7.4 | 12.5 |
| El-Minya | 1 | 0- 20 | 2.2 | 8.1 | 4.8 |
| | | 20- 70 | 1.5 | 8.3 | 9.9 |
| | | 70-150 | 3.0 | 8.3 | 16.3 |
| | 45 | 0- 25 | 0.9 | 8.1 | 2.1 |
| | | 25- 60 | 1.0 | 8.4 | 5.2 |
| | | 60-150 | 1.4 | 8.3 | 7.0 |
| | 81 | 0- 30 | 3.5 | 8.1 | 5.0 |
| | | 30- 90 | 1.8 | 8.2 | 8.7 |
| | | 90-150 | 0.8 | 8.3 | 3.2 |

a/ Adapted from EWUP PTR No. 2, 33, 34 for Beni Magdul, El-Minya, and Kafr El-Sheikh, respectively.

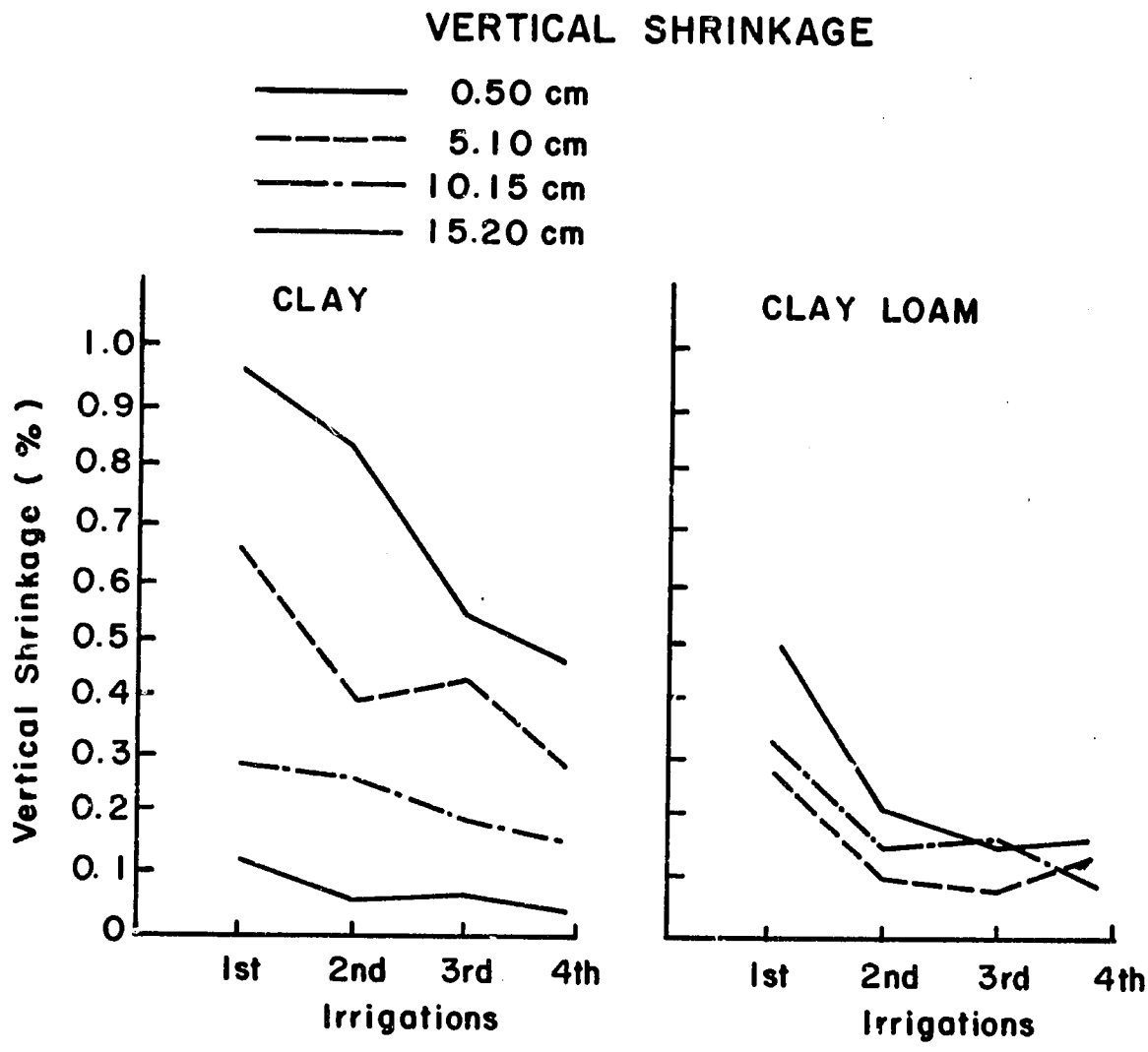


Figure 3. Vertical expansion rate of clay and clay loam soils with different irrigations (Adapted from Salib, 1981).

the vertical shrinkage rate was 0.56 and 0.30 mm/week for the surface 5 cm of the 2 soil types, respectively. The same analysis also showed that the extent of vertical shrinkage decreased with both depth and number of irrigations (Figure 4).

The force of expansion can be substantial. The formation of gilgai micro-relief pattern implies an upward lifting force capable of raising 1 m columns of soil. The soil heaving has been known to tilt fences, and utility poles, heave sidewalks and roads, and crack building and other structures (Boul et al, 1973; Soil Survey Staff, 1976)

## III. WATER MANAGEMENT OF VERTISOLS

### A. Bulk Density

The bulk density values needed to determine the volumetric soil water content in calculating irrigation applications, could be expected to vary widely, because of the volumetric changes with wetting and drying. Different studies have shown that bulk density values vary with space, moisture content, and degree of alkalinity. At the Sakha Experimental Station samples taken from a 25 x 150 m field had bulk density values ranging from 1.26 to 1.49 g/cm$^3$ in the surface soil and from 1.43 to 1.60 g/cm$^3$ in the subsoil, a range of 15% (Table 4) (Sixth Annual Report). The same set of data also shows a tendency for the bulk density of the mid layer to be higher than the surface or deeper subsurface layer. This mid depth maximum values of bulk density could be the result of:

- plow sole or traffic pan from puddling and transplanting rice;
- the sedimentation process of soils; and/or
- dry clods sluffing into the crack, getting stuck at this level and then trying to expand into the adjacent soil during the next wetting. This is thought to cause the gilgai micro-relief pattern mentioned previously.

Studies relating bulk density to soil moistrue have been made in Gizeria, Sudan with similar Nile Sediments (Zein El-Abedine et al, 1969). These studies showed substantial increases in bulk density as the soils dried from 0.1 to 15 atm. tension (Table 5).

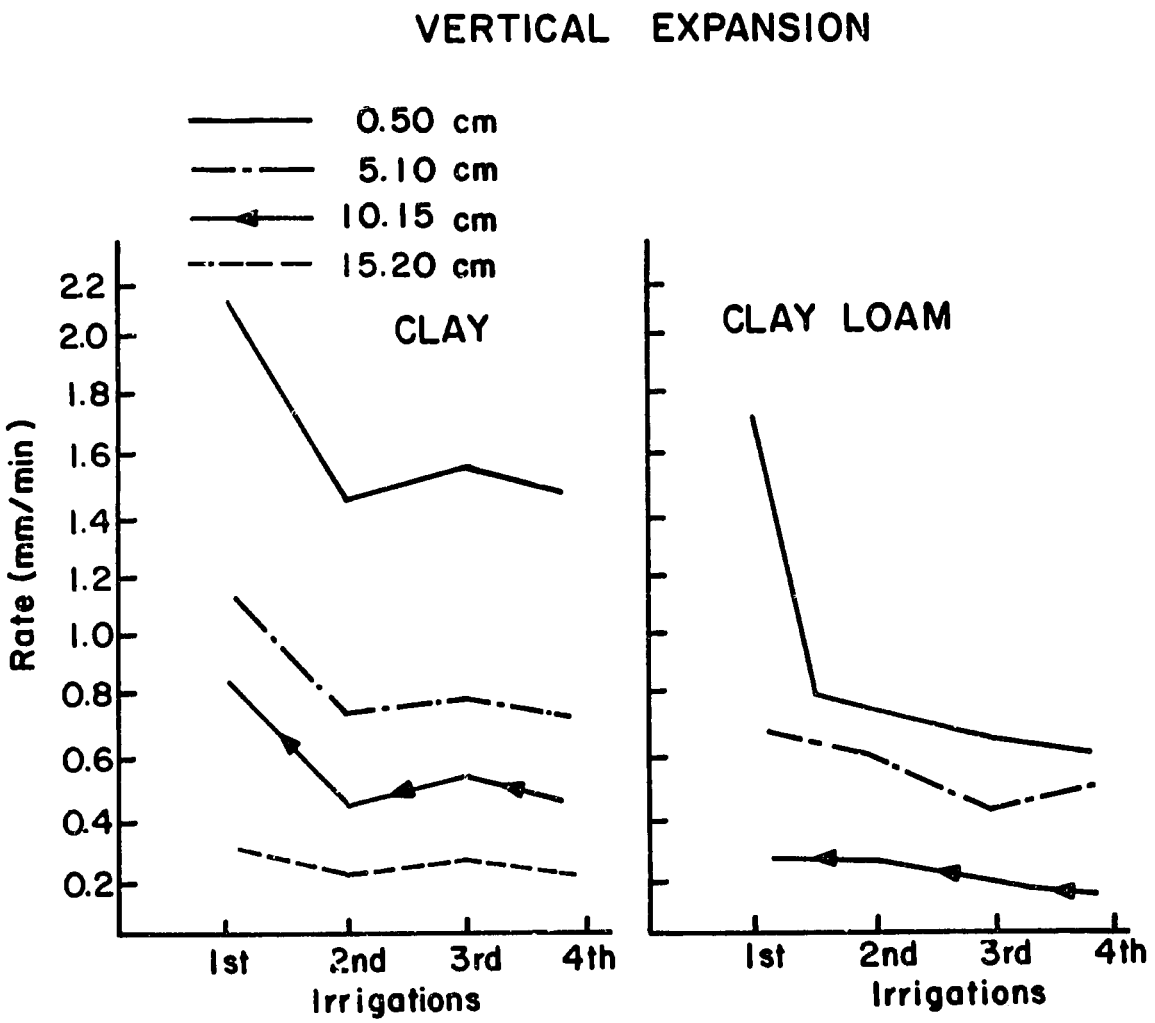


Figure 4. Vertical shrinkage of clay and clay loam soils with different irrigations (Adapted from Salib, 1981).

Table 4. Variability of Bulk Density With Depth & Space a/

| Depth | Bulk Density | | | | | |
|---|---|---|---|---|---|---|
| --cm-- | ----------g/cm$^3$---------- | | | | | |
| 0- 18 | 1.40 | 1.37 | 1.26 | 1.44 | 1.34 | 1.49 |
| 18- 30 | 1.63 | 1.51 | 1.53 | 1.50 | 1.60 | 1.67 |
| 30-120 | 1.59 | 1.46 | 1.47 | 1.43 | 1.43 | 1.60 |

a/ Sakia Expermential Station, Kafr El-Shiekh. Samples taken after Cotton from an area 25 X 150 meters. (Adapted from Sixth Annual Report, 1981).

Table 5. Bulk Density vs. Soil Moisture

| Depth | Tension in Atmospheres | | | | | | |
|---|---|---|---|---|---|---|---|
| | 15 | 8 | 4 | 1 | 0.67 | 0.33 | 0.10 |
| cm | g/cm$^3$ | | | | | | |
| 1-30 | 1.52 | 1.48 | 1.43 | 1.34 | 1.20 | 1.22 | 1.08 |
| 30-40 | 1.52 | 1.49 | 1.42 | 1.28 | 1.24 | 1.15 | 1.08 |
| 40-70 | 1.45 | 1.41 | 1.34 | 1.20 | 1.16 | 1.10 | 1.04 |
| 70-105 | 1.46 | 1.41 | 1.32 | 1.16 | 1.11 | 1.04 | 0.97 |
| 105-140 | 1.46 | 1.41 | 1.33 | 1.21 | 1.17 | 1.09 | 1.03 |
| 140-160 | 1.45 | 1.41 | 1.33 | 1.19 | 1.14 | 1.08 | 1.04 |
| 140-200 | 1.50 | 1.45 | 1.39 | 1.27 | 1.24 | 1.15 | 1.10 |

Source: Zein El-Abedine, et al 1969.

Exchangable sodium also affects the bulk density. Laboratory research has shown a 24% increase in bulk density from 1.62 to 2.10 $g/cm^3$, as the exchangable sodium increased from 2.6 to 9.3% (Zein El-Abedine, 1965). This change in bulk density would result from the increase in colloidal dispersion caused by increased sodium content.

These variations in bulk density can effect the soil infiltration, and crop development, as well as substantially distort the volumetric soil moisture measurements used to calculate irrigation efficiency and introduce a large systematic potential error in any irrigation evaluation.

B. Soil Seepage and Compaction

The expansion and contraction with wetting and drying can greatly increase the conveyance losses of irrigation water, especially on raised waterways such as gravity delivery mesqas and on-farm marwas. The horizontal contraction will cause cracks that allow initial direct leakage of water until the cracks have swollen shut. The vertical expansion and contraction during wetting and drying cycles may cause repeated heaving and loosening of the banks even if initially well compacted. This will allow lateral above ground seepage to the cultivated lands. This problem is particularly acute in Kafr El-Sheikh where marwa length from saqia discharge to the field can be 500 m or more. Conveyance loses from saqia to field ranged from 30 to more than 50% of the water lifted (Figure 5).

The problem is also serious in El-Minya where the Abyuha canal and all mesqas are elevated for gravity irrigation. In this case a simple solution to the problem may be evident. The solution is to maintain a reasonable traffic pattern on the mesqa banks. This traffic can be provided by the regular road traffic along the maintenance right-of-ways beside Abyuha canal and the normal animal and man walking on footpaths beside the mesqas. The continuous traffic could provide a compacting force to counteract the repeated vertical heaving and maintain the necessary compaction to minimize seepage. The possible effect of traffic on seepage losses was observed in Abyuha on some mesqas during an 'on' period. In each case the traffic pattern was noticeably

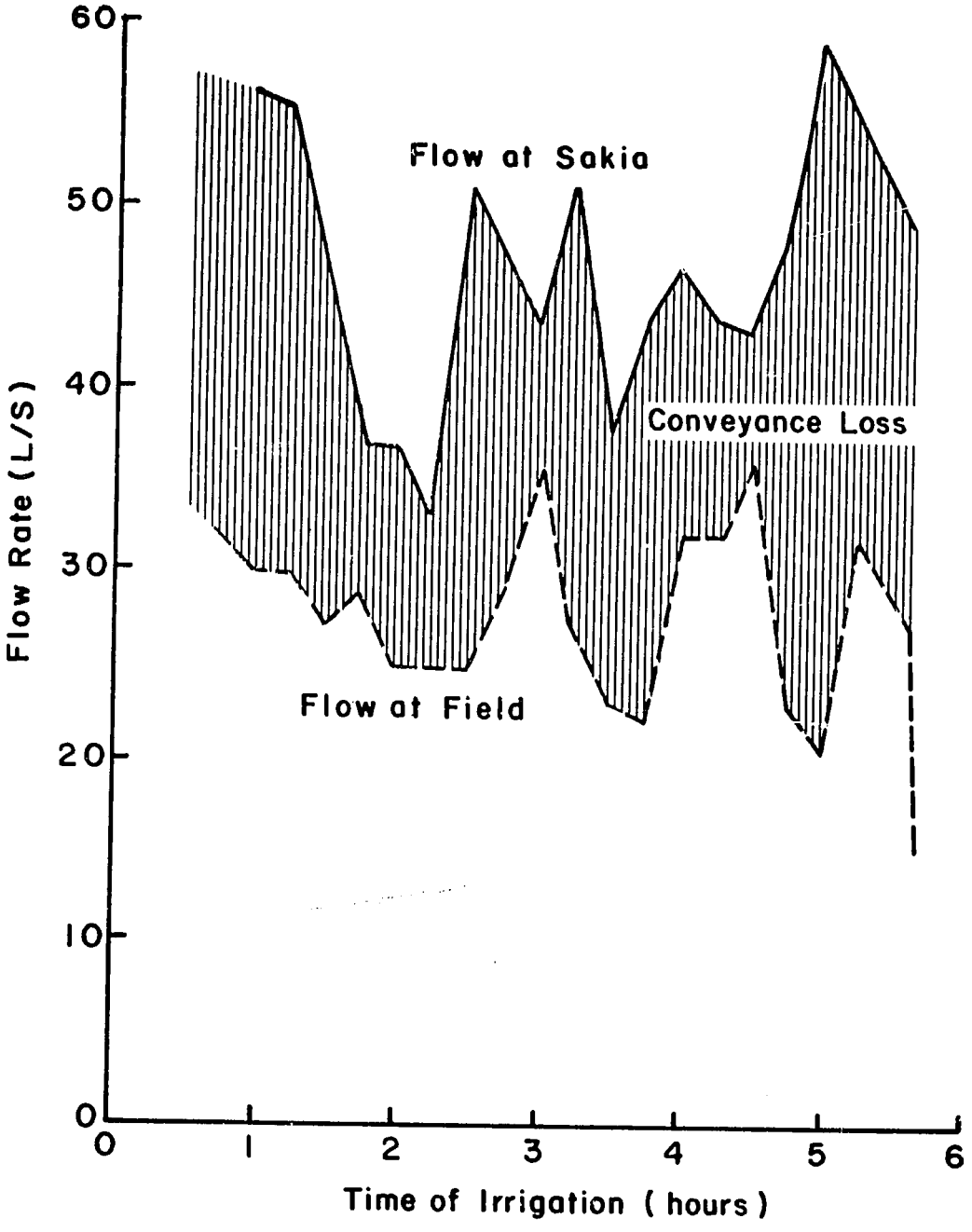


Figure 5. Marwa conveyance losses in Kafr El-Sheikh.

concentrated on the South (left) bank of the mesqas. Extensive seepage was occurring through the less trafficked North (right) bank, with essentially no seepage on the more heavily travelled South bank. The seepage on the right bank resulted in wetting fronts extending up to one meter into the crops, with some small pools of water forming. The crops in the seepage area showed some of the chloritic symptoms associated with excessive wetness.

Maintaining traffic patterns on banks of raised distributary canal and mesqas would be reasonable and frequently are the farmers' major means of access to their fields and maintenance of distributary canals (EWUP PTR No. 32). However, maintaining adequate traffic on marwa banks would be difficult because marwa banks are generally too small to walk on, and there is generally no need to walk along the marwas except during an irrigation. When marwa length is a problem, alternative means of reducing seepage may be necessary.

C. Infiltration

The infiltration rate at which water enters the soil is of critical importance in irrigation design. For Vertisols, with their potential for cracking and swelling, and water movement into the cracks, the infiltration can be a very complex phenomenon. EWUP made a comprehensive study of infiltration in Kafr El-Sheikh. The analysis involved 21 infiltration tests on wheat over a period of several years (EWUP PTR No. 57). Much of the following discussion has been taken from that study.

1. Horizontal movement. If a field has well developed cracks, as when a pre-plowing irrigation is being applied, the initial water applied will simply disappear into the cracks. During this time, the water will be distributed below ground through the cracks and can be easily seen flowing in the bottom of the cracks several meters in front of the surface advance front. Even if it remains on the surface, the retaining bunds for the basins will be subjected to the same seepage problems as the raised canals. Thus irrigation water can easily run into neighboring basins via a combination of cracks and bund seepage. This was well illustrated by a delayed irrigation of a wheat field in Kafr El-Sheikh in March 1983. The field was laid out with several 200 m

long basins. By the time the wetting front reached the end of the first basin, water had already been applied to 2/3 of the adjacent basin and 1/2 of the third basin. This type of water loss from basins makes measuring applied water and computing irrigation efficiencies difficult.

2. Vertical movement. If the irrigation of a level basin is preceded by land preparation, that fill the cracks with tillage aggregates, so they are not visible; the wetting fronts will move uniformly across the field; and the infiltration will frequently proceed in 2 distinct stages. These stages can be clearly seen on a log-log plot of time vs. depth infiltrated (Figure 6). The initial very rapid stage is thought to represent the movement of water around the aggregates, and then horizontally into the soil peds. This is essentially a two dimensional water adsorption process. The second, much slower stage, is thought to be the vertical movement through the soil and greatly affected by the soil wetness below the cracked layer. The difference in rate of infiltration between the 2 stages can average a 100 fold decline. The rate drops from 173 mm/hr during the first minute to 1.73 mm/hr after 2 hours.

In almost 1/3 of the tests in the Kafr El-Sheikh study the final stage represented a sealed or nearly sealed condition in which only negligible amount of water entered the soil (Table 6). The stage change and sealing, if it occurred, usually took place within the first hour of irrigation. This time period is less than the 2 to 3 hours usually required to advance a wetting front across the entire field. Thus it is almost impossible to finish an irrigation before the stage change occurs at the head of the field.

3. Surface drainage. With the stage change and potential sealing occurring before an irrigation of the entire field can be completed, ponded water will remain in field depressions. This water will have to be channeled to a drain. The depth of ponding will depend on the levelness of the field or basins within the field. However, even a precision leveled field to a tolerance of $\pm$ 2 cm can have a field

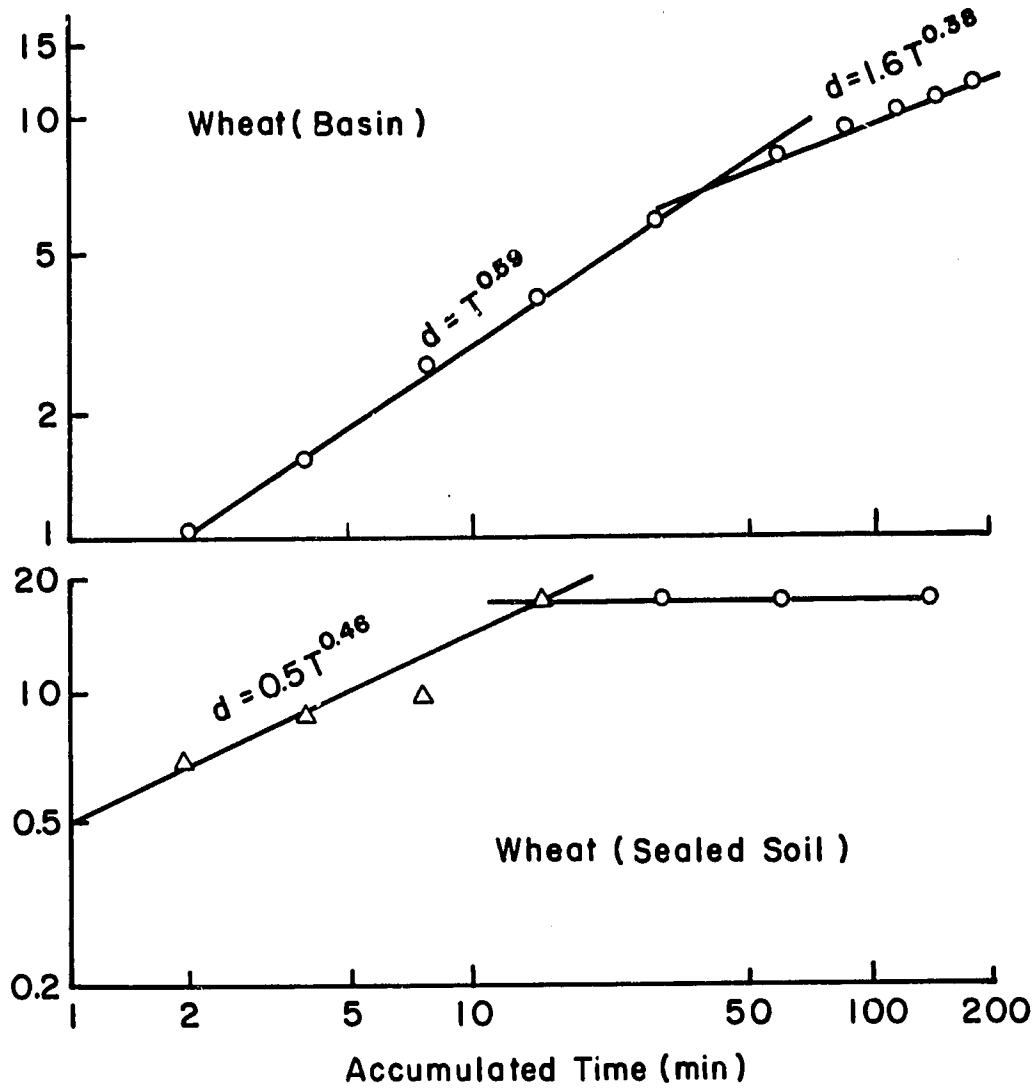


Figure 6. Two stage infiltration curves from Kafr El-Sheikh.

Table 6. Summary of Wheat Infiltration Study in Kafr El-Sheikh

| Test | Irri. No | Inflection Time | Inflection Water Inf. | % of Total a/ | Sealing |
|---|---|---|---|---|---|
| | | min | mm | | |
| 1 | 2 | 15.4 | 17.0 | 100 | yes |
| 2 | 2 | 8.2 | 8.0 | 56 | |
| 3 | 2 | 24.2 | 15.5 | 70 | |
| 4 | 1 | 14.8 | 58.3 | 88 | |
| 5 | 1 | | | | |
| 6 | 1 | 13.3 | 18.6 | 49 | |
| 7 | 1 | 54.9 | 96.0 | 100 | yes |
| 8 | 1 | 46.4 | 52.5 | 78 | |
| 9 | 1 | 45.7 | 64.0 | 100 | yes |
| 10 | 1 | 65.7 | 58.7 | 68 | |
| 11 | 1 | 58.7 | 81.0 | 64 | |
| 12 | 1 | 54.9 | 124.5 | 79 | |
| 13 | 1 | 43.5 | 78.4 | 62 | |
| 14 | 1 | 39.5 | 94.2 | 68 | |
| 15 | 1 | 32.1 | 91.7 | 65 | |
| 16 | 3 | | | | |
| 17 | 3 | | | | |
| 18 | 3 | | | | |
| 19 | 1 | 97.0 | 31.0 | 100 | yes |
| 20 | 1 | 84.2 | 43.0 | 100 | yes |
| 21 | 1 | 125.4 | 45.0 | 100 | yes |
| | | | | % Sealing | 33.3 |

a/ Assuming 220 minutes total infiltration time
Adapted from EWUP PTR No. 57

depression and pond of up to 4 cm. depth. If this must evaporate it could take up to 10 days during winter when evaporation rates are in the order of 0.2 - 0.3 cm/day (Table 7). EWUP has experienced a 10 day pond following an irrigation of a newly levelled wheat field in Mansouria during December 1980. The problem resulted in very poor germination and the ponded area had to be reseeded after a 2-week delay (Sabah et al, 1982).

The potential for water to pond in field depressions for adversely long periods, indicates a need for water removal from the soil surface. Under farmers' traditional practices of dividing their fields into relatively small basins, surface drainage is possible by using the same in-field marwas that delivered the water. In the EWUP study areas of Beni Magdul and Kafr El-Sheikh, it has been frequently observed that farmers drain their fields immediately after irrigating. The water has usually been discharged either into small field drains or back into the mesqas.

In the case of large basins, the surface drainage of field depressions may be more difficult and restrict the ability of farmers to use large basins, even when levelled. It is quite possible that in these two areas most of the water applied in excess of the crop's needs is lost from the fields via surface runoff.

4. Uniform applications. With leveled basins and the 2-stage very rapid/very slow infiltration curve, most of the water that enters the soil does so during the first stage. In the Kafr El-Sheikh study, it was estimated that 75% of all infiltrated water, entered during the first stage. This is consistent with other reports in which 90% of the infiltrated water entering heavy clays occurred within the first 15 min. (Miller et al, 1982). This then allows for relatively uniform application of water, independent of the amount of time the irrigation takes. The Kafr El-Sheikh study again illustrates this (Figure 7). A typical infiltration opportunity time of between 3 and 4 hours, as would occur at the head vs. tail of the field, resulted in approximatley 1 cm

Table 7. Estimated Time of Recession From Field Depressions [a]

| Test | Depression Depth (mm) | | |
|---|---|---|---|
| | 20 | 40 | 80 |
| | -------days------- | | |
| 1 | 9.1 | 18.2 | 36.4 |
| 2 | 4.0 | 11.0 | 26.9 |
| 3 | 2.8 | 8.7 | 23.4 |
| 4 | 3.9 | 11.2 | 27.7 |
| 5 | 0.7 | 2.0 | 7.4 |
| 6 | 0.7 | 2.0 | 7.4 |
| 7 | 9.1 | 18.2 | 36.4 |
| 8 | 0.7 | 2.0 | 7.4 |
| 9 | 9.1 | 18.2 | 36.4 |
| 10 | 0.3 | 0.5 | 1.1 |
| 11 | 0.2 | 0.3 | 0.6 |
| 12 | 0.3 | 0.6 | 1.7 |
| 13 | 0.2 | 0.4 | 0.8 |
| 14 | 0.3 | 0.5 | 1.1 |
| 15 | 0.3 | 0.4 | 1.1 |
| 16 | 0.2 | 0.3 | 0.4 |
| 17 | 0.2 | 0.3 | 0.5 |
| 18 | 0.3 | 0.4 | 0.8 |
| 19 | 9.1 | 18.2 | 36.4 |
| 20 | 9.1 | 18.2 | 36.4 |
| 21 | 9.1 | 18.2 | 36.4 |

a/ Assumed advance time of 213 min. Computations based on combination of infiltration rate and evaporation.

Adapted from EWUP PTR No. 57

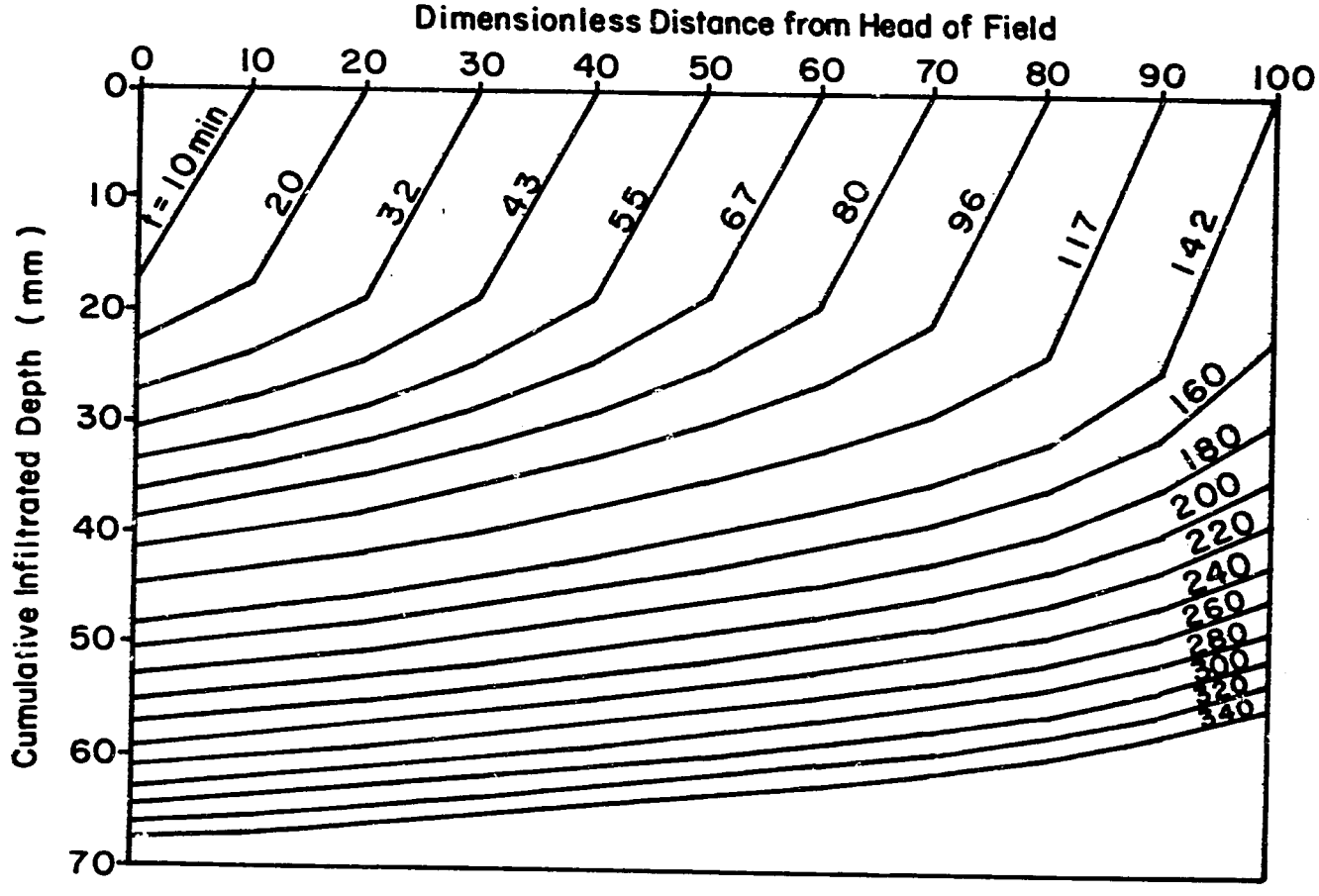


Figure 7. Uniform distribution of water in soil as a function of opportunity time (Source EWUP PTR No. 57).

difference in infiltrated water. The Christenson Uniformity coefficient, which was developed to measure uniformity of application, has values exceeding 90% for all tests in Kafr El-Sheikh (EWUP PTR No. 57).

Since the time required to irrigate is frequently related to the available discharge, reasonably uniform applications can be obtained almost independent of discharge. This may be why EWUP has had difficulty obtaining the discharge vs. application depth relationship usually obtained on other soil types (EWUP PTR No. 41). In Egypt the possibility of relatively uniform applications with a wide range of discharge can be important as the farm level discharge can be highly variable. In EWUP study areas measured discharges have been as low as 10-12 l/s and as high as 40-50 l/s depending on the study area, location of the farm on the canal, time of day, etc. (EWUP PTR No. 41).

D. Soil Water Movement

At the end of an irrigation, the water redistribution within the soil profile may be very slow. Detailed soil water sampling in Mansourja during winter including the closure period showed water losses for the top 30 cm of a berseem field to follow a 2 phase pattern with a change at about 15 days (Figure 8). The first and faster phase is thought to represent a combination of gravity flow and ET. The slower second phase was equal to estimated ET rates. If this is the case, it would indicate that gravity flow in winter can continue in the upper 30 cm for up to 15 days after an irrigation. This is 5 times the normal expected 3 days used in defining "Field Capacity". Hydraulic conductivity studies by EWUP have shown values in the range of 1 to 2 mm per day, which would also indicate the possibility for prolonged gravity flow.

If it is taking nearly 15 days for gravity drainage from the upper 30 cm, and longer for a wetting fringe to move deeper, the time required for a wetting fringe to reach the watertable could easily exceed the interval between successive irrigations. In this case, it is possible for 2 or 3 wetting fringes to be simultaneously moving through the soil profile above the watertable. This would then imply that any "capillary"

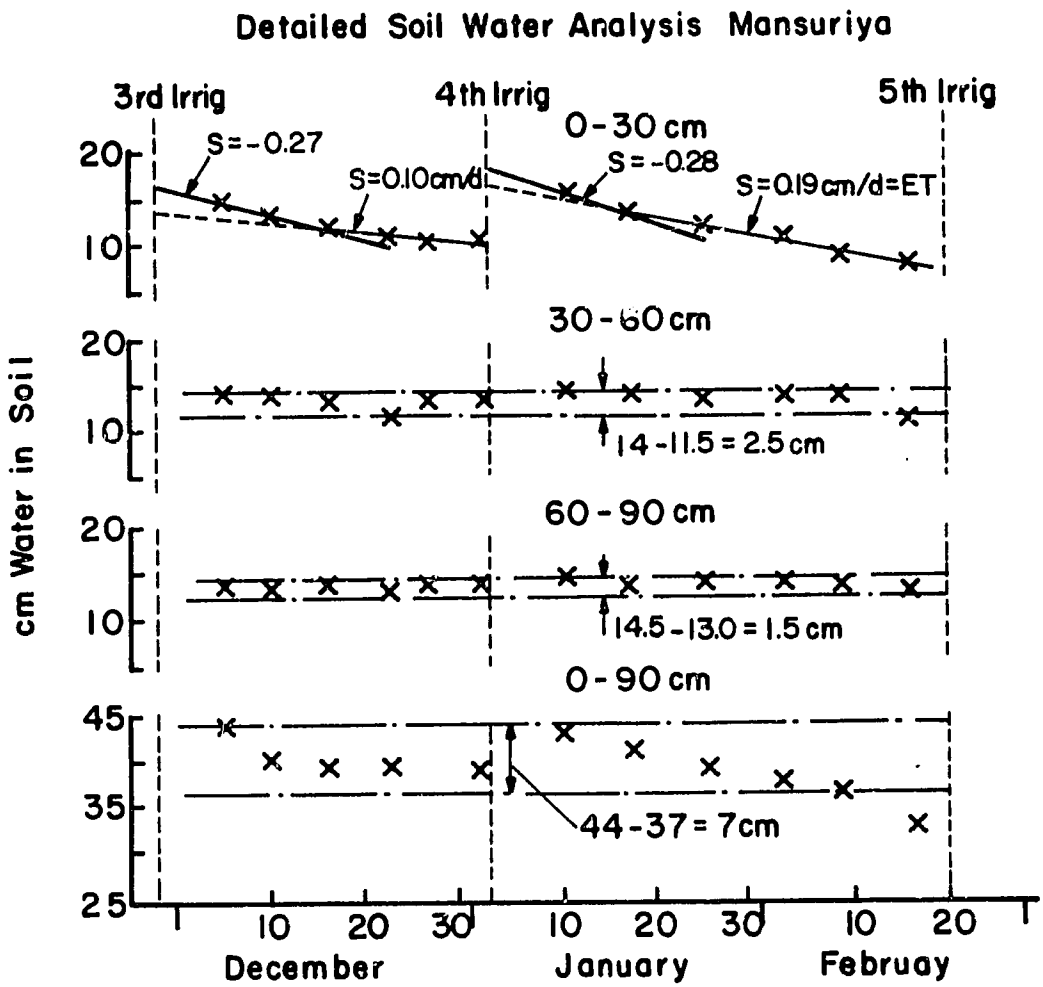


Figure 8. Soil water distribution with time after irrigations in Mansuriya.

upward movement would be from the latest advancing wetting fringe rather than the actual watertable.

The possible presence of multiple wetting fringes could partly account for the occasional negative depletion values between irrigation from lower levels. These have occurred in EWUP evaluation of irrigations, mostly during early irrigations or closely spaced irrigations.[4]

Also, the slow water movement and the potential of multiple wetting fringes make it possible for saturated conditions to exist close to the surface, even without a free watertable. Computations of aeration at El-Minya, where the watertable is below 1.25 meters at all times, have indicated that saturated conditions exist in the 30-60 cm depth most of the time after the first irrigation of the season, and continuously in the 60-90 cm. depth (Table 8) (Abdel Satter et al, 1980). To some extent the saturated conditions in El-Minya may be the result of increases in subsurface alkalinity (EWUP PTR No. 33).

## E. Root Penetration

Important in the plants ability to obtain water and nutrients is the extent of root penetration. In repeated sampling in EWUP study areas the recoverable roots were restricted to the upper 30 to 40 cm depth (Tables 9 and 10), almost independent of crop (Tinsley et al, 1980, 1982a, 1982b). This includes such strongly taprooted crops such as cotton. The winter crops tended to have a slightly greater root penetration than did summer crops. The increased root penetration noticed for winter crops may be the result of the watertable being slightly lower in winter, and the low temperatures reducing microbial activity so that anaerobic conditions below the advancing wetting fringes would take longer to develop, allowing more time for the wetting fringes to advance to deeper levels.

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4. Unpublished EWUP data.

Table 8. Changes in Volume of Soil Water and Air at Different Depth for Wheat in El-Minya, 1979-1980[a/]

| Depth | Bulk Density | % Mineral | Water Air | 1st Irri. Before | 1st Irri. After | 2nd Irri. Before | 2nd Irri. After | 3rd Irri. Before | 3rd Irri. After | 4th Irri. Before | 4th Irri. After | 5th Irri. Before | 5th Irri. After | 6th Irri. Before | 6th Irri. After | Harvest |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| --cm-- | g/cm$^3$ | | | % by volume | | | | | | | | | | | | |
| 0-15 | 1.22 | 46 | water | 29 | 59 | 33 | 57 | 41 | 66 | 41 | 60 | 41 | 58 | 44 | 60 | 33 |
| | | | air | 25 | sat | 21 | sat | 14 | sat | 13 | sat | 13 | sat | 10 | sat | 21 |
| 15-30 | 1.32 | 50 | water | 33 | 53 | 45 | 58 | 47 | 62 | 55 | 59 | 53 | 54 | 51 | 57 | 43 |
| | | | air | 17 | sat | 5 | sat | 3 | saturated | | | | | | | 7 |
| 30-60 | 1.43 | 54 | water | 43 | 47 | 46 | 58 | 54 | 58 | 56 | 69 | 52 | 59 | 58 | 54 | 51 |
| | | | air | 3 | saturated | | | | | | | | | | | |
| 60-90 | 1.50 | 57 | water | 52 | 53 | 53 | 59 | 59 | 58 | 52 | 57 | 51 | 59 | 58 | 60 | 54 |
| | | | air | saturated | | | | | | | | | | | | |

a/Source Abdel Satter et al. 1980. EWUP Staff Paper 33
% mineral calculated from bulk density assuming a particle density of 2.65.

Table 9. Root Penetration for Summer Crops in EWUP Sites

| Depth | Maize | | | | | | Cotton | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Kafr El-Sh | | El-Minya | | Mansouria | | Kafr El-Sh | | El-Minya | |
| | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % |
| cm. | g | | g | | g | | g | | g | |
| 0-10 | 4.7 | 88.7 | 2.8 | 59.6 | 3.0 | 83.3 | 10.4 | 54.6 | 8.3 | 65.9 |
| 10-20 | 0.5 | 98.1 | 1.0 | 80.9 | 0.3 | 91.6 | 7.9 | 96.2 | 2.4 | 85.0 |
| 20-30 | 0.1 | 100.0 | 0.3 | 87.3 | 0.1 | 94.4 | 0.4 | 98.5 | 0.9 | 92.1 |
| 30-40 | | | 0.2 | 91.6 | 0.0 | 94.4 | 0.1 | 99.0 | 0.4 | 95.3 |
| 40-50 | | | 0.4 | 100.1 | 0.1 | 97.2 | 0.1 | 99.5 | 0.3 | 97.7 |
| 50-60 | | | | | 0.1 | 100.0 | 0.0 | 99.5 | 0.2 | 99.3 |
| 60-70 | | | | | | | 0.1 | 100.0 | 0.1 | 100.1 |
| Total | 5.3 | | 4.7 | | 3.6 | | 19.0 | | 12.6 | |

Table 10. Root Penetration for Winter Crops in EWUP Sites

| Depth | Wheat | | | | | | Berseem | | | | | | Broad Beans | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Kafr El-Sh | | El-Minya | | Mansouria | | Kafr El-Sh | | El-Minya | | Mansouria | | Kafr El-Sh | | El-Minya | |
| | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % | Wt. | Acc % |
| cm. | g | | g | | g | | g | | g | | g | | g | | g | |
| 0-10 | 2.1 | 52.5 | 2.3 | 44.2 | 3.3 | 54.1 | 4.7 | 77.0 | 2.7 | 30.0 | 5.7 | 86.4 | 1.2 | 46.2 | 1.1 | 30.6 |
| 10-20 | 0.3 | 60.0 | 0.2 | 48.1 | 0.6 | 63.9 | 0.4 | 83.6 | 1.7 | 48.9 | 0.4 | 92.4 | 0.6 | 69.2 | 0.6 | 47.2 |
| 20-30 | 0.3 | 67.5 | 1.9 | 84.6 | 0.4 | 70.5 | 0.1 | 85.2 | 2.0 | 71.1 | 0.2 | 95.6 | 0.1 | 73.1 | 0.4 | 58.3 |
| 30-40 | 0.5 | 80.0 | 0.2 | 88.5 | 0.4 | 77.0 | 0.1 | 86.9 | 0.7 | 78.9 | 0.1 | 97.0 | 0.2 | 80.8 | 0.2 | 63.9 |
| 40-50 | 0.6 | 95.0 | 0.3 | 94.2 | 0.3 | 81.9 | 0.3 | 91.8 | 0.5 | 84.4 | 0.1 | 98.5 | 0.2 | 88.5 | 0.1 | 66.7 |
| 50-60 | 0.1 | 97.5 | 0.1 | 96.2 | 0.3 | 86.8 | 0.3 | 96.7 | 0.4 | 88.9 | 0.1 | 100.0 | 0.1 | 92.3 | 0.3 | 75.0 |
| 60-70 | 0.1 | 100.0 | 0.1 | 98.1 | 0.3 | 91.7 | 0.1 | 98.4 | 0.2 | 91.1 | | | 0.1 | 96.2 | 0.4 | 86.1 |
| 70-80 | | | 0.1 | 100.0 | 0.2 | 99.9 | 0.1 | 100.0 | 0.3 | 94.4 | | | 0.1 | 100.0 | 0.3 | 94.4 |
| 80-90 | | | | | | | | | 0.5 | 100.0 | | | | | 0.2 | 100.0 |
| Total | 4.0 | | 5.2 | | 6.1 | | 6.1 | | 9.0 | | 6.6 | | 2.6 | | 3.6 | |

The presence of a shallow watertable did not seem to have a major effect. The root penetration in the El-Minya area where the watertable is the lowest was only 10-15 cm greater than the same crops grown in other areas. Yet even in El-Minya, few roots were recovered from depths greater than the watertable of the sites with a high watertable. Again, part of the problem in El-Minya could be attributed to the increased subsurface alkalinity.

In all cases the root penetration was less than half the depth expected from studies on other soil types in which wheat and maize developed roots to 1.5 m. or more (Metcalfe & Elkins, 1980) and cotton greater than 2.0 m (Prentice, 1972). Vertisol restriction on cotton root development has been observed by others, and associated with yield reductions (Young, 1976). However, no solutions were known. Even deep tillage would be effective for only one season (Young, 1976). The limited root penetration of cotton is most dramatically demonstrated in Kafr El-Sheikh each fall when farmers commonly remove their cotton stalks by physically pulling them from the soil with taproot intact after a heavy post harvest irrigation.

The restriction in root penetration as observed by the EWUP studies is consistent with other studies recognizing that heavy soils in general make root penetration difficult (Miller et al, 1982), and a review of all seven Vertisol profile descriptions listed in Soil Taxonomy (Soil Survey Staff, 1976). In the Soil Taxonomy listing only one description had more than "few fine roots" for Vertisols horizons below 38 cm. This is also consistent with the EWUP soil profile descriptions from all three areas (EWUP PTR Nos. 2, 32, 33) and those from EMCIP (Abdel Wahed, 1983) taken at the Experiment Stations and Governmental farms where EMCIP is involved, and including sites with subsurface tile drainage.

The reasons for restricted root penetration in irrigated Vertisols could be a combination of:

1. The slow internal water movement causing limited aeration below the highest advancing wetting fringe. This would normally be within the upper 50 cm. of the profile.
2. The mechanical impedance of the heavy clay to the roots.

3. The potential for cracks to prune roots, and thus the farmers are irrigating frequently enough to keep the cracks from becoming large enough to break the roots.

The concept of root pruning in Vertisols may be important. It is considered the main reason the natural vegetation for Vertisols is usually savanna grasslands, and only rarely open forest (Soil Survey Staff, 1976). Forest trees are thought to be unable to thrive, because of the root pruning by the cracks during extended dry periods. Even within savanna or temperate prairie the actual grass species may be affected. A study in South Dakota has shown that the grasses under Vertisols tend to be those with more vertical root systems, while surrounding areas will have grasses with more branching root system (White & Lewis, 1969). In the EWUP project areas observations of crops that have not been irrigated for 2 weeks have shown roots stretched across cracks of 5 cm. These roots, upon touching, appear to have been stretched very tight and some may have been broken.

F. Limited Available Water

Since plants absorb most of their water through the root system, the restriction on root penetration restricts the depth from which water can be extracted. This is the case in all EWUP study areas, and can best be illustrated in the figure for Mansouria (Figure 8). In this figure the measured change in soil moisture between irrigations is 5 cm in the 0-30 cm depth, 2 cm in the 30-60 cm depth and at most 1 cm in the 60-90 cm depth. This represented 63, 25, and 12 % of the measured water loss, respectively. Additional examples come from all three areas using both summer and winter crops (Table 11, 12 & 13). In the examples shown the measured soil water depleted at an irrigation, other than the first irrigation, averaged 5 to 7.5 cm for all locations. The variation in the depletion was nearly 40% (Table 11).

More detailed analysis of cotton and wheat indicated nearly all measured water losses between irrigations were between 4 and 8 cm with

Table 11. Operational Available Water in Egyptian Vertisols

| Crop | Location | No. Irri | Cm Water / 90 cm Soil Before | After | Difference |
|---|---|---|---|---|---|
| Sugarcane | El-Minya | 16 | 44.8+/-2.3 | 50.6+/-1.8 | 5.7+/-1.5 |
| Wheat | | 7 | 45.6+/-4.0 | 51.1+/-1.4 | 6.9+/-2.3 |
| Cotton | | 9 | 45.2+/-2.0 | 51.2+/-1.4 | 5.6+/-2.4 |
| Berseem | Mansouria | 7 | 39.8+/-3.0 | 44.6+/-0.8 | 5.0+/-3.1 |
| Maize | | 7 | 36.4+/-2.4 | 44.8+/-2.3 | 7.4+/-3.5 |
| Wheat | | 5 | 40.3+/-2.5 | 46.8+/-0.9 | 6.5+/-2.9 |
| Wheat | Kafr El-Sheikh | 5 | 40.9+/-1.1 | 48.2+/-1.3 | 6.8+/-1.2 |
| Sugarbeet | | 6 | 40.8+/-2.8 | 48.5+/-1.6 | 7.1+/-2.8 |
| Cotton | | 8 | 40.3+/-1.6 | 46.8+/-0.7 | 6.5+/-2.0 |
| Maize | | 8 | 41.8+/-1.2 | 47.2+/-0.9 | 5.3+/-1.1 |

Table 12. Measured Soil Water Changes for Wheat in EWUP Study Areas

| Location | | Kafr El-Sheikh | | | | El-Minya | | | | | Beni Magdul | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irri. No. | Depth/ Sample | 0-30 | 30-60 | 60-90 | 0-90 | 0-15 | 15-30 | 30-60 | 60-90 | 0-90 | 0-15 | 15-30 | 30-60 | 60-90 | 0-90 |
| | | % Volume | | | | | | | | | | | | | |
| 1 | Before | 25.0 | 39.7 | 48.7 | | 33.3 | 40.0 | 43.3 | 55.0 | | 24.0 | 44.7 | 46.0 | 46.0 | |
| | After | 54.3 | 56.7 | 29.7 | | 66.7 | 51.3 | 47.0 | 54.3 | | 57.0 | 51.3 | 52.0 | 54.3 | |
| 2 | Before | 48.3 | 53.3 | 55.7 | | 45.3 | 48.7 | 52.7 | 54.7 | | 32.0 | 44.7 | 49.3 | 50.0 | |
| | Depl[a/] | 1.8 | 1.1 | 1.2 | 4.1 | 3.2 | 0.4 | -1.7 | -0.1 | 1.8 | 3.6 | 1.0 | 0.8 | 1.3 | 6.7 |
| | After | 56.0 | 54.3 | 55.3 | | 63.3 | 56.0 | 54.0 | 58.3 | | 52.7 | 50.0 | 53.0 | 54.0 | |
| 3 | Before | 38.0 | 51.3 | 54.3 | | 42.0 | 46.0 | 52.7 | 58.3 | | 26.0 | 36.7 | 44.0 | 47.0 | |
| | Depl | 5.4 | 0.9 | 0.3 | 6.6 | 3.3 | 1.5 | 0.4 | 0.0 | 5.2 | 4.0 | 2.0 | 2.7 | 2.1 | 10.8 |
| | After | 49.7 | 51.0 | 54.3 | | 66.7 | 58.7 | 53.3 | 60.0 | | 48.0 | 50.0 | 54.0 | 52.0 | |
| 4 | Before | 37.3 | 50.3 | 52.7 | | 46.7 | 46.0 | 49.7 | 53.7 | | 33.3 | 43.3 | 51.7 | 50.7 | |
| | Depl | 3.7 | 0.2 | 0.5 | 4.4 | 3.0 | 2.0 | 1.8 | 1.9 | 8.6 | 2.2 | 1.0 | 0.7 | 0.4 | 4.3 |
| | After | 56.7 | 55.3 | 57.7 | | 68.7 | 59.3 | 53.0 | 59.7 | | 48.7 | 50.0 | 53.0 | 52.0 | |
| 5. | Before | 42.7 | 54.7 | 55.7 | | 41.3 | 42.7 | 50.3 | 57.0 | | 34.0 | 40.0 | 46.7 | 53.3 | |
| | Depl | 4.1 | 0.3 | 0.6 | 5.0 | 4.1 | 2.5 | 0.8 | 0.8 | 8.1 | 2.2 | 1.5 | 1.9 | -0.4 | 5.1 |
| | After | 47.7 | 48.7 | 50.3 | | 62.7 | 50.0 | 54.0 | 57.0 | | 45.3 | 49.3 | 53.7 | 51.7 | |
| 6 | Before | | | | | 36.7 | 42.7 | 49.3 | 54.7 | | | | | | |
| | Depl | | | | | 4.0 | 1.1 | 1.4 | 0.6 | 7.1 | | | | | |
| | After | | | | | 61.3 | 52.0 | 52.0 | 57.3 | | | | | | |
| | Harvest | 31.3 | 44.7 | 49.0 | | 32.7 | 37.3 | 49.7 | 54.3 | | 14.0 | 25.3 | 34.3 | 44.7 | |
| | Depl | 4.9 | 1.2 | 0.3 | 6.5 | 4.3 | 2.2 | 0.7 | 0.9 | 8.1 | 4.7 | 3.6 | 5.8 | 2.1 | 16.2 |
| Ave Before[b/] | | 41.6 | 52.4 | 54.6 | | 42.4 | 45.2 | 50.9 | 55.7 | | 31.3 | 41.2 | 47.9 | 50.3 | |
| Ave After | | 52.9 | 53.2 | 55.5 | | 64.9 | 54.6 | 52.2 | 57.8 | | 50.3 | 50.1 | 53.1 | 52.8 | |
| Total Depl | | 20.0 | 3.4 | 2.8 | 26.2 | 21.8 | 9.6 | 3.3 | 4.2 | 38.9 | 16.7 | 9.1 | 11.9 | 5.5 | 43.1 |
| % of Total | | 76.3 | 13.0 | 10.7 | | 56.0 | 24.7 | 8.5 | 10.8 | | 38.7 | 21.1 | 27.6 | 12.8 | |
| Accum % | | | 89.3 | 100.0 | | | 80.7 | 89.2 | 100.0 | | | 59.8 | 87.4 | 100.0 | |

a/ Depletion measures in cm.
b/ Average of before irrigation soil moisture excludes initial irrigation.

Table 13. Measured Soil Water Changes for Cotton in EWUP Study Areas

| Location Irri. No. | Depth/ Sample | Kafr El-Sheikh 0-30 | 30-60 | 60-90 | 0-90 | El-Minya 0-15 | 15-30 | 30-60 | 60-90 | 0-90 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % Volume | | | | | | | | |
| 1 | Before | 30.1 | 44.2 | 48.6 | | | | | | |
| | After | 51.4 | 51.1 | 49.9 | | 55.3 | 56.9 | 56.9 | 58.1 | |
| 2 | Before | 41.0 | 45.1 | 48.4 | | 42.7 | 49.2 | 56.4 | 58.4 | |
| | Depl[a] | 2.8 | 1.8 | 0.5 | 5.1 | 1.9 | 1.2 | 0.2 | -0.1 | 3.1 |
| | After | 50.9 | 51.8 | 54.8 | | 57.0 | 56.2 | 58.6 | 60.0 | |
| 3 | Before | 34.5 | 47.8 | 50.8 | | 37.6 | 44.4 | 55.4 | 59.5 | |
| | Depl | 4.9 | 1.2 | 1.2 | 7.3 | 2.9 | 1.8 | 1.0 | 0.1 | 5.8 |
| | After | 44.5 | 48.4 | 49.4 | | 55.3 | 53.7 | 57.1 | 60.7 | |
| 4 | Before | 29.3 | 45.3 | 45.7 | | 36.7 | 46.3 | 52.3 | 56.2 | |
| | Depl | 4.5 | 0.9 | 1.1 | 6.6 | 2.8 | 1.1 | 1.5 | 1.4 | 6.7 |
| | After | 42.2 | 53.5 | 49.6 | | 54.5 | 54.8 | 58.4 | 59.2 | |
| 5 | Before | 27.9 | 48.2 | 47.9 | | 35.4 | 45.6 | 54.0 | 56.7 | |
| | Depl | 4.5 | 1.6 | 0.5 | 6.4 | 2.9 | 1.4 | 1.3 | 0.8 | 6.3 |
| | After | 45.8 | 46.1 | 50.0 | | 54.6 | 54.3 | 58.6 | 58.4 | |
| 6 | Before | 23.2 | 38.3 | 42.2 | | 37.7 | 43.2 | 52.7 | 57.2 | |
| | Depl | 6.9 | 2.3 | 2.3 | 11.5 | 2.5 | 1.7 | 1.7 | 0.4 | 6.2 |
| | After | 39.6 | 4.08 | 44.0 | | 55.5 | 53.9 | 56.7 | 59.9 | |
| 7 | Before | 26.6 | 39.3 | 43.1 | | 33.9 | 42.9 | 50.1 | 51.9 | |
| | Depl | 3.9 | 0.5 | 0.3 | 4.6 | 3.2 | 1.7 | 2.0 | 2.4 | 9.3 |
| | After | 42.2 | 42.6 | 45.5 | | 50.5 | 49.8 | 53.2 | 55.2 | |
| 8 | Before | | | | | 35.2 | 44.3 | 51.4 | 54.4 | |
| | Depl | | | | | 2.3 | 0.8 | 0.5 | 0.3 | 3.9 |
| | After | | | | | 63.7 | 59.9 | 59.6 | 53.0 | |
| 9 | Before | | | | | 36.7 | 42.9 | 50.6 | 52.9 | |
| | Depl | | | | | 4.1 | 2.5 | 2.7 | 0.0 | 9.4 |
| | After | | | | | 57.5 | 56.9 | 56.6 | 58.0 | |
| Harvest | | 21.2 | 35.2 | 40.8 | | 43.1 | 52.3 | 56.3 | 53.9 | |
| | Depl | 6.3 | 2.2 | 1.4 | 9.9 | 2.2 | 0.5 | 0.1 | 1.2 | 4.0 |
| Ave Before[b] | | 30.4 | 44.0 | 46.4 | | 37.0 | 44.9 | 52.9 | 55.9 | |
| Ave After | | 45.2 | 47.8 | 49.0 | | 56.0 | 55.2 | 57.4 | 58.1 | |
| Total Depl | | 33.6 | 10.5 | 7.3 | 51.6 | 24.8 | 12.7 | 10.8 | 6.4 | 54.7 |
| % of Total | | 65.2 | 20.4 | 14.2 | | 45.3 | 23.2 | 19.7 | 11.7 | |
| Accum % | | | 85.6 | 100.0 | | | 68.5 | 88.2 | 100.0 | |

a/ Depletion is measured in cm.
b/ Average before irrigation soil samples exclude initial irrigation.

approximately 70% or more of the measured water losses coming from the top 30 cm. Very little, if any, water losses occurred in the 60 to 90 cm. depth. This was true in project areas with a shallow watertable such as Kafr El-Sheikh and Beni Magdul, and in areas with a deeper watertable as in El-Minya. The 4 to 8 cm becomes the "operational available water" representing the water depletion at which the farmers irrigate. The 4 to 8 cm of "operational available water" is a sharp reduction from the 17-22 cm of available water computed from the pF curve to a depth of 90 cm (Table 2).

However, these EWUP results are again consistent with results obtained in Gizeria, Sudan (Fadl, 1978) with Vertisols derived from the same Nile sediments as found in Egypt. The results from Sudan were obtained with a neutron probe and the more carefully controlled environment of an Experiment Station.

The tension at which the available water was held can be evaluated by comparing the soil water measurements of Tables 11 & 12 with the pF data in Table 2. This comparison shows that the tension of the operational available water is dependent on the season and the depth in the soil. In winter, soil water in the upper 30 cm appears to fluctuate between less than 0.33 atm. and 3.0 atm. The after irrigation value of less than 0.33 atm. indicates that the soils were still draining towards 0.33 atm. used in estimating "Field Capacity" when sampled. The deeper samples tended to remain near the 0.33 atm. tension or wetter. In Mansouriya the deeper samples were closer to 0.1 atm. (Table 12). This may indicate the samples were taken from saturated soils.

In Summer, the soil moisture in the first 30 cm. for cotton in Kafr El-Shiekh and El-Minya fluctuated between 0.33 and near 15 atm. This could indicate that some stress was occurring in the upper soil levels. The mid levels of the soil tended to fluctuate between 0.33 and 3.0 atm while the lowest levels remained close to 0.33 atm. (Table 13).

## G. Irrigation Applications

The combination of a soil water deficit at the time of irrigation of only 4 to 8 cm., and the very rapid initial infiltration rate make it extremely difficult, with a surface irrigation system, to apply less

than a complete replenishment of the soil deficit. This is illustrated by the very small variation in the after irrigation soil moisture content (Table 11). Therefore, it is usually safe to assume that each irrigation is a complete replenishment of soil water losses and all computations of soil deficits can assume a fully recharged soil at the beginning of each interval between irrigations.

1. Irrigation requirements. In irrigating clay alluvial Vertisols the irrigation water requirement may best be divided into two components:

-the soil water deficit, and

-the "application requirement".

The soil water deficit as discussed previously is the 4 to 8 cm. "operational available water" for most irrigations or the 12 to 15 cm. initial irrigation deficit. The "application requirement" is the water in excess of the soil water deficit that is essential to advance the wetting front across the field from the inlet to the opposite side. The amount of water needed to meet the application requirement should be a reasonable constant for a field. It may vary with the levelness of the field and roughness of the crop being grown. EWUP data indicates a relatively uniform 2 to 3 cm of irrigation water is applied over that needed for replenishing the soil water depleted.[5] The water used for the "application requirement" will then be dissipated either as deep percolation or surface runoff. That which percolates could help leach salts. The application requirement automatically accounts for some of the leaching needs. Traditionally the MOI has allocated water for this as part of the conveyance requirement. However, "application requirement" may be a more accurate expression for some of the conveyence requirements. This implies a constant requirement with each irrigation.

2. Irrigation efficiency. When irrigations are comprised of both the soil water deficit component plus a relatively constant application requirement component, the irrigation efficiency will largely depend on the value of the deficit. The greater the soil moisture deficit at the time of irrigation, the smaller the ratio of water deficit to

5. Unpublished EWUP data.

application requirement, and the greater the irrigation efficiency. Figure 9, showing 72 irrigations in cotton field trials at Kafr El-Sheikh, illustrates this. These 72 irrigations had a highly significant correlation between irrigation efficiency and depth of water stored (Awad et al, 1981).

3. Over-irrigation. The "application requirement" is in reality a component of over-irrigation, in that it represents the application of more water than the crop needs. It is the minimum amount of over-irrigation the farmer can apply. It cannot be avoided. Any water applied above this minimum is avoidable and unless needed for salt control is wasteful. The over-irrigation water is removed from the land either by deep percolation or surface runoff. In areas of high water-tables such as Kafr El-Sheikh and Beni Magdul most of the excess water will go to surface runoff. In Beni Magdul most of the surplus water was drained back through the marwas and discharged back into the mesqas from which it was taken. In Kafr El-Sheikh most of the surface water was drained through shallow field drains that flowed directly into the drainage network. Some of it was drained back through the marwas and into the mesqa similar to what occurred in Beni Magdul.

The idea of surface drainage going back into the mesqa from which it was originally lifted provides some opportunity for immediate reallocation of the water. When this happens the over-irrigated water is not all lost, and the overall efficiency of the delivery system improved. In Beni Magdul the mesqas discharged directly into Nadia drain so the surface drainage can only be recovered by pumping from the drain. This occassionally was done at the end of Mesqa 10. However, in Kafr El-Sheikh the mesqas were generally deeper and closed-ended. The water returned to the mesqa can be and is reused.

In El-Minya there is no field drainage system. All surplus water applied infiltrated within a non detrimental period, became deep percolation, and assisted in salt removal.

4. Initial irrigations. The exception to the 4 to 8 cm application needs is the initial irrigation of a crop season. This irrigation frequently follows a 80-120 day irrigation gap and is the period when the soil is at its driest. The irrigation gap is the period from the

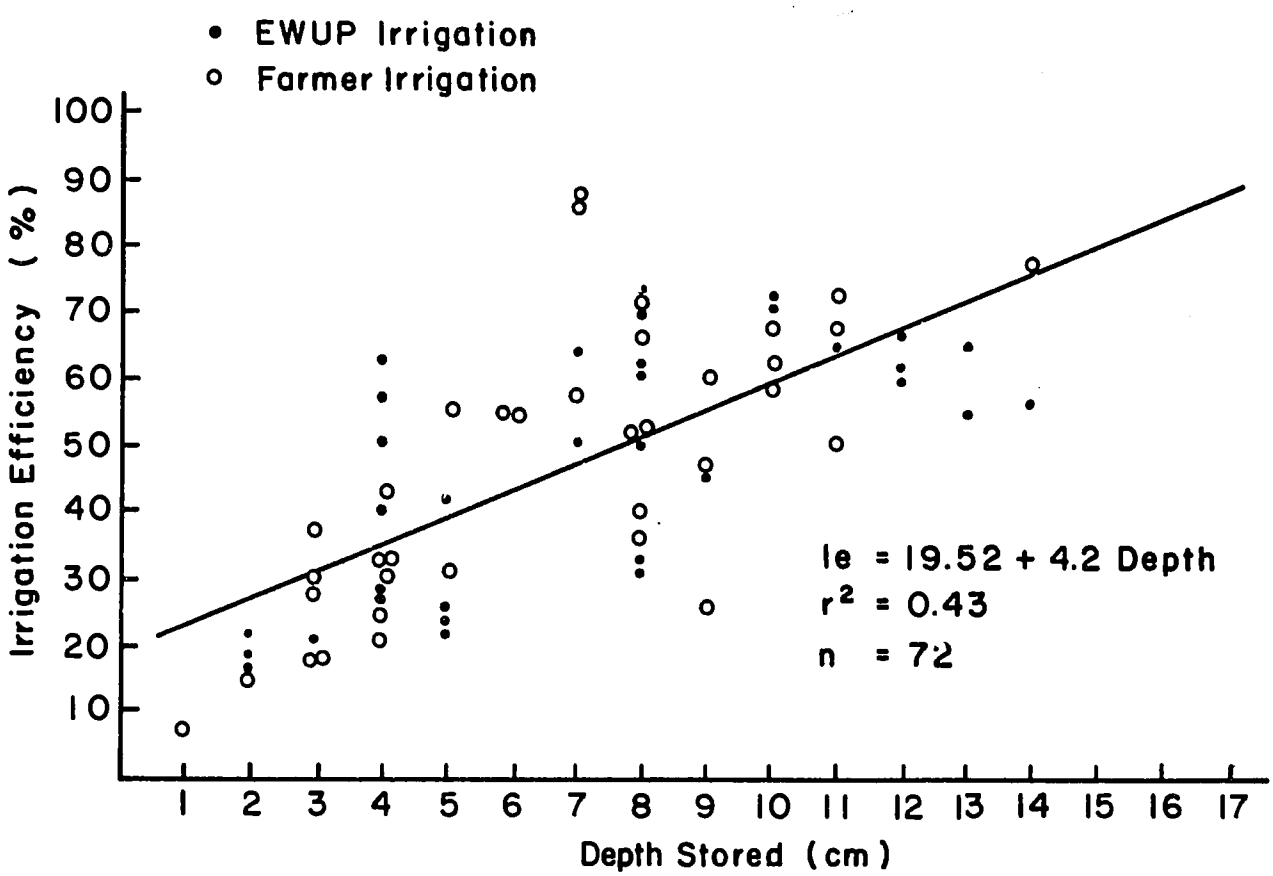


Figure 9. Irrigation efficiency vs. depth of water stored for 72 irrigations of cotton in Kafr El-Sheikh (Adapted from EWUP PTR No. 57).

last irrigation of the previous crop to the first irrigation of the current crop. It includes the period when the plant is maturing and drying out plus the normal turnaround time between crops. Soil water deficits at this time average around 12 cm and require irrigation applications of 15 to 18 cm (Awad et al, 1981). The initial irrigation of rice is also an exceptional condition. This irrigation not only had to overcome an extensive irrigation gap, but it also had to provide enough surplus water to puddle the soil and pond water for transplanting. This required an application of about 25 cm (EWUP PTR No. 9).

## H. Watertable and Subsurface Drainage

Since each irrigation results in a small amount of excess water applied and infiltrated, and the internal water movement is extremely slow there is a tendency for a shallow watertable to develop (Table 14) (Hellal et al, 1984). The water table tends to fluctuate with each irrigation (Figure 10) and also with the seasonal frequency of irrigation applications. Watertables are generally higher in summer when ET rates are highest and irrigations more frequent, and lowest in winter when ET rates are lowest and irrigations less frequent. The implication is that the natural drainage away from the watertable is nearly constant, and the seasonal rise and fall of the watertable is a function of the frequency of irrigations; each irrigation having an increment of deep percolation. The overall effect of the watertable is an equilibrium during the year, as the watertable returns to near the same place at relative times of different years (EWUP PTR No. 61).

The presence of a shallow watertable does indicate the possible need for subsurface drainage. Experiments is Sakha Station in Kafr El-Sheikh governorate have shown a positive crop response with wheat, cotton, etc. to tile drainage for both lowering the watertable and removal of soluble salts from the soil profile (Figure 11) (Sixth Annual Report, 1981).

Table 14. Monthly Average Depth to Watertable for Egyptian Clay Soils

| Location | 1981 | | | | | | | | | 1982 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
| | cm below surface | | | | | | | | | | | | |
| El-Minya | 177 | 168 | 158 | 149 | 120 | 137 | 125 | 146 | 159 | 179 | | 191 | 175 |
| Kafr El-Sheikh | 68 | 79 | 47 | 26 | 30 | 37 | 55 | 71 | 68 | 73 | 92 | 59 | 72 |
| Beni Magdul | 79 | 84 | 79 | 90 | 82 | 91 | 66 | 69 | 78 | 82 | 90 | | |

Adapted from EWUP PTR No. 47.

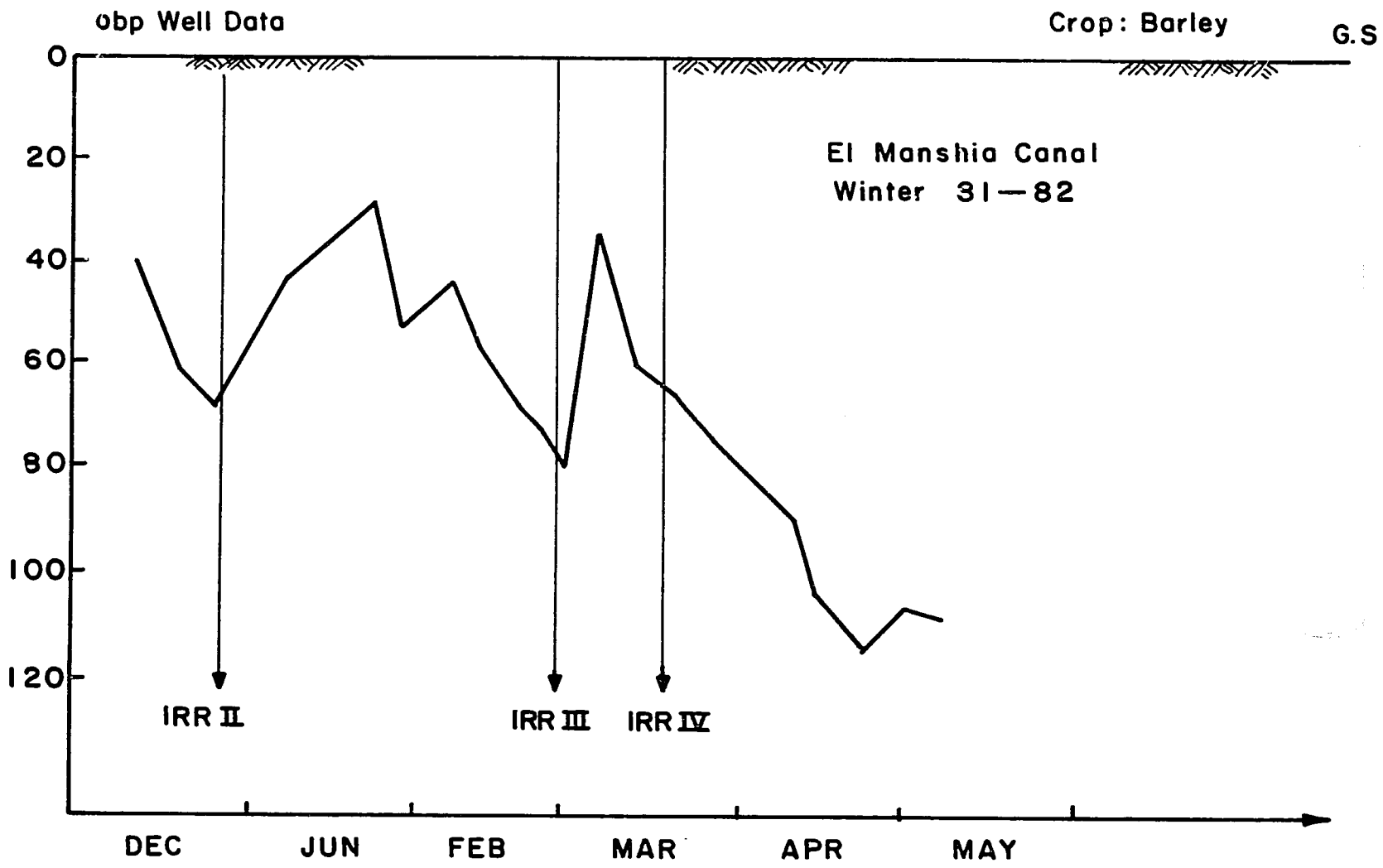


Figure 10. Fluctuations in watertable with irrigations in Kafr El-Sheikh.

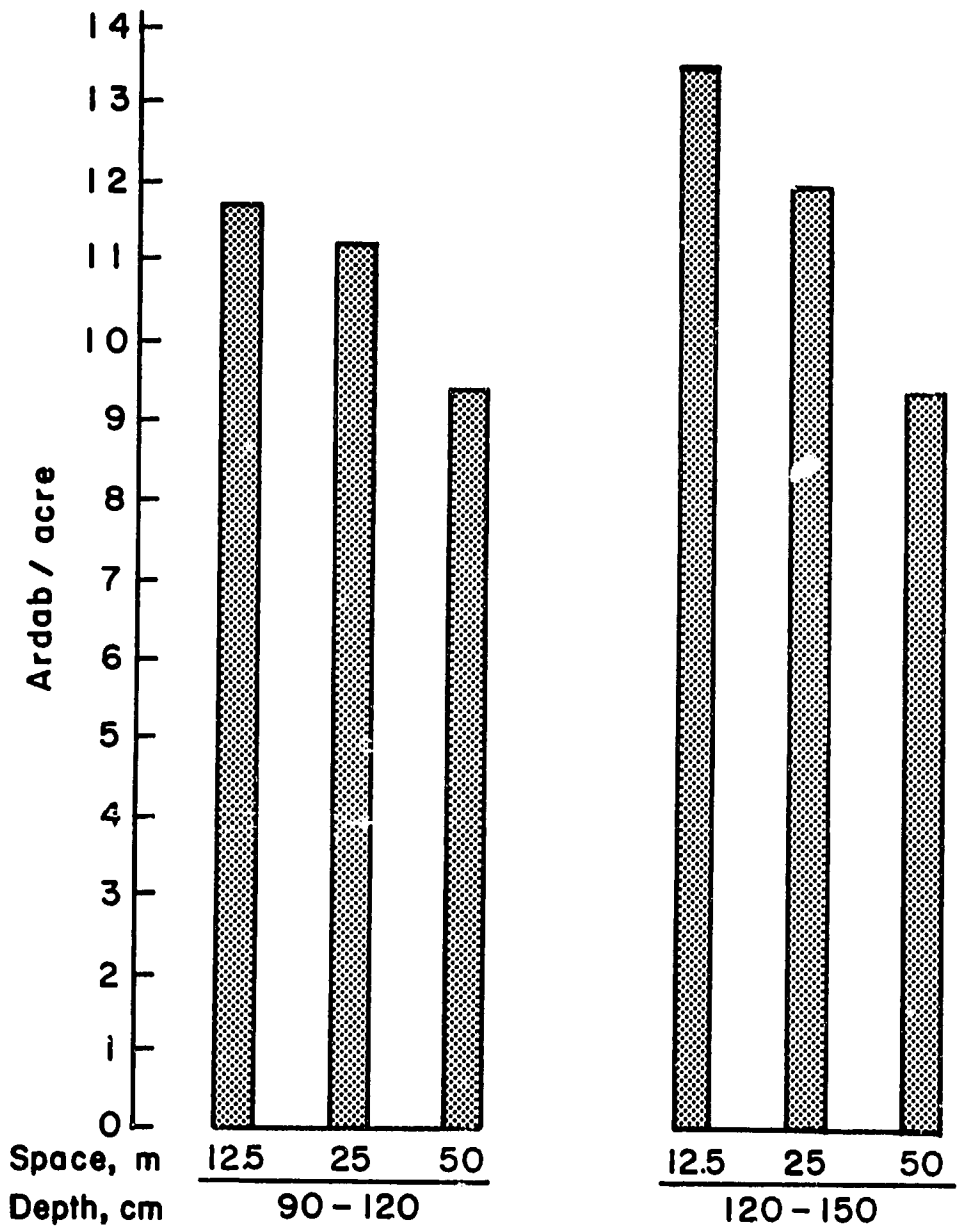


Figure 11. Crop response to subsurface tile drains at Sakha Experimental Station, Kafr El-Sheikh (Source Sixth Annual Report).

I. Capillary Movement

The watertable contribution to consumptive use was determined by observing the day vs. night lowering of the watertable in Kafr El-Sheikh (EWUP PTR No. 61). A clear day/night difference in rate of drawdown could be seen starting immediately after the last irrigation of cotton with the depth to the watertable of 24 cm and continuing for more then 25 days and a depth to the watertable of nearly 150 cm. (Figure 12). During this period the amount of water moving upward during the day and downward continuously day and night was evaluated (Table 15). The analysis showed a continuous decline in both the upward movement and downward deep percolation as the depth of the watertable increased. In the early periods the upward movement accounted for all the estimated consumptive use of cotton or 67% of the potential ET. This declined until, at 150 cm depth the estimated upward movement accounted for only 7% of the consumptive use or 4% of the potential ET. At this point the estimated downward movement exceeded the upward movement. The relatively limited contribution from watertables below 125 cm is consistent with other studies using totally different, more controlled, lysimeter techniques in Alexandria (Moustafa et al, 1975, 1977).

This very slow upward movement, when the watertable was below 125 cm, occurred in summer when the soil water content of the upper soil profile was approaching the wilting point so the tension pull is at its highest (Table 12). In winter the tension gradients are less and the rate of water movement correspondingly slower. For this reason, when the watertable is below 125 cm it probably will not be detrimental to soil aeration or root development. It could still contribute to upward salt movement, but only during fallow periods between crops.

## IV. INFLUENCE OF VERTISOLS ON IRRIGATION DESIGN

This report has reviewed the available data on Egyptian alluvial clays of the old lands (Vertisols) and the water management of these soils. This information is now used to infer various concerns for the

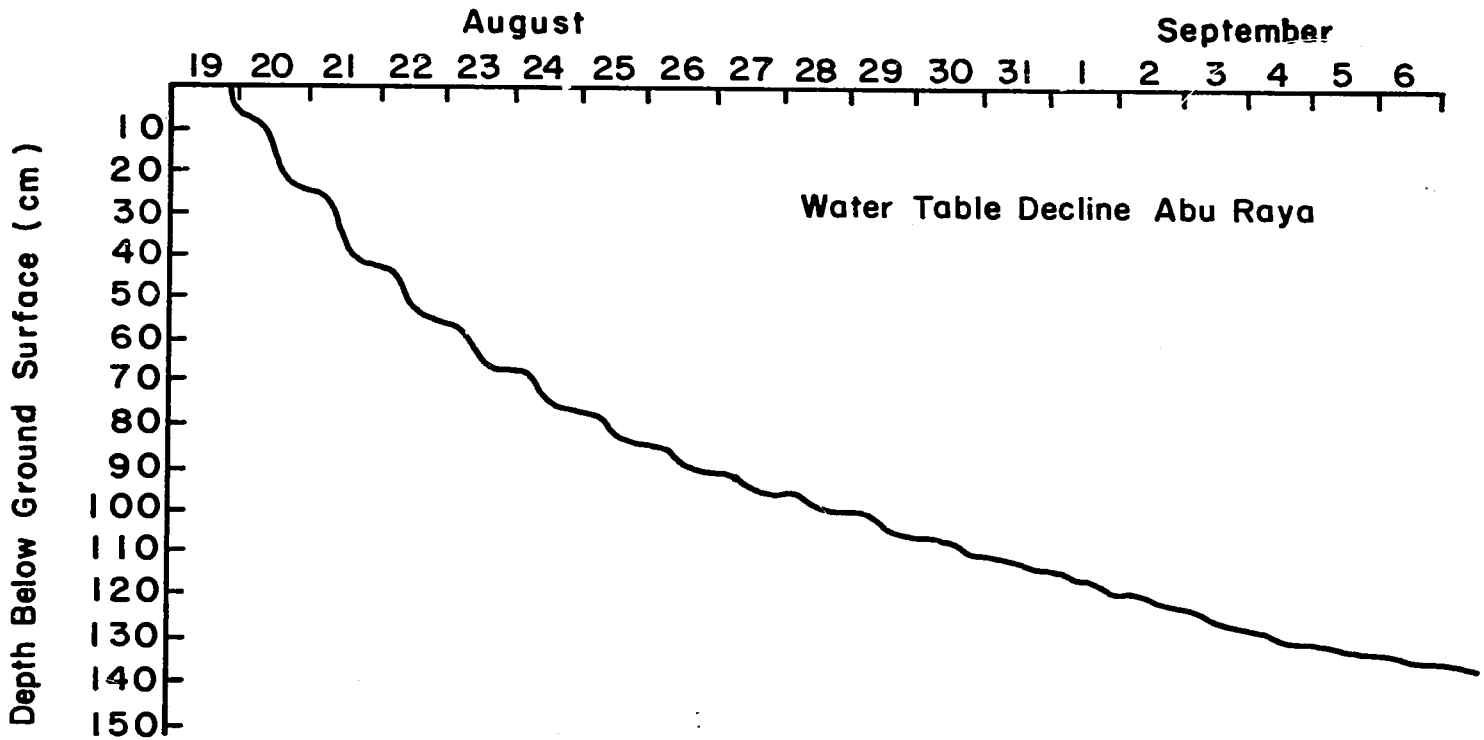


Figure 12. Diurnal decline in watertable after last irrigation of cotton in Kafr El-Sheikh Source EWUP PTR No. 61).

Table 15. Watertable Contributions to Consumptive Use[a/]

| Depth to WT | Days After Irrigation | Water Move[c/] Upward | Water Move[c/] Down | Ratio Up/Down | Upward Contri.[c/] CU | Upward Contri.[c/] ETo |
|---|---|---|---|---|---|---|
| -cm- | | ---mm/day-- | | | ------%------ | |
| 50 | 3 | 3.8 | 1.5 | 2.5 | 127 | 63 |
| 75 | 5 | 2.8 | 1.0 | 2.8 | 93 | 46 |
| 100 | 9 | 1.6 | 0.7 | 2.3 | 53 | 46 |
| 125 | 15 | 0.6 | 0.6 | 1.0 | 20 | 11 |
| 150 | 25 | 0.2 | 0.5 | 0.4 | 7 | 4 |

a/ Adapted from EWUP PTR No. 61.

b/ Calculated from change in water level during day vs night times 0.04 specific yield.

c/ Based on August potential ET and consumptive use for Cotton as reported in Water Master Plan Tech. Report No. 17.

system, and in planning the operation of the system as it now exists. These concerns will be discussed, both in terms of what hard data there are to support them and what can be rationally expected to occur. Additional study is needed to determine how critical these concerns are.

A. Soil-Water-Plant-System

The heavy clay soils tend to cause the severe restrictions in the root zone of all crops so there is really very little difference among crops in their effective root zones. These result in a root zone and measured soil moisture changes being concentrated largely within the upper 40 cm. regardless of the watertable depths found in the EWUP sites. The available water in this limited depth averages only 5 to 7 cm. Below this level there may be saturated water conditions and aeration problems that would reduce root penetration. It may be possible to withhold irrigations to encourage deeper root penetration and greater moisture extraction, but the cracking of the surface soil could become large enough to stretch and prune the plant roots.

B. Water Application and Distribution

The infiltration properties of the Vertisols in conjunction with a surface irrigation system make it both virtually impossible to apply less than the soil water deficit, and very difficult to infiltrate more than the deficit. Under these conditions all irrigations completely recharge the soil water reservoir. Each irrigation will have two components, the soil water deficit and the "application requirement" needed to force the water across the field. The application requirement represents an unavoidable over-irrigation. The application requirement is then dissipated through deep percolation, evaporation, or surface runoff. The proportion of each of these is dependent upon location. In El-Minya all would go to deep percolation, in Kafr El-Sheikh and Mansouria most would go to surface runoff. The application requirement is probably dependent on the overall levelness of the field, and is relatively constant with each irrigation of a given field. Precision land levelling could substantially reduce the volume of water applied. However, even under the best leveled conditions, the formation of a

gilgai microrelict pattern may result in field depressions of detrimental depth. Provisions must then be made for some surface drainage. For this reason long dead level basins may be difficult to manage, and graded basins preferable.

Another impact of the soil rapidly infiltrating the water deficit and then slowing down to minimum rates is that water will be uniformly distributed over the field relatively independent of the available stream flow. It would be almost impossible, under field slopes available with these soils in Egypt, to have a stream flow large enough to advance water across an entire field without the infiltration going to the very slow second stage, thus completely replenishing the soil water deficit. Light irrigations are only possible on already wet soils. Once in the second infiltration stage the time required for the irrigation advance has limited influence on depth infiltrated, thus low stream flows only require more time to irrigate, and more labor expense to the farmer.

Once water actually gets into the soil mass, its movement can be very slow. If the first stage of infiltration is through macro pores or cracks, small pockets of trapped air may occur which will limit the void space for water to move. Also much of the water may be actually entering the soil peds from the side rather than the top. This could reduce the extent of downward salt movement needed to leach the soil. Likewise the slow second phase may just not allow enough water into the soil to get the desired leaching done.

In the clay soils, even with the very limited amount of surplus water entering the soil, the adhesive water at wilting point is relatively high and fills from 20 to 30 percent of the soil voids. Thus there is little opportunity for soil water movement, or additional storage. This allows perched watertables to form at shallow depths. The specific yield, flow into and flow out of these watertables would be extremely low. The slow internal flow rates could also mean that a wetting fringe may not have completely reached the watertable during the intervals between irrigations. If this happens then more than one wetting fringe could be stacked on top of each other slowly moving toward the watertable.

## C. Delivery Design

The potential for soil movement with Vertisols may require some special design consideration in constructing or renovating irrigation delivery systems. One of these is canal bank stability. The heaving nature of the soils could make it difficult to maintain good compaction on newly constructed or renovated canals, regardless of how well the initial compaction is done. It may, therefore, be essential to maintain some form of continuous compacting force. This may be possible by encouraging either footpaths or access roads to be built on the banks of mesqas and canals. If not soil heaving could take place and major seepage occur. The problem could be particularly acute with elevated watercourses because the seepage could be more severe and flow out on the surface where it can damage crops. The alternative to traffic patterns may be expensive lining procedures.

Sunken canals and lift irrigation delivery systems may be more suited than elevated canals and gravity systems. This not only because of the reduced problems with seepage as noted above, but also because sunken canals, if of sufficient depth could also serve as the surface drains. This could then reduce the total area needed for waterways. In addition if the mesqas were closed as in Kafr El-Sheikh and did not discharge into the drains, the water returned to the mesqa through surface drainage could be reallocated immediately. This would increase the overall efficiency of the system. Consideration should be given to field layouts that encourage the surface drainage to return to the mesqas.

## D. Irrigation Evaluation

The accurate evaluation of irrigation practices with Vertisols may be difficult. The variation in bulk density for various reasons causes potential large systematic errors in determining the volumetric soil water content. With the small usually narrow fields found in Egypt, the horizontal flow into neighboring fields or basins during the early

stages of irrigation makes the accurate measurement of applied water difficult. And, the presence of multiple wetting fringes results in occasional anomalies in the soil moisture values by having negative soil water depletion values in some of the lower horizons.

## V. SANDY SOILS

In the "Old Lands" of Egypt sandy soils are found mostly on the edges of the valley where the desert and the Nile sediments interface. In the EWUP study sites only the El-Hammami part of Mansouria contains mostly sandy soils. Sandy soils, including those in El-Hammami, are characterized by a very low potential water holding capacity, plus a high infiltration and subsurface seepage rates.

The irrigation of sandy soils was evaluated from a study of 3 farms distributed through the El-Hammami command area. The farms were located at the beginning of the canal, the end of the canal, and on mesqa 2 that extends from the end of the canal.

The study showed that the sandy soil were poorly suited for surface irrigation. Infiltration test indicated that the infiltration rate was outside the US Soil Conservation Services family of infiltration curves (EWUP PTR No. 72). This would make it almost impossible to surface irrigate the area efficiently and small basins would be essential. If the basin exceeded more then 25x25 meters all the available discharge could infiltrate before the wetting front advances across the entire field. Because of the excessive infiltration rate farmers had to extensively over-irrigate just to get the water applied. An inevitable high watertable developed with related potential waterlogging, root restriction, and salinity problems.

The analysis of the individual farm irrigations (Table 16) showed that farmers had substantially different amounts of water available to them depending on how far from the source they were. This then affected their use of the canal vs. pumping from a well, the amount of water they applied, and their overall irrigation efficiency (EWUP PTR No. 74).

Table 16. Irrigation and Water Use for Crops on El-Hammami Sands

| Farm | Crop | No. Irri. | Water Applied | Water Stored | Water Depl. | Est. ET | % of Applied Stored | % of Applied ET |
|---|---|---|---|---|---|---|---|---|
| | | | mm | | | | | |
| 1 | Wheat | 6 | 679 | 91 | 74 | 475 | 13.4 | 70.0 |
| | Berseem | 10 | 1791 | 226 | 198 | 677 | 12.6 | 37.8 |
| 2 | Berseem | 4 | 276 | 53 | 56 | 170 | 19.2 | 61.6 |
| 3 | Broad beans | 7 | 261 | 110 | 150 | 373 | 42.1 | 142.9 |
| | Wheat | 9 | 278 | 128 | 155 | 475 | 46.0 | 170.9 |
| | Berseem | 12 | 894 | 282 | 261 | 677 | 31.5 | 75.7 |

Adapted from EWUP PTR No. 74.

As would be expected the farmer at the beginning of the canal was always able to lift water from the canal with his saqia, obtain a good discharge, and applied substantially more water than he was able to store. The farmer at the end of the canal used a combination of canal water with his saqia and pumping from a neighbor's well when there was not sufficient water in the canal. He applied relatively less water, but still more than the soil could store and the crop needed. The farmer on Mesqa 2 was unable to depend on the canal and thus had to use a pump and well for most of his irrigations. He applied less water than either of the other farmers. This was still more water then he could store in the soil, but less than the estimated crop requirements.

In each case, major interactions with the watertable appeared. This is because the total water stored was always less than the estimated water requirements. Irrigation efficiencies ranged from 14% to 46%. However, when the irrigation application was expressed as a percent of crop needs the values ranged from 38% to 171% for the near versus the far farmer, respectively.

From this analysis it appears that in El-Hammami there is a de facto combination of both surface and subsurface irrigation (Figure 13). When a farmer applies water to his land he not only recharges the soil deficit but adds a large volume of surplus water which flows laterally on the watertable to his neighbor's fields. Likewise when his neighbor irrigates, his surplus water flows under the first farmer's field. This provides both the hazard of a high water table and the benefit of some subsurface irrigation which contributes to the crops water requirements. Concurrently, during each 'on' period there is probably substantial subsurface flows from the canals across the watertable to further sub-irrigate all crops. Estimates show that most of the crops water requirements actually come from this watertable "subsurface" irrigation.

One problem with the interactive watertable is that it can provide for confusing soil moisture data in which the lower level samples before irrigation can contain more water than the after irrigation samples from the previous irrigation. This will depend on the relative timing of irrigation of the farmer and his neighbors versus the time samples are taken. The high watertable and extensive lateral subsurface flow in

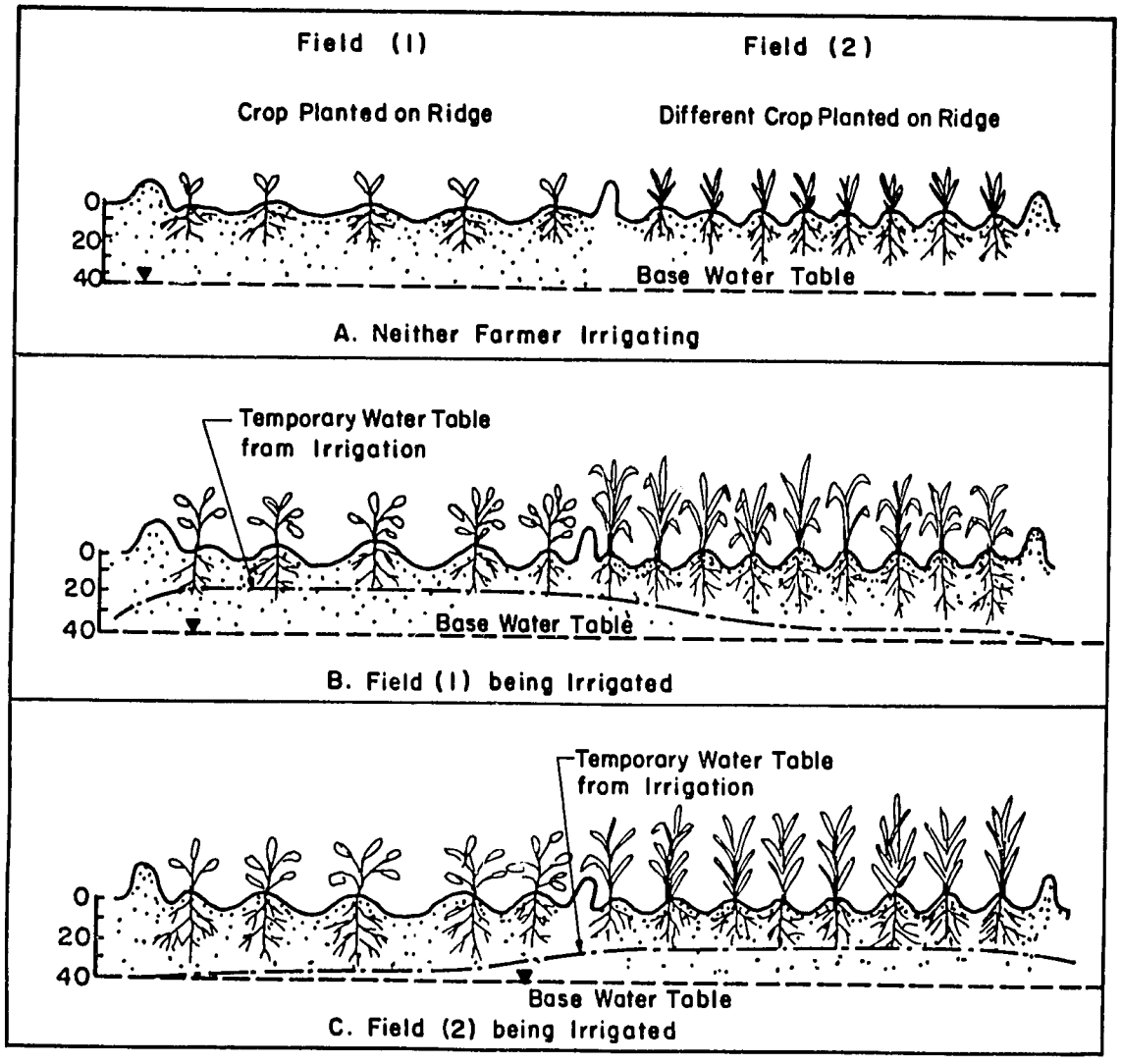


Figure 13. Movement of irrigation water on top of the watertable to neighboring fields. (Source EWUP PTR No. 74).

which neighbors irrigations interacted compromises any evaluation of individual farm irrigations. An accurate appraisal of El-Hammami irrigation would require some exceptionally complex analysis involving large areas.

The results of the study shows:

1. The sandy soils were not really suitable for surface irrigation. Other techniques need to be investigated.
2. Water was less equitably distributed through the system with the farmers with land near the beginning able to apply much larger quantities of water than those further away. The farmers further from the inlet had to rely more on pumping wells than the canal to get adequate water.
3. Farmers had to extensively over-irrigate just to get the water on their land. This resulted in a high watertable throughout the area.
4. Extensive amounts of subsurface flow resulted in de facto subsurface irrigation. Most of the crops actual consumptive use needs came from the watertable and subsurface irrigation.

## VII. SUMMARY

The soils in the EWUP study area were either heavy clay Vertisol related soils, or sandy Entisols. The Vertisols are generally very difficult soils to physically manage. However, they could be irrigated reasonable efficiently with minimum management. This was because the infiltration characteristics allowed for the replacement of the soil deficit and little more. Uniform applications were generally possible even with highly variable flow rates. The available water was considerably less then would be expected from a clay soil so irrigations had to be planned around a soil deficit of only 5 - 7 cm. Problems of canal maintenance in areas of significant cracking and heaving, soils, and surface drainage due to sealing suggest that canals lower than the farmers fields and lift irrigation are preferable to raised canals and gravity irrigation in these areas.

The sandy soils were not really suitable for surface irrigation. The infiltration rates were too high resulting in extensive conveyance losses. Distribution of water through the system was not equitable, and irrigation efficiency was very low. This results in a high watertable throughout the area. The high watertable in turn helps compensate for irrigation inefficiency by allowing for substantial lateral water movement and de facto subirrigation. Most of the plants water requirements appeared to have come from the subsurface water movement and the watertable.

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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 | $100 \times 10^4$ | 247.105 | 238.048 | 100.000 |
| 1 sq. mile | $259 \times 10^6$ | 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.)

## EGYPT WATER USE AND MANAGEMENT PROJECT

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| NO. | TITLE | AUTHOR |
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