The influence of quantity of irrigation water on the agro-hydro-salinity conditions of the soil using the SaltModM model with data from the Mashtul Pilot Area, Egypt.

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Abstract
The quantity of irrigation water can be of influence on the irrigation efficiency and/or sufficiency, the amount of percolation (leaching) water, the soil salinity, the depth of the groundwater table, and the discharge of the subsurface drainage system. In this articles simulations are made of the factors mentioned using the data of the Mashtul Pilot Area in the eastern Nile Delta, Egypt. The simulations are performed with the SaltModM model (the modernized version of SaltMod) which has previously been calibrated and validated for this area. The model uses a range of assumed irrigation practices to evaluate the values of the factors mentioned.

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1. Introduction

When the natural underground drainage of irrigated land in (semi-) arid regions is insufficient to leach the salts that are brought in with the irrigation water, the land can be affected by the twin problems of a shallow water table and a high soil salinity. The problems can be aggravated when groundwater moves upward into the rootzone. This groundwater can originate from canal water that infiltrates into the soil elsewhere, or from excess irrigation water that percolates downward, either in fields nearby or in higher-lying lands farther away (Figure l). As the water thus lost moves through the underground, it picks up salt and brings it to the already affected yields. Insufficient natural underground drainage can be corrected by artificial drainage systems consisting of ditches, subsurface channels (mole drains), and subsurface pipe drains, laid more or less parallel to the soil surface at some depth (0.5 to l.5 m and sometimes more), These systems are called horizontal drainage systems; they can work entirely by gravity but. if there is no free outfall through which to evacuate the water, pumps can be used. Insufficient natural drainage can also be corrected by a vertical drainage system, which consists of pumped wells.

It has been estimated that, world-wide, 52 million ha of irrigated land needed improved drainage systems (United Nations l977). In Egypt"s Nile Delta, almost l.4 million ha have so far been equipped with pipe drainage systems. This covers roughly two-thirds of the total cultivable area of Egypt (Abdel-Dayem 1988). Many new drainage projects are envisaged, and monitoring programs are being considered to evaluate the effectiveness and efficiency of the older drainage projects and to find out whether agricultural or technical drainage criteria need to be refined. New pilot areas are being planned for the further development of criteria.

With such investments at stake. salt-and-water-balance models can be instrumental in the planning, design, monitoring, and evaluation of the projects. SALTMOD is such a model. It was developed to make long-term predictions of the impact of water management programs (including drainage) on the height of the water table, and on the salt contents of the soil, the groundwater, and the drainage effluent. It can also assess the impact of re-used drainage water. It accommodates different kinds of agricultural practices such as rain-fed and irrigated agriculture, distinguishing in the latter between 'dry-foot' crops and submerged paddy fields. It can also simulate farmers' agricultural and water-management responses to changes in water table depth and soil salinity responses which can influence the salt and water balances.

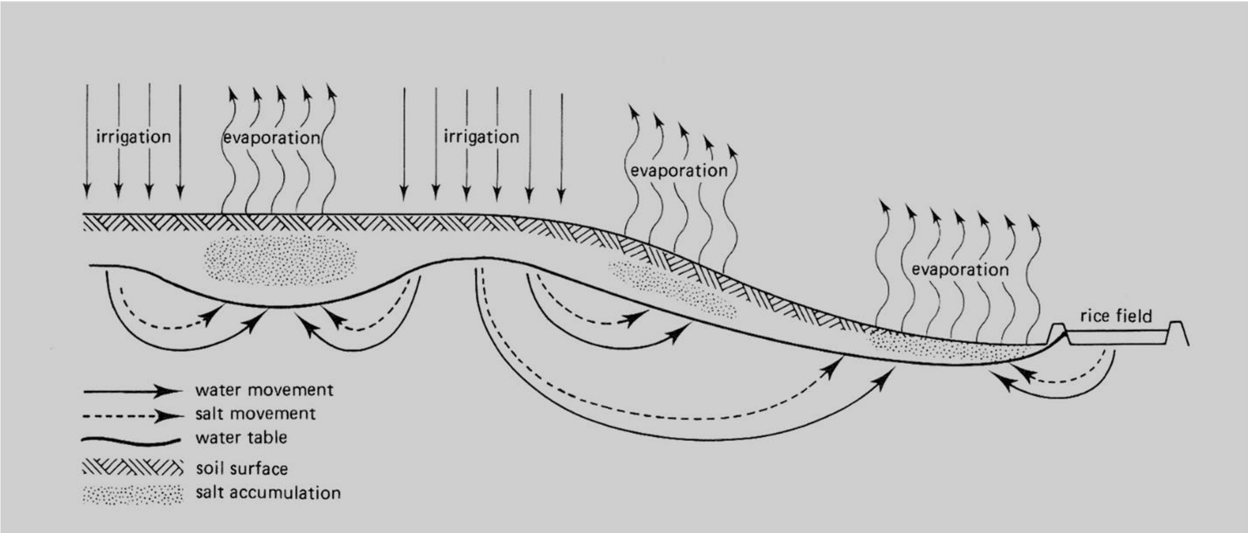


Figure 1*. Water and salt movements in irrigated soil.*

A more detailed description can be seen at https://www.waterlog.info/pdf/salintro.pdf

A list of international articles in which SaltMod is used can be found at https://www.waterlog.info/pdf/SaltModlist.pdf

2. Managing the input menu of SaltModM

The quantity of seasonal irrigation water can be entered in the input menu of SaltModM when clicking on the "Irrigation quantity" radio button as shown in figure 2.

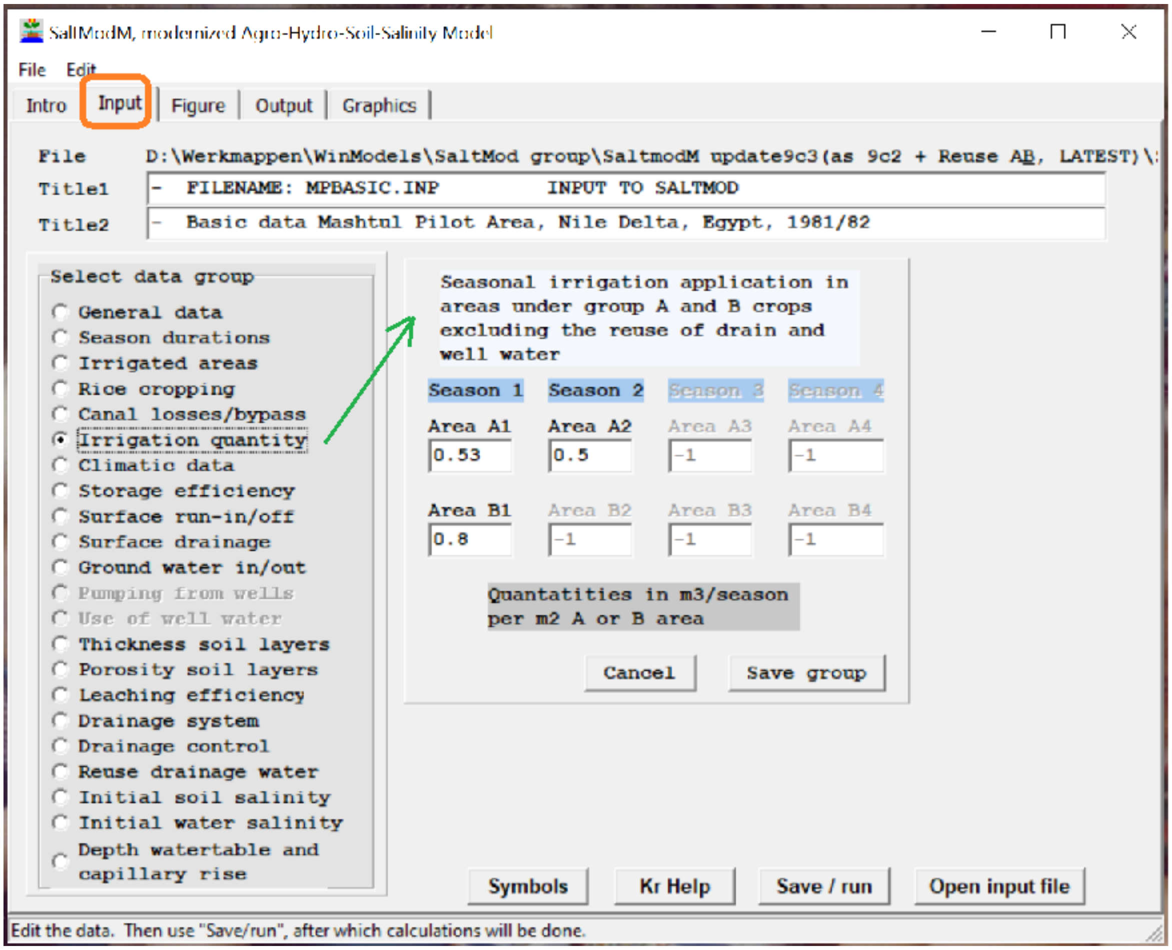


Figure 2. *Entering the seasonal irrigation quantities on the user interface of the input menu of SaltModM. In season 1 (summer), the main crops are maize and cotton which have been classified as A1-type crops cultivated in 80% of the area. In this season 20% of the area is under a submerged rice crop with a high irrigation intensity of 0.8 m^3/season per m^2 area, classified as B1-type of crop. In the second season (winter) the main crop is wheat classified as A2-type of crop and it is grown in the total area. The irrigated areas under the different types of crop are determined by clicking on the "Irrigated areas" radio button. The season durations (5 months in summer and 7 months in winter), can be found clicking on the "Season durations" radio button.*

The entire data set under all radio buttons can be viewed when downloading the free SaltModM model software from https://www.waterlog.info/saltmod.htm and opening the Mashtul input file in the "Data" subdirectory.

To study the data on the drainage system on can consult figure 4 in the article https://www.waterlog.info/pdf/SaltMod menu.pdf

For the purpose of finding SaltMod responses (simulations) to different amounts of irrigation water, the following quantities have been employed to area A1 (80% of the total area with the summer crops maize and cotton) and A2 (100% of the total area with the winter crop wheat): 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0,65 and 0.70 m^3/season per m^2 area.

The maximum crop consumptive water use (potential evapotranspiration) use of these crops is 450 mm per season (to be entered with radio button “Climatic data”, figure 2, where it can also be seen that the rainfall is negligibly small).

At the lower seasonal irrigation quantities, the storage efficiency (see figure 2) ranges from 100% for the smaller seasonal amoutns of irrigation water to 85% as the smaller irrigation amounts are almost entirely stored in the rootzone. At higher irrigation gifts the storage efficiency is maintained at 80% . In these cases its influence is limited as downward percolation of part of the irrigation water is mainly determined by the excess of irrigation over the maximum possible crop consumptive use of the water.

The runs with the model are made for a period of 10 years and the results in the figures further down are given for the 10th year.

3. Simulations

For the selection of output groups see Appendix I
For copying the table with data of an output group to the clipboard see Appendix II

3.1 Irrigation efficiency and sufficiency

The influence of the amount of irrigation water for the A1-type crops in season 1 on the irrigation efficiency (formally called field application efficiency) and sufficiency are shown in figure 3 and 4 respectively. The field irrigation efficiency is defined as the maximum possible crop consumption of the water by evapotranspiration (to be entered via “Climatic data”, figure 2) divided by the amount of irrigation water, while the sufficiency is defined as the actual crop consumption divided by the maximum possible consumption.

When the irrigation is more than the maximum possible crop consumption, the field irrigation efficiency is less than one. In practice this efficiency is in the order of 50 to 70% For irrigation in arid zones a certain amount of water is required for downward percolation of irrigation water (see section 3.2) to the water table for salt leaching of the soil to maintain a proper salt balance in the soil and keep the soil salinity below the level at which the crop production starts to decline as a result of too high a soil salinity which is damaging to the crops. Hence, in those zones, the field irrigation efficiency needs to be less than 100%

When the irrigation, less the percolation losses (see figure 5), is smaller than the maximum possible crop consumptive use then the irrigation sufficiency is less than 100% meaning that there is a shortage of irrigation water and that the crop yield may decline.

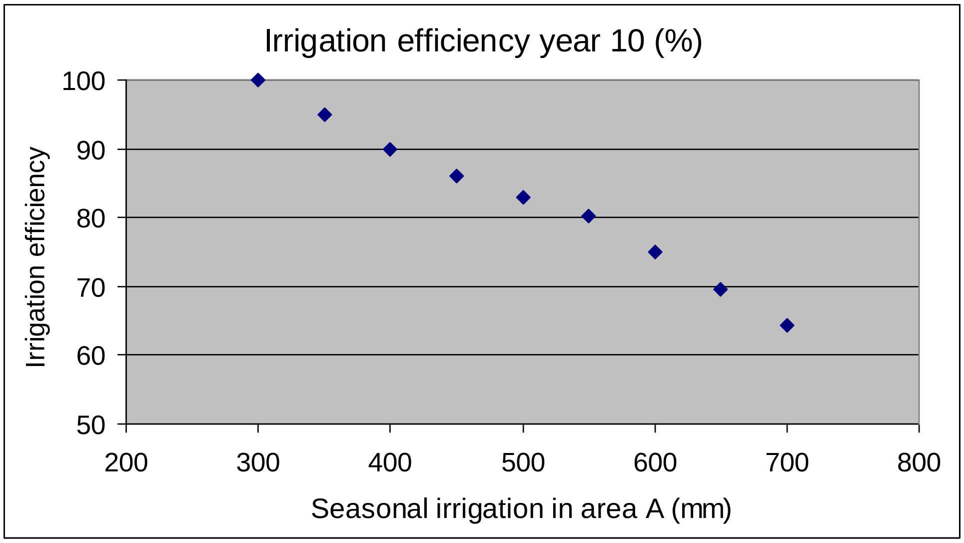


Figure 3*. Field irrigation efficiency versus seasonal irrigation. The initial efficiency is 100% owing to the small irrigation gift that is completely stored in the root zone and consumed by the crop. At higher irrigation gifts, the efficiency value goes down as there is an increase of deep percolation losses on account of a storage efficiency of the soil less than 100%. When the irrigation gifts in season 1 exceed 550 mm the efficiency descends further because the percolation losses increase.*

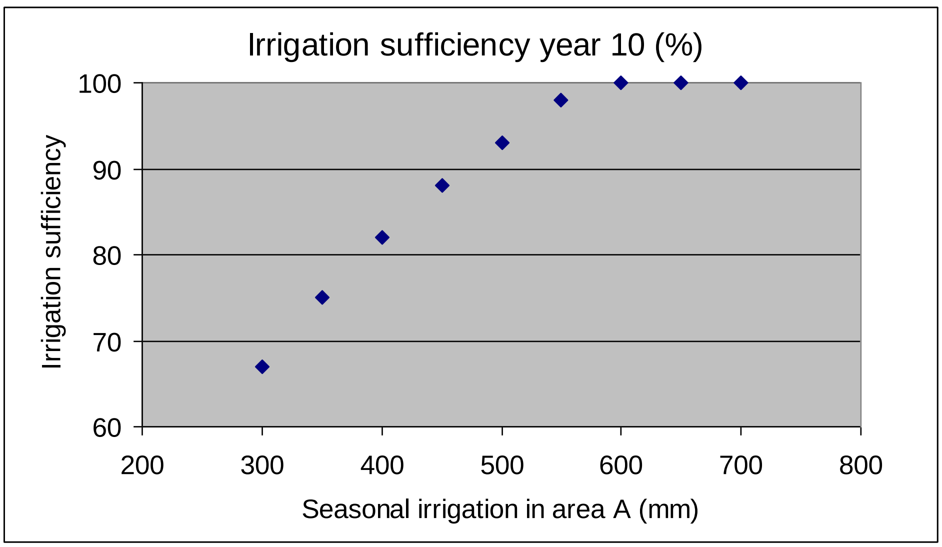


Figure 4*. Irrigation sufficiency versus total irrigation in season 1. Initially the sufficiency is low as the amount of irrigation is not enough to cover the optimum crop consumptive use by evaporation. After a seasonal irrigation application of 550 mm, the sufficiency becomes 100%*

3.2 Percolation (leaching) of the soil and soil salinity

The percolation losses of the irrigation water to the underground and/or to the subsurface drainage system increase with increasing seasonal irrigation supplies as illustrated in figure 5.

The percolation losses are inversely related to the soil salinity (figure 6) because the percolation acts as a salt leaching instrument.

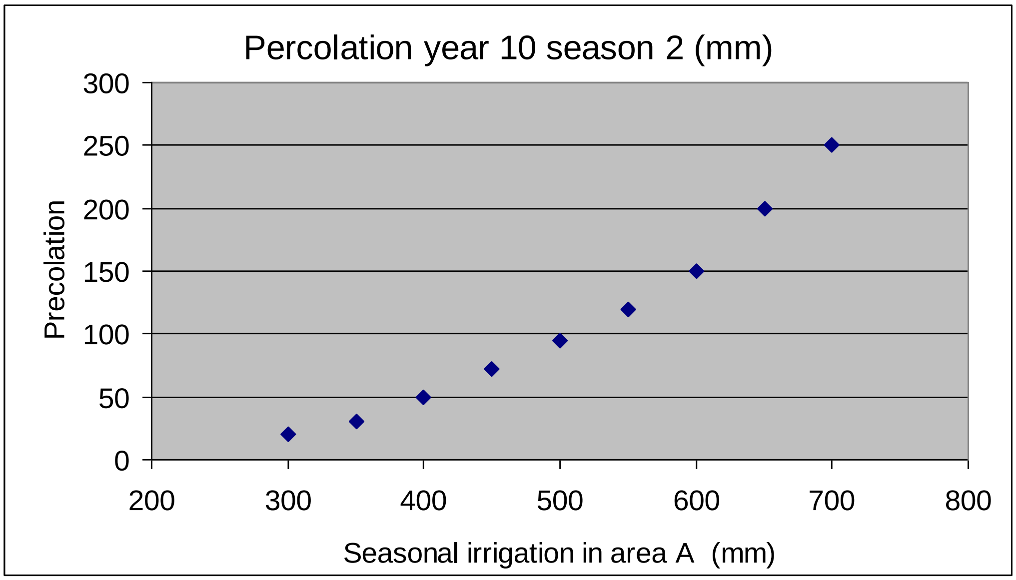


Figure 5*. Percolation losses to the underground and/or to the subsurface drainage system versus the seasonal irrigation amount. Initially the percolation is very small as practically all of the irrigation water is stored in the rootzone and consumed by the crops. At higher irrigation applications the percolation increases strongly while at the same time the field irrigation efficiency reduces (figure 3).*

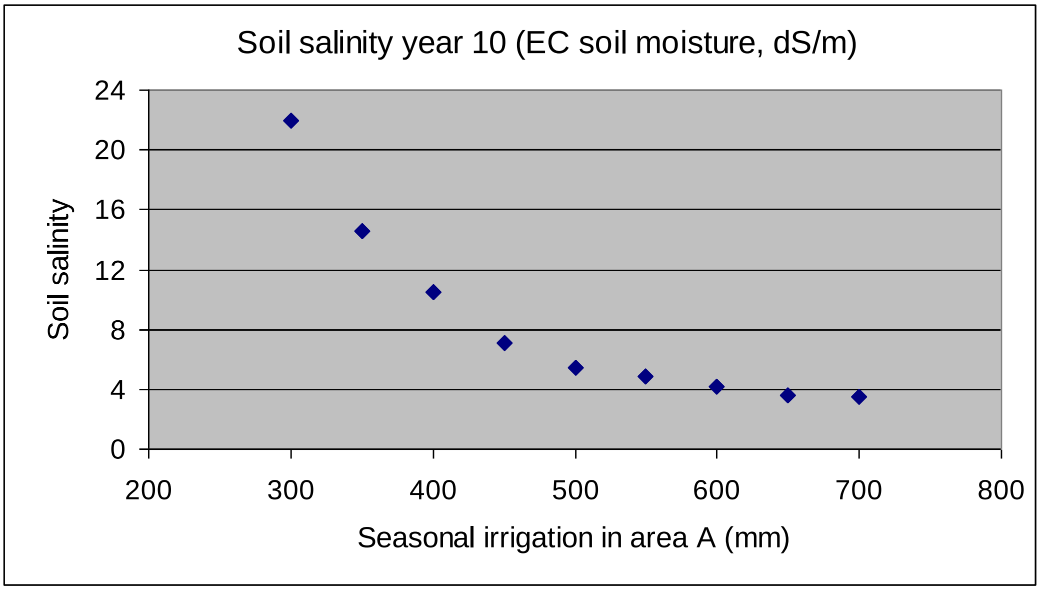


***Figure 6**. Soil moisture salinity (at field capacity) in terms of electric conductivity (ECsm) versus seasonal quantity of irrigation water. The initial value of ECsm is 20 dS/m. It gets higher than the initial value (20 dS/M) when the irrigation is only 300 mm. The reason is that there is little percolation (leaching, figure 5) to remove salts from the soil while almost all irrigation water evaporates, leaving salts brought in with the irrigation water behind. With higher irrigation gifts, the soil salinity is lower then the initial value reducing to about 4 dS/m at the highest irrigation quantities.*

The ratio between ECsm employed in figure 6 (when the soil moisture is at field capacity) and the often used ECe (the EC value of the extract of a soil super saturated with water) is about 2:1 (Oosterbaan 1990). Many crops suffer yield reductions when the ECe value is greater than 4 dS/m, i.e. the ECsm value is greater than 8 dS/m.

To maintain an acceptable soil salinity, the seasonal irrigation in the A1 (summer, 5 months) and A2 (winter, 7 months) areas the seasonal irrigation should be at least 450 mm.

A complement of figure 6 is presented in the appendix III.

3.3 Depth of the groundwater table and drain discharge

It is understandable that the water table gets shallower at higher irrigation applications because the subsurface drainage system needs higher hydraulic heads at higher drain discharges to evacuates the excess irrigation over crop consumptive use (evaporation), see figure 7.

When the water table gets shallower and the hydraulic head (the height of the water table above drain level, with drains installed at 1.2 m depth) increases, the drain discharge augments (figure 8).

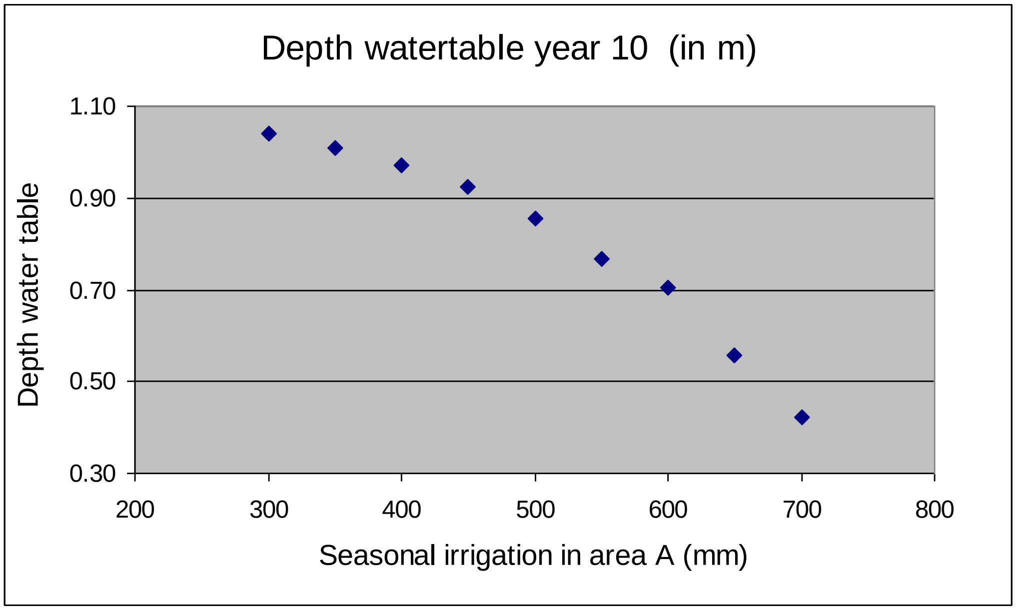


Figure 7. *Depth of the water table versus seasonal irrigation in area A. The higher the amount of irrigation water applied, the shallower the level of the water table becomes. As the drainage system has been installed at a depth of 1.2, the hydraulic head above the drains can be found from this figure subtracting the depth of the water table from 1.2 With an irrigation application of 700 mm per season the water table depth is only about 0.4 m which can be harmful for the crop (Oosterbaan 2021a).*

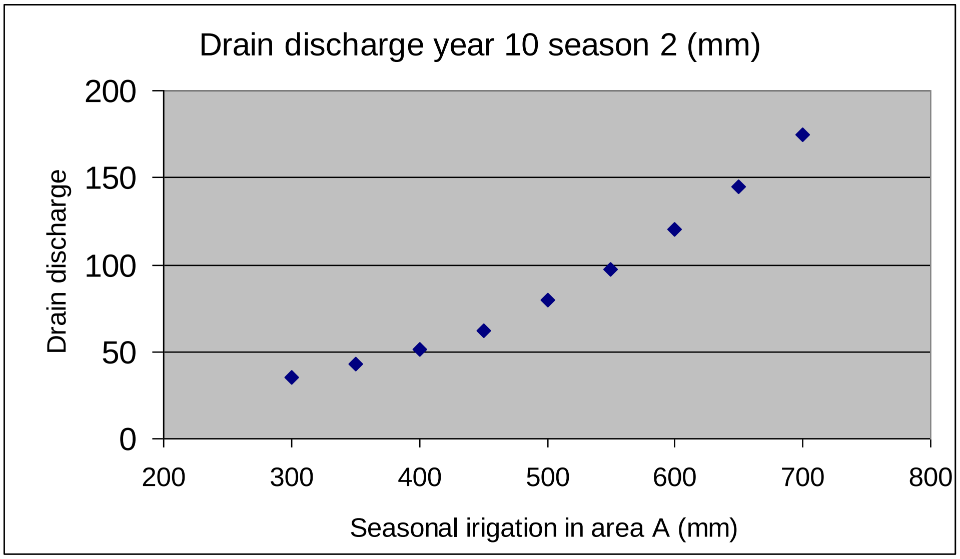


Figure 8. *Drain discharge versus seasonal irrigation. As the irrigation and the downward percolation to the water table increase (figure 5), while the water table gets shallower (figure 7), the drain discharge becomes larger. The drain discharge is somewhat less than the percolation (figure 5) owing to the presence of a small amount of natural drainage into the aquifer (see radio button "Ground water in/out", figure 2).*

4. Conclusions

The optimal seasonal field irrigation gift in the A1 area (summer, maize and cotton, 5 months) and the A2 area (winter, wheat, 7 months) appears to be around 500 mm.

With this amount of irrigation water, the EC value (soil salinity) of the soil moisture is at most 5 dS/m corresponding to an ECe value of 2.5 dS/m (figure 6), which is a safe value for almost all crops (Oosterbaan 2021b).

Also in that case the irrigation sufficiency is 95% (figure 4) ,close enough to 100% to avoid crop yield losses due to scarcity of irrigation water.

Further the irrigation efficiency is relatively high (80%, figure 3), keeping in mind that a higher efficiency is difficult to achieve in practice and that the losses of irrigation water help, by leaching of salts, in keeping the soil salinity at an acceptably low level.

Finally, with the existing drainage system, the seasonal average depth of the water table is between 0.8 and 0.9 m (figure 7), a safe value for almost all kinds of crop (Oosterbaan 2021a).

A seasonal field irrigation gift in the A1 area (summer, maize and cotton, 5 months) and the A2 area (winter, wheat, 7 months) of 450 mm instead of 500 mm also seems good.

5. References

Abdel-Dayem, M.S. l988. Development of Land Drainage in Egypt. In: Proceedings Symposium 25th International Course on Land Drainage. J. Vos (Ed). Publ. 42, ILRI. Wageningen.

United Nations. 1977. Water for Agriculture. ln: Water Development and Management. Proceedings of the United Nations Water Conference. Part 3. Mar del Plata.

Oosterbaan, R.J. 2003. This paper discusses soil salinity. https://www.waterlog.info/pdf/salinity.pdf

Oosterbaan, R.J. 2021a. Crop Yield versus Depth of the Ground Water Table, Statistical Analysis of Data Measured in Farm Lands Aiming at the Formulation of Drainage Needs

Oosterbaan, R.J. 2021b. Using the Free Partial Regression Software (PartReg) to Determine the Maximum Tolerance of Crops to Soil Salinity as Measured in Farm Lands

Further reading

SALTMOD; description of principles, user manual, and examples of application, Version 1.1

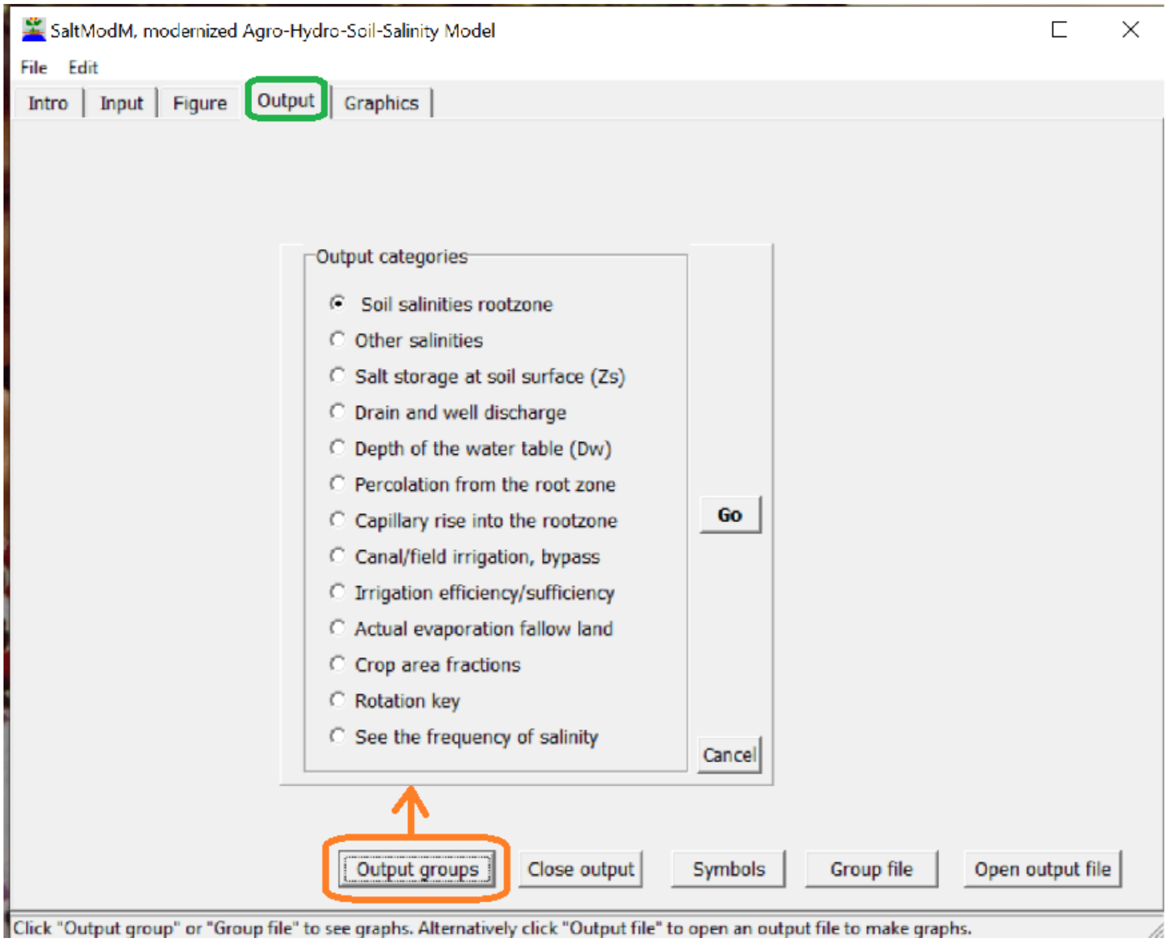
Saltmod: a Tool for Interweaving of Irrigation and Drainage for Salinity Control.

The role of farmers' responses in the Agro-Hydro-Salinity model SaltMod regarding water management, cropping patterns, or crop rotations, in the case of inadequate irrigation, drainage (water logging) problems, and/or excess soil salinity

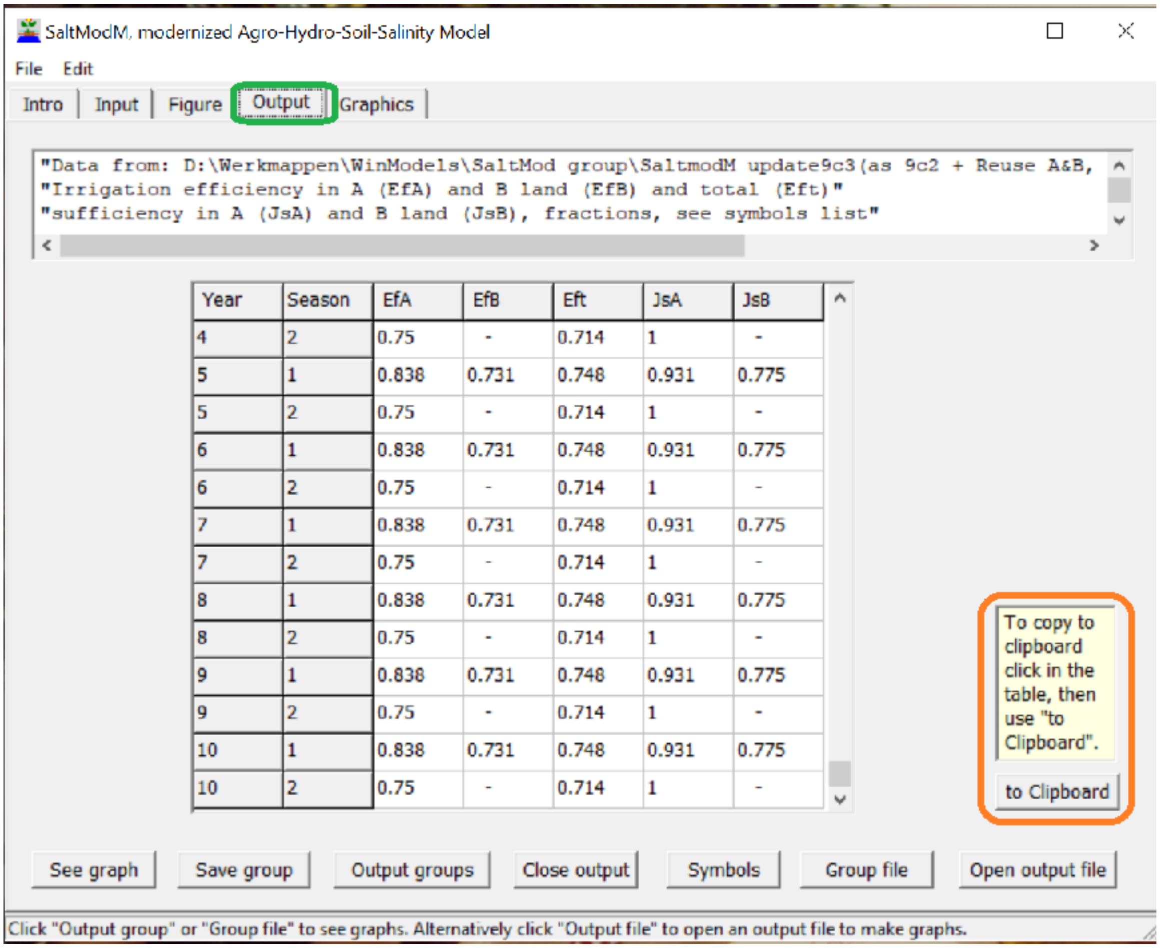
SALTMOD Model Validation and Application in Segwa Minor Canal Command Area

6. Appendices.

Appendix I. Selection of output groups



Appendix II. Copy table to clipboard, e.g. for use in Excel



Year	Season	EfA	EfB	Eft	JsA	JsB
4	2	0.75	-	0.714	1	-
5	1	0.838	0.731	0.748	0.931	0.775
5	2	0.75	-	0.714	1	-
6	1	0.838	0.731	0.748	0.931	0.775
6	2	0.75	-	0.714	1	-
7	1	0.838	0.731	0.748	0.931	0.775
7	2	0.75	-	0.714	1	-
8	1	0.838	0.731	0.748	0.931	0.775
8	2	0.75	-	0.714	1	-
9	1	0.838	0.731	0.748	0.931	0.775
9	2	0.75	-	0.714	1	-
10	1	0.838	0.731	0.748	0.931	0.775
10	2	0.75	-	0.714	1	-

Appendix III. Soil salinity all years

The figure below shows the development of salinity of the soil moisture from year to year to complement the data shown in figure 6 where only the salinity in year 10 is given. The irrigation quantity is indicated in m^3/ha per season or mm/season for A-type crops in season 1 and 2.

The graph shows that for seasonal irrigations of A-type crops of 450 mm and more the salinity reaches an equilibrium in year 10 or earlier after coming down from an initial value of 20 dS/m in year 0 and that the land reclamation is completed. With irrigations of 700 mm/season the equilibrium is already reached in year 3. For 600 mm/season the equilibrium is found in year 5, for 500 mm/season in year 7 and for 450 mm/season in year 9.

For irrigation with only 300 mm/season the soil salinity increases with time.