MAPPING OF SOIL SALINITY PREDICTED BY DRAINMOD FOR DRAINED AND UNDRAINED CONDITIONS IN IRRIGATED LANDS

Sema Kale[1], **Armagan Karabulut**[2]
[1]Suleyman Demirel University, Turkey
[2]Soil, Fertilizer and Water Resources Central Research Institute, Turkey
semakale@.sdu.edu.tr

Abstract
The purpose of this study was to predict and compare salt accumulation in the soil profile under drained and undrained conditions. The water management simulation model, Drainmod (Ver. 6.1) was used to determine the optimal drainage system design parameters, which will decrease soil profile salinity and provide maximum crop yields in Ankara-Bala Basin of Turkey. Soil sampling points were coordinated with the Global Positioning System (GPS). Soil, crop and site parameters were obtained as an input. The model was run for 5 years from 2005 to 2010 to simulate optimum drainage design parameters (drain depth, drain spacing) while controlling soil salinity in the root zone. Soil water conditions and soil salinity level were simulated for crop rotation of corn (*Zea mays*) and winter wheat (*Triticum*). Yield of individual crops was predicted for each growing season. The results of the simulations were analyzed to identify alternatives of subsurface drainage system that would satisfy maximum crop productions. According to the simulation results, the drain spacing of 130 m and drain depth at 160 cm are recommended for Bala Basin. Soil salinity maps were created for undrained and drained conditions. Results showed that the soil salinity level and salinity stress can be reduced and yield increased by installing a drainage system.
Key words: soil salinity, Drainmod, drainage, mapping.

Introduction

Under most arid and semi-arid climate, as is the case with almost all Mediterranean countries, drainage improvement works are needed to alleviate waterlogging and salinity problems caused directly, or indirectly, by irrigation practices. And more often than not, subsurface drainage systems are needed to reclaim these areas for viable agricultural production. The main cause for waterlogging and soil salinization is usually water seepage from the irrigation canals that lose a lot of water through their unlined banks and beds (Ayers et al., 1987). Furthermore, frequent irrigation applications also tend to keep the water table close to the soil surface, and this combined with normal fertilizer applications causes a slow salinization of the root zone, and affects crop yields. The natural drainability of these soils, as such, cannot cope with this man-caused problem. If this phenomenon is not checked on time through the installation of interceptor drains and subsurface drainage systems, most of the farmland that was very productive at one point becomes unproductive. Then the farmers either have to change their cropping practices or, in some cases, they cannot grow any crop at all (Gupta et al., 1993).

Waterlogging problems in arid and semi-arid regions are usually associated with high salinity problems. Salinity build-up in the soil has an adverse effect on crop yield because of many factors. The processes involved are complicated, and interrelated with such factors as crop species, soil properties and salinity of irrigation water and subsurface drainage (Kandil et al., 1995). Computer simulation models are developed to describe this comprehensive system. Drainmod is one of the well known drainage simulation models used to characterize the response of the soil water regime to various combinations of surface and subsurface water management.

Bala basin opened for irrigation in 1970. Until mid-1980 the irrigation rate was not more than 50% because of the inadequate system component, field problems or uneducated farmers. In recent years, the irrigation rates are much higher than before, however, farmers meet different kind of problems at this time. The most important problem is that no efficient drainage system exists in this area. So a high water table, waterlogging and soil salinity problems get increased day by day because of the irrigation. The aim of this study was to estimate the optimum drainage system design parameters to prevent soil salinity, water logging and insufficient yield. And additionally, to show the initial and simulated salinity results to the decision makers by creating soil salinity maps.

Materials and Methods

Experimental sites are located in Ankara Bala - the Central Anatolia region of Turkey. The average annual rainfall is about 350 mm and annual pan evaporation is 1255 mm for the region. The field (39°25’N, 33°23’E) experiment was carried out on 1475 ha plot area. Irrigation waters are diverted from Kesikkopru Dam Lake on the Kızılırmak River. Irrigation water quality is high saline and non-alkaline. Forty one soil sampling points were coordinated with GPS on the basin. Soil, crop and irrigation inputs were obtained from those points as an input for the model. Sampling points and geographic conditions are shown in Figure 1.

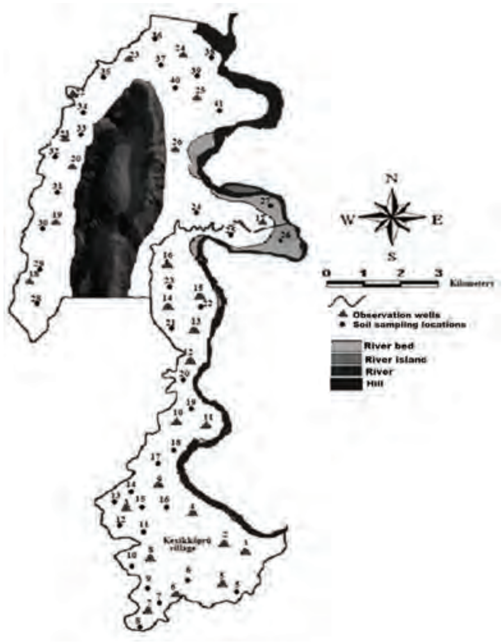

Figure 1. Sampling points in the experiment area.

Table 1

Soil textures and hydraulic conductivity of the field site

Soil depth, cm	K (cm h^{-1})	Texture
0-23	0.59	C
23-54	0.33	C
54-102	0.54	C
102-140	0.20	C
140-180	0.45	C

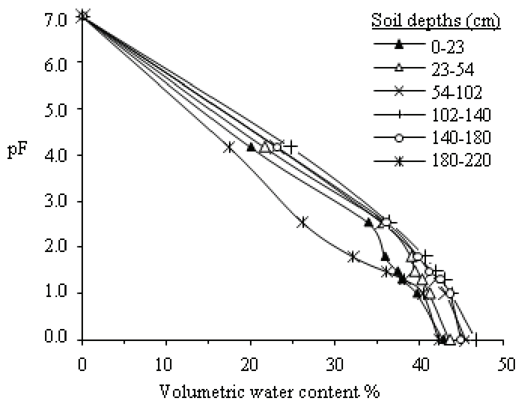

Figure 2. Soil water characteristics (pF curves).

Drainmod was used to simulate the drainage system design effects on soil profile salinity and crop yields of wheat (*Triticum)* and corn (*Zea mays)*. Simulation results were combined with Geographic Information System (GIS) and created the soil profile salinity (for different depths) maps.

Drainmod, which was developed by R.W. Skaggs, is a water management model based on a water balance for a section of soil on a unit surface area that extends from the impermeable layer to the surface and is located midway between adjacent drains. The model can be used to predict the water table depth, subsurface drainage, evapotranspiration and surface runoff as affected by the various drainage, weather and soil property data. The research project was carried out to calibrate and validate the model in the same catchment (Kale, 2004).

The model requires soil, weather, crop, salinity and irrigation inputs. Soil inputs are initial soil water content, soil water content versus pressure head (pF curve), lateral conductivity of each soil layer. Disturbed and undisturbed soil samples were taken in the field for laboratory analysis. Soil water characteristic was determined by active standard method (D6836-02) on soil cores. The lateral conductivity was found by Auger Hole method (Van Beers, 1958) in the field. Impermeable layer was measured at 4 m. Soil texture and hydraulic conductivity are given in Table 1.

The soil water characteristic data for the predominant soil type were determined on soil cores using pressure plate tests, which allowed a calculation of the volumetric water content at suction pressures of 10, 20, 33, 63, 346, and 1500 kPa (pF curve in Figure 2).

Weather inputs are daily maximum and minimum air temperature, hourly rainfall amounts, Potential evapotranspiration (PET). Climate data were obtained from Bala meteorology station. PET was calculated by Penman-Montheid method. PET data were used directly in the model.

Model simulation can be run with a relative yield input data set or without specifying a relative yield input data set, and crop inputs are rooting depths, planting delays, excess soil water stress, deficient soil water stress and salinity stress.

While more research is needed to determine crop parameters, they are directly available for some crops, such as corn (Evans and Skaggs, 1993) and can be estimated, based on data in the literature FAO, Irrigation and Drainage Paper 33 (Doorenbos, 1979) for others. For this region the wheat planting dates are generally 15-20 October, harvesting dates 15-20 July, planting dates of corn are 10-15 May and harvesting dates 15-20 October. According to the planting and harvesting date, two periods are specified in the model - a spring and fall period - for calculating trafficable conditions in the field. The equation (1) was used for computing crop relative yields. .

$$YR = Y/Y_o = YR_p * YR_w * YR_d * YR_s \quad (1)$$

Where YR is the relative yield, Y is the yield for a given year, Yo is the optimum long term average yield,

YR_p is the relative yield that would be obtained if only reduction due to planting date delay is considered, YR_w is the relative yield if only reductions due to excessive soil water conditions are considered, YR_d is the relative crop yield if the only reductions are due to deficient soil water and YR_s is the relative crop yield if the only reductions are due to soil salinity.

An excessive accumulation of salts in the soil profile causes a decline in productivity. Some plants can survive in a salt affected soil, but many are affected to varying extent depending on their tolerance to salinity. Even the same crop has different tolerance levels of salinity for its different growing stages. E.V. Mass and Hoffman G.J. (1977) indicate that each increase in soil salinity (salinity was expressed in terms of the electrical conductivity of the saturated paste) in excess of the concentrations that initially begin to affect yield will cause a proportional decrease in yield. They have proposed equation (2) to express this effect.

$$YRs = 100 - b^* (EC_e - a) \quad (2)$$

Where RY is the relative crop yield (%), ECe is the salinity of the soil saturated extract (dS m^{-1}), a is the salinity threshold value for the crop representing the maximum ECe at which a 100% yield can be obtained (dS m^{-1}) and b is the yield decrement per unit of salinity, or % yield loss per unit of salinity (EC_e) between the threshold value (a) and the EC_e value representing the 100% yield decrement. The threshold value depends on the crop tolerance to salinity. The coefficients a and b for corn and wheat were 1.7 dS m^{-1} and 12 dS m^{-1} and 6.0 dS m^{-1} ve 7.1dS m^{-1}, respectively (Maas and Hoffman, 1977).

The order of crops grown in the rotation was corn and winter wheat. The simulations were performed for 5 years (from 2005 to 2010). An effective rooting depth as a function of time is used in Drainmod to define the zone from which water can be removed to meet the ET demand. The effective root depths for crops were measured in the growing season. Relative yield to stresses due to planting delay, excessive and deficient soil water conditions along with stress-day factors were taken from R.O.Evans et al., (1990), R.O.Evans and R.W.Skaggs, (1992), R.W.Skaggs, (1982) and R.M.Seymour (1986).

Initial soil salinity, irrigation water salinity, dispersion coefficient and crop salt tolerance parameters are required as salinity input in the model. Dispersivity has been derived using the S.P.Neuman (1990) equation (3).

$$\alpha_L = 0.0175\ L^{1.46} \quad (3)$$

Where a_L is dispersivity and L is the field scale. Dispersivity was calculated as 4.13 cm.

The timing of irrigation requires the day and month when the irrigation is initiated along with the irrigation interval. The starting and ending hours of irrigation are also specified. The total irrigation water requirement for corn is 590-600 mm in the Bala basin. According to the carried out irrigation projects on this area, the irrigation scheduling for corn and wheat are given in Table 2.

Table 2

Irrigation date and applied irrigation water amount (mm)

Crop	Irrigation date	Irrigation water
Corn	23 June	43.4
	15 July	171.6
	6 August	132.0
	28 August	132.0
	19 September	113.1
Wheat	25 October	88
	15 April	88 (fine textured soils)
	20 May	179
	15 June	79

In this study, the model was used to compare the soil salinity changes in soil profile with the installed drainage system (predicted) and without drainage system in the field. Generally farmers are using 100-150 mm more water than required. Excess water applications are assumed as leaching water. So excess water applications are causing an increasing water table depth in the soil profile. On average 125 mm of leaching water amount was added to the irrigation water. Thus, these simulation results will show that differences between the soil salinity level on soil profile for farmer irrigation applications with and without drainage.

Soil salinities were continuously simulated for crop rotation of corn and wheat during a 5 year period. Yields of individual crops were predicted for each growing season. Simulations were made for each soil sampling points (40 points). The model was run in the years from 2005 to 2010. Simulation was made for six drain depths (from 100 cm to 200 cm with 20 cm interval) and ten drain spacing (from 40 m to 220 m with 20 m interval) using by analysis option of the model.

Results and Discussion

In the experiment site there is no big drainage problem in the winter-time due to the semi-arid climate conditions. Generally in this region evapotranspiration is high and rainfall is not enough for plant water requirement. Because of that irrigation is definitely essential for crop production. Irrigation water applications by farmers are not conscious in the experiment site. Because of that, water table level is getting up in irrigation seasons. Depending on the irrigation without drainage, soil salinity also is increasing and accumulating in the soil profile.

The simulated wheat yield results for almost all points (except sampling point number 10 where the soil salinity level was much higher than the threshold value so the yield was very low without enough leaching water) showed that crop yields were not affected by salinity stress.

Results for corn relative yields indicate that soil salinity level in the root zone caused a 10-40% drop in yield. Soil salinity level of sampling point numbers 10, 28 and 41 was still high for corn production after installed drainage systems with an existing condition. Corn yields were less than 30% for those points. Stress due to excessive and deficit soil water conditions did not limit yields too much. Relative corn yield results are showed in Figure 3.

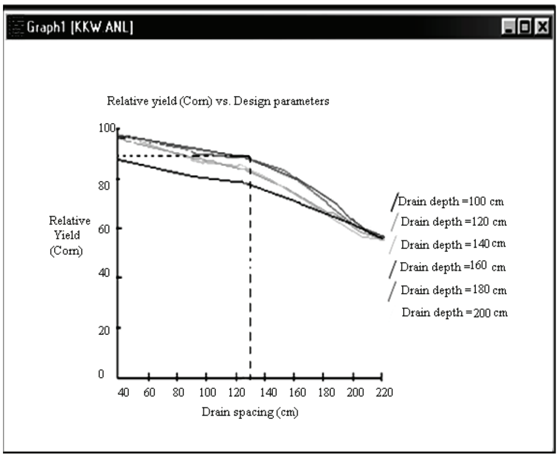

Figure 3. Relative corn yield results.

According to simulation results; any reduction was not observed on wheat yield for different drainage

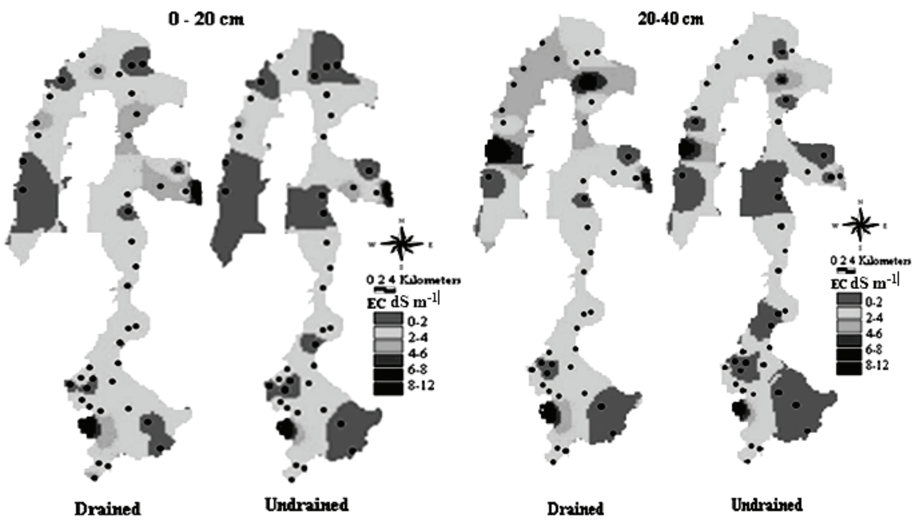

Figure 4. Soil salinity level for 0-20 cm and 20-40 cm soil depths with and without the drainage system.

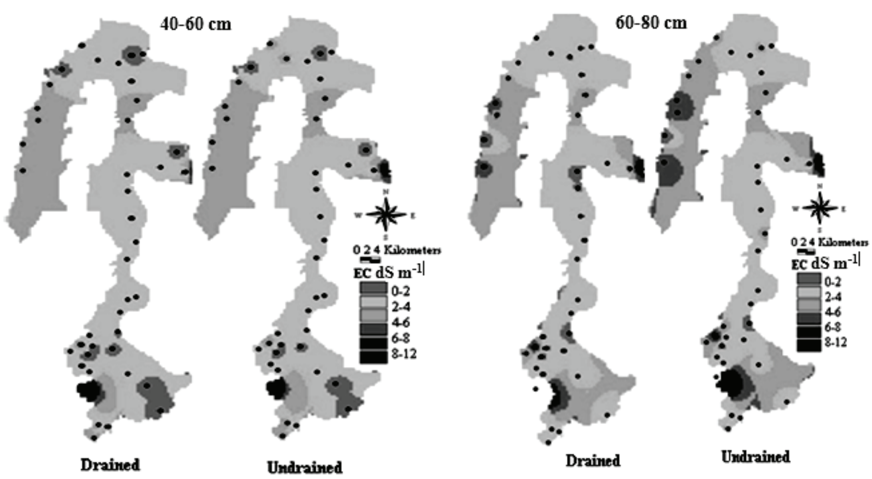

Figure 5. Soil salinity level for 40-60 cm and 60-80 cm soil depths with and without the drainage system.

design parameters. Because of that only corn yield results were taken into consideration for evaluation. Optimum drain depth of160 cm and optimum drain spacing 130 m were accepted for Bala Basin, according to corn yield results. Those drainage design parameters provide 90% corn yield and 100% wheat yields.

At the end of the study, the soil salinity simulation results of optimum drainage system design were compared with the field soil salinity values. Simulated and measured data were used to create salinity situation maps of the basin with the drainage system and without it. Created measured soil salinity and simulated soil profile salinity maps for 0-20 cm and 20-40 cm soil depths are presented in Figure 4 while those between 40-60 cm and 60-80 cm soil depths are shown in Figure 5.

Results showed that soil salinity diversity changed after installed drainage system. Soil salinity level decreased at almost all depths. Drainage systems were effective on soil salinity decreases, especially at 0-20 cm and 20-40 cm soil depths.

Conclusions

The results of the simulations were analyzed to identify the effects of subsurface drainage system that would satisfy maximum crop production. According to the simulation results, the drain spacing of 130 m and drain depth at 160 cm are recommended for Bala Basin. Results showed that soil salinity level and salinity stress can be reduced and yield increased by installing drainage systems. Results of simulations presented herein clearly demonstrate the interdependence of drainage requirement and soil salinity. This supports the often stated proposition that drainage, irrigation and salinity for arid lands should be considered a component of water management system and that design of each component should depend on the others.

According to the model predictions, if the current conditions remain without a drainage system in this basin salinity will be very a important factor for limiting crop productivity. Created maps provide a visual tool for evaluating the potential impact of salinity on soil profile, thereby providing knowledge to make management decisions with the aim of minimizing environmental impact without reducing future agricultural sustainability. The greatest attention must be given to reduction of salt loading either through the installation of drainage systems or changes in irrigation systems and management strategy.

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