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Full Length Research Paper

Impact of drained and un-drained soil conditions on water table depths, soil salinity and crop yields

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The purpose of this study was to determine the comparison of salt accumulation in soil profile and crop yields under drained and un-drained conditions. Current field conditions were used to represent poorly drained conditions where drainage system was not installed yet. Simulations were performed to illustrate well drained condition using the water management simulation model while controlling soil salinity in root zone. To put forward drainage system impacts; soil salinity and relative crop yields for well drained conditions were compared to poorly drained conditions. Soil, crop and site parameters were obtained from coordinated 40 soil sampling locations where dry bean, winter wheat and fallow crop rotations were applied. Results of the study showed that water table decreased rapidly after installing proper drainage system. Percentage of salt decreases in soil profile occurred by 24.1, 37.9 and 14.4% for wheat, bean and fallow locations respectively with adequate drainage conditions. On the drained soils, the relative yield of the winter wheat was higher by 11.2%, on the average, whereas that of bean was higher by 24.7%. Overall the net impact of yield enhancement due to drainage was about 36%. This shows the positive impact of drainage system on crop yields in this area.

Key words: Drainage, soil salinity, crop yield, water table, computer model.

INTRODUCTION

The aim of agricultural drainage systems is to increase yields and the reliability of production. The goal is to have high crop yields with the minimum investment of energy, water and other resources. Undermost 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. Furthermore, frequent irrigation applications also tend to keep the water table close to 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 large 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 developed to describe this comprehensive system. Field work as well as literature review (Goossens et al., 1994; Halverson and Rhoades, 1974; Rhoades, 1975; Kovda, 1975) showed that there is a close relation between soil salinity and the soil drainage conditions. It can be stated in a general way that the more poorly the drainage conditions are the higher the electrical conductivity of the soil will be. The problem of soil salinity is interconnected with the waterlogging status

Figure 1. Location of experimental field.

of the soil. Drainmod (Ver. 6.1) is one of the well known drainage simulation model to characterize the response of the soil water regime and salinity changes to various combinations of surface and subsurface water management (Kandil et al., 1992). It can be used to predict water table depth, subsurface drainage, evapotranspiration and surface runoff affected by the various drainage, weather and soil property data. Kesikkopru basin was opened to irrigation in 1970. Until mid-1980 irrigation rate were not more than 50% because of the inadequate system component, field problem or uneducated farmers. Recent years, irrigation rates are much more than before but at this time farmers faced to face different problems.

The most important problem in this area is where there is no efficient drainage system. So high water table, waterlogging, soil salinity problems are getting increase day by day because of the irrigation. The aim of this study is to determine impact of the drainage system on soil salinity changes on soil profile, water table depths and wheat and dry bean crop yields comparing with adequate drainage conditions and insufficient drainage. End of the study salinity maps were created for drained and un-drained conditions. These maps will be a useful tool for the decision makers to settle out future projections about water management.

MATERIALS AND METHODS

In the experiment site; subsurface drainage system was installed in 1998; only 150 ha parts of 1500 ha are irrigated area (1350 ha is still un-drained). In this study, drained and un-drained soil conditions were compared to put forward drainage system impacts on salt accumulation in soil profile and crop yield in basin scale. Current fields where drainage system was not installed yet, so waterlogging and soil salinity were the main problems that were assumed as poorly drained conditions (un-drained). Plants were affected by both shallow water table and high soil salinity level. Drainmod (Ver. 6.1) computer model was performed with optimum drainage design parameters which were obtained from previous project carried out on experimental area to illustrate well drained soil conditions (Kale, 2011). Forty different soil sampling locations were coordinated in 1350 ha study area. Model was run to simulate crop yields and salt loading in soil profile for 40 soil sampling locations. Simulated soil salinity and crop yield results of the model for well drained conditions were compared to current un-drained field conditions.

Site description

Field experiment was carried out in Kesikkopru Basin (39° 25' N, 33° 23' E) with an altitude of 750 m above sea level, located in Central Anatolia of Turkey and the irrigated area from Kesikkopru Dam on the Red River is about 6600 ha and the field experiment was conducted on 1350 ha (Figure 1). Average annual rainfall is about 350 mm and annual pan evaporation is 1255 mm for the region. Long-term monthly average climatologic data are given in Table 1 (TSMS, 2009). The soil of the experimental area is mostly ranging in texture from clay for 0.40 m, clay loam for 0.40 to 1.00 m thick lying on the surface with a layer of clay texture roughly in 1.80 m below the surface. Soil physical characteristics such as bulk density, texture, depth, field capacity, permanent wilting point, saturated hydraulic conductivity and water content at saturation of the experimental sites for every sampling location was determined in the Soil and Fertilizer Research Institute laboratories. Wheat, barley, corn and dry bean are grown in the experimental site. During the growing period, irrigation water quality was moderate saline (Ayers and Westcot, 1994).

Model description

Drainmod (Ver. 6.1) has been extended to predict the movement of salt (Skaggs, 1991; Kandil, 1992). The model is able to predict soil salinity distribution, salt concentrations of drainage water, and the

Table 1. Long-term average climatological data of Ankara-Bala (1976 to 2009).

Meteorological data	Months												
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Annual
Aver. temperature (°C)	11.1	4.7	0.7	-3.8	-2.5	3.7	9.1	11.8	16.3	20.5	21.1	16.3	9.1
Max. temperature (°C)	27.6	20.4	14.4	9.3	12.1	20.6	25.3	28.0	30.4	32.1	34.3	32.0	34.3
Min. temperature (°C)	-3.0	-10.4	-14.7	-14.6	-14.5	-9.8	-3.2	-1.7	3.7	9.8	5.0	4.8	-14.7
Precipitation (mm)	23	31.7	50.2	30.5	32.1	31.6	38.5	53.4	27.3	12	7.6	13	350.9
Rel. humidity (mm)	57	70	79	72	71	60	58	58	50	37	35	41	57
Evaporation* (mm)	95.2	44.3	-	-	-	-	103.0	146.6	200.0	254.2	244.0	167	1255
Wind speed (m s^{-1})	1.2	1.3	1.3	1.2	1.3	1.4	1.2	1.3	1.2	1.2	1.2	1.1	1.2

Note: Evaporation is measuring with Class A Pan method; measurement were not taken at winter time.

Table 2. Soil chemical and physical properties in experimental area.

Depth	pH	EC	CEC	ESP	$CaCO_3$	OM	FC	WP	BD	K_{sat}	S	C	L	Texture
0-20	8.15	3.12	26.11	2.24	16.9	1.41	30	15	1.18	6.8	23	33	44	C
20-40	8.16	1.50	18.83	2.12	17.7	0.92	29	15	1.39	34.2	35	31	34	CL
40-60	8.21	2.00	17.20	0.21	17.5	0.46	25	13	1.19	50.7	31	32	37	CL
60-80	8.05	2.25	15.90	1.35	16.8	0.37	26	14	1.14	123.0	57	24	19	SL
80-150	8.15	3.28	11.31	3.10	16.9	0.18	28	15	1.28	148.0	69	18	13	SL

Depths: Soil depths (cm); EC dS m^{-1}, electrical conductivity of soil saturated extract; CEC, cation exchange capacity (me 100 g^{-1}); ESP, exchangeable sodium percentage (%); $CaCO_3$, calcium carbonate (%); OM, organic matter (%); FC, field capacity (vol.%); WP, wilting point (vol.%); BD, bulk density (g cm^{-3}), K_{sat}, saturated hydraulic conductivity (m day^{-1}); S, sand (%); C, clay (%) and L, loam (%).

effects of salinity on crop yield. It can be used to predict soil salinity as affected by irrigation water quality and drainage system design. This is particularly useful in arid regions for designing irrigation and drainage systems that will minimize yield reduction due to excess soil salinity. In the model, the overall relative yield function also includes the effect of salinity stress on crop yield. The salinity option includes sections to enter the dispersion coefficients, precipitation limit of salt, soil depth use to calculate average salinity for crop yield, initial salt concentration in the profile and additional output options. Model calibration and validation had been implemented for semi arid conditions in Turkey (Kale, 2011).

Collection of the field data

Soil samples were taken from all locations in the field before growing season and after harvesting. Crop yields under un-drained conditions were obtained from farmers. The input parameters needed by the model for each soil layer include: climatological, soil property, crop parameter, irrigation and drainage system data.

Climatological data

Hourly precipitation, maximum-minimum daily temperature, class-A pan evaporation, wind speed, and sunshine hours were continuously obtained from Bala auto-meteorological station, located 2 km from the experimental site. Daily PET was computed using the FAO, Penman-Monteith methods (Raes, 2009).

Soil data

The lateral saturated hydraulic conductivity (K_{sat}) and soil water characteristics of the soil profile down to the drain depth for all sampling locations were obtained in the laboratory using undisturbed soil cores. Bulk density, available moisture capacities and infiltration rates changed between 1.10 and 1.56 g cm^{-3}, 20 and 58 mm, 30 cm^{-1}, 1.5 and 27.6 mm h^{-1}, respectively depending on soil textures. Variations in some chemical and physical properties according to soil depths for representative soil in experimental area were presented in Table 2. The drainage volume, upward flux and infiltration parameters were calculated by an internal model sub-program which uses the soil water characteristic of each layer of the soil to produce values of volume drained for water table positions ranging from the surface to the bottom of the soil profile. The soil water available to the plant is limited by the upward flux from the water table to the plant roots. The soil preparation program includes a routine that calculates the maximum water table depths that will support a given upward flux value. Coefficients of the Green–Ampt infiltration equation and maximum rate of upward water movement as a function of the ground water table depth were determined from the lateral saturated hydraulic conductivity and soil water characteristic relationships using the ‘soilprep’ program of the model (Skaggs, 1980).

Crop data

Simulation was conducted for crop rotation of winter wheat (*Triticum durum)*, fallow and dry bean (*Phaseolus vulgaris* L.) to estimate relative crop yields. Equation 1 used by the model for computing relative crop yields is:

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

Where *YR* is the relative yield (overall); *Y* is the yield for a given

Table 3. Some input ranges for sampling locations.

Crop parameter	Winter wheat	Dry bean
Planting date	10 - 20 October	7 - 17 May
Harvested date	11 - 20 July	15 - 29 September
Length of growing season (day)	270 - 275	130 - 135
Last day of year to plant without yield loss	305 (1 November)	140 (20 May)
Period to count wet -dry days (month day^{-1})	9/30 - 7/1	5/10 - 10/5
Irrigation number	3 (October, May, June)	4 (May, June, July, August)
Irrigation water amount (mm)	340 - 520	260 - 390
Effective root depths (cm)	90	75
Irrigation and trafficability parameter		
Soil layer thickness		0 - 80 cm (20 cm interval)
Irrigation water salinity (ppm)		1126 - 1312
Soil salinity (ppm)		570 - 9574
Days required to prepare seedbed and plant (day)		2
Lower limit of water content in the root zone (cm^3 cm^{-3})		0.176
Limiting water table depth for no crop damage (cm)		30
Minimum water-free pore space needed to work the soil (cm)		1.5
Minimum daily rainfall to stop field operations (cm)		0.5

year; Y_o is the optimum long term average yield; YR_p is the relative yield that would be obtained if only a 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 only reductions due to deficient soil water conditions are considered; 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. Soil salinity affects plants directly by reducing the osmotic potential of the soil solution and by the toxicity of specific ions such as boron, chloride and sodium. Some plants can survive in salt affected soil but many are affected to varying extents, depending on their tolerance to salinity. The same crop may even have different levels of salinity tolerance during its different growing stages. Mass and Hoffman (1977) indicate that each increase in soil salinity (salinity was expressed in terms of the electrical conductivity of the saturated extract) in excess of the concentrations that initially begin to affect yield will cause a proportional decrease in yield. They proposed the following Equation 2 to express this effect:

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

Where YR_s is the relative crop yield (%) if the only reductions are due to soil salinity; EC_e is the salinity of the soil saturated extract (dS m^{-1}); a is the salinity threshold value for the crop, representing the maximum EC_e 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 dry bean and wheat were 640 ppm (1.0 dS m^{-1}) and 19% per dS m^{-1}, and 3840 ppm (6.0 dS m^{-1}) and 7.1% per dS m^{-1}, respectively (Mass and Hoffman, 1977).

Drainmod (Ver. 6.1) requires maximum effective rooting depth and effective rooting depth–time distribution for each crop. Maximum effective rooting depths were used for 90 cm for wheat and 75 cm for dry bean. Skaggs (1982) suggested using 60% of the actual maximum rooting as the maximum rooting depth in the model because most of the water would be taken up near the surface. A value of 3 cm was used for the fallow periods to reflect the soil depth from which water could be evaporated in the absence of a crop (Skaggs et al., 1981). Length of the growing period was calculated in reference to planting and harvesting dates of crops. Wheat and dry bean planting dates were between 15th and 20th October, 2007 and 17th May, harvesting dates were between 15th and 20th July, 15th and 29th September, respectively. Two periods (spring and fall) were specified for calculating trafficable conditions in the field. Crop and trafficability parameters are listed in Table 3.

Irrigation data

The date, time, quantity and quality of irrigation water are required for the simulation (Table 3). Total applied irrigation water was between 340 to 520 mm for wheat and 260 to 390 mm for bean depending on the soil texture in basin scale.

Salinity data

Soil samples were collected at 20 cm increments within the soil profile, down to 80 cm below the soil surface at the beginning of the growing period and these values were used as an input for initial soil salinity. Irrigation water samples were taken before irrigation events for salinity analysis. Irrigation water salinities were within the range of 1126 to 1312 ppm. Dispersivity coefficient was derived using the Neuman (1990) Equation 3:

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

Where α_L is dispersivity and L is the field scale.

Sensitivity analysis of the model had been performed on the dispersivity parameter of salinity input while in model calibration stage (Kale, 2004). Dispersivity had been tested between 3 and 20

Table 4. Drainage design inputs for experimental field.

Parameter	Value
Drain tube	Plastic drain tubing
Drain spacing (m)	160
Drain depth (cm)	125
Drain diameter (mm)	100
Drainage coefficient (mm day^{-1})	9.2
Effective drain radius (cm)	3.0
Depth from drain to restrictive layer (m)	4.50

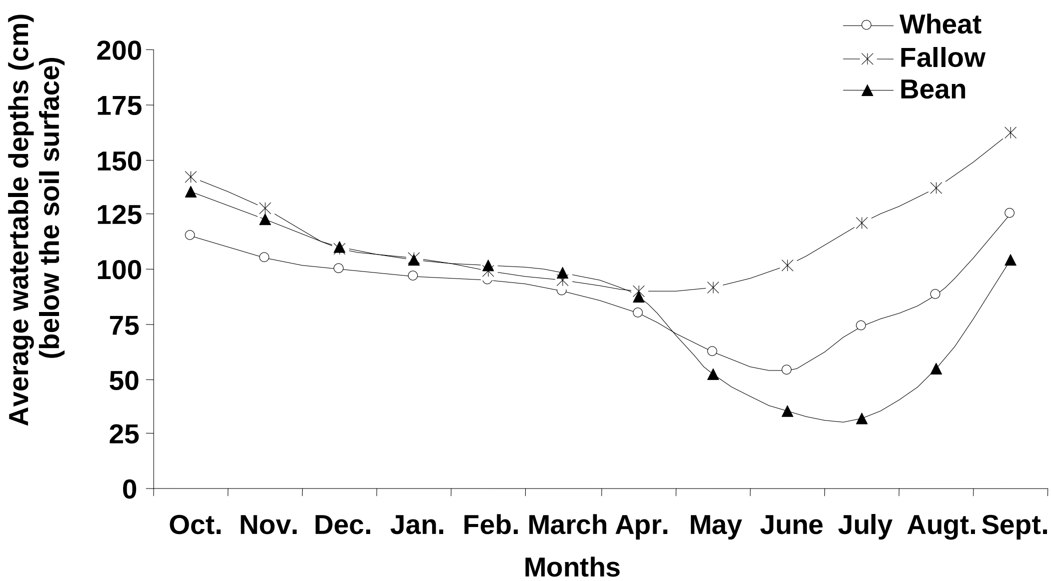

Figure 2. Monthly average water table fluctuations in wheat, fallow and bean locations.

cm. The results of the sensitivity analysis on dispersivity showed that it had very little effect on the model outputs. Dispersivity was calculated as 5.34 cm.

Drainage system parameters

Drainage system input parameters required for simulation include the depth from the soil surface to drain, drain spacing, drainage coefficient, the effective radius of the drains used and the depth of the impermeable layer. Field studies had been carried out for obtaining optimum drainage design parameters under semi arid regions (Kale, 2011). This data set was used as an input for this study which was given in Table 4.

RESULTS AND DISCUSSION

The experimental site was located in semi-arid region where evapotranspiration was high and rainfall was not enough for plant water requirement in growing season. Therefore, irrigation is definitely necessary for optimum crop production. In the meantime, adequate drainage is essential to water table and salinity management in irrigated areas. Options for management are limited if it is not possible to install drainage. As it is well known, poor drainage and sustained water logging of soil is built up salt in the soil profile causing stress to crops. Eventually, almost all poorly drained or non-draining soils in arid environments will become saline (Mass, 1990; Skaggs et al., 1994; Chandra et al., 1997).

Water table depths

A series of 25 representative observation wells (5 m soil depths) which had been installed by State Hydraulic Works were chosen to observe monthly water table level during the simulation period. Monthly average water table depths in wheat, fallow and bean locations were given in Figure 2. Water table level reached 32 and 54 cm below the surface at bean and wheat planting locations respectively which are the crops suffering from waterlogging problem. However, simulation results showed that depth of the water table decreased rapidly after installing proper drainage system. The level of the

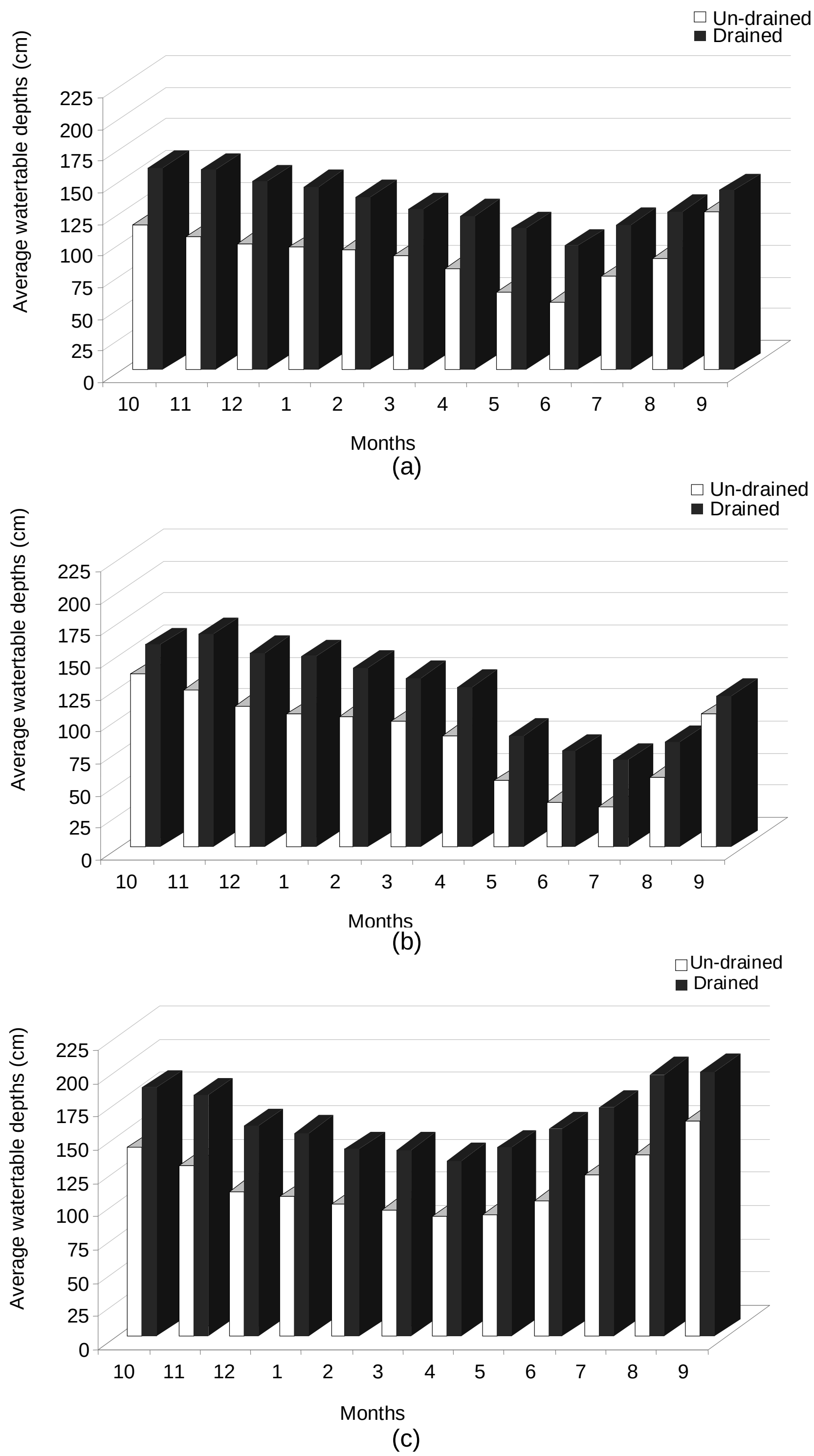

Figure 3. Monthly average water table fluctuations at wheat (a), bean (b) and fallow (c) locations.

water in soil profile for drained condition risen at least 68, 98 and 132 cm for bean, wheat and fallow locations respectively. Water table level fluctuations during the simulation period for un-drained and drained conditions were presented in Figure 3. Water table level dropped under root zone for each crop during growing period. It may be indicated that subsurface drainage provides the mechanism for poorly drained soils to drain to field

Table 5. Soil salinity level under un-drained and drained conditions after growing season.

Loc. No	Land use	Soil salinity (ppm)		Percent salt content increase (+) / decrease (-)
		Un-drained	Drained	
1	Wheat	3149	2449	-22.2
2	Fallow	4919	4132	-8.2
3	Bean	3078	2106	-31.6
4	Bean	2662	1685	-36.7
5	Fallow	2012	1703	-15.4
6	Fallow	2151	1721	-13.5
7	Bean	1779	1152	-35.2
8	Wheat	2707	2443	-9.8
9	Wheat	2701	2084	-22.8
10	Fallow	11024	9099	-8.8
11	Wheat	2746	2085	-24.1
12	Wheat	2387	1868	-21.7
13	Fallow	2875	2396	-15.9
14	Fallow	1606	1356	-13.6
15	Fallow	517	475	-9.8
16	Wheat	2714	2428	-10.5
17	Wheat	2029	1508	-25.7
18	Wheat	2144	1608	-25.0
19	Bean	1914	1148	-40.0
20	Wheat	2355	1772	-24.8
21	Wheat	1626	1269	-22.0
22	Bean	2099	1346	-35.9
23	Wheat	2464	1799	-27.0
24	Fallow	1363	1060	-14.3
25	Bean	1875	1264	-32.6
26	Wheat	2784	2100	-24.6
27	Bean	1728	1498	-13.3
28	Wheat	7469	5527	-26.0
29	Fallow	1112	937	-13.5
30	Bean	2554	1570	-38.5
31	Wheat	3277	2584	-21.2
32	Bean	3558	2847	-20.0
33	Bean	3981	2464	-38.1
34	Bean	3411	3078	-9.8
35	Wheat	2650	2218	-16.3
36	Fallow	3109	2665	-14.3
37	Wheat	3046	2313	-24.1
38	Bean	2138	1580	-26.1
39	Bean	2010	1428	-28.9
40	Wheat	2195	1903	-13.3

capacity in a reasonably short period of time so that plant growth is not significantly impaired.

Soil salinity

Waterlogging in irrigated regions may result in excess soil salinity, that is, the accumulation of salts in the plant root zone. Salt accumulation in Kesikkopru Basin was associated with at irrigation season. To assess the impact of subsurface drainage on soil salinity, soil samples were collected from coordinated locations after the harvest of winter wheat and dry bean crops from un-drained area and compared it with the drained area which was simulated. Depending on the available period of salt leaching, the decrease in soil salinity in different sampling locations ranged from 8.2 to 53.3% for simulation period (Table 5). After growing season; average soil salinity

Table 6. Impact of subsurface drainage system on soil salinity (ppm).

Area	Average soil salinity, ppm		Percentage of salt increase (+)/decrease (-)
	Before growing season	After growing season	
Un-drained	2798	2884	+ 3.4
Drained	2798	2208	- 23.7

Table 7. Percentage of salt content changes of wheat, bean and fallow locations under drained and un-drained conditions.

Area	Percentage of salt increase (+) / decrease (-)		
	Wheat	Bean	Fallow
Un-drained	+3.1	+3.6	+3.2
Drained	-24.1	-37.9	-14.4

level increased to 3.4% in poorly drained location according to initial soil salinity. On average, 23.7% decrease in salt content occurred when compared with the earlier growing season (Table 6). It can be seen that degreases of salinity in soil profile was 24.1, 37.9 and 14.4% for wheat, bean and fallow locations respectively (Table 7). These results indicate the possibility of further improvements in soil salinity, soil properties, and crop yields in ensuing years, indicating that subsurface drainage system is a viable management option for waterlogged saline lands in irrigated semi-arid lands.

Relative yields

After installation of subsurface drainage, the real impact is not limited to an improvement of the wet season crop but also includes early sowing of the winter crop. Moreover, most of the saline waterlogged fallow lands were reclaimed for crop production. Relative yields of the experimental site were calculated based on potential yields data of the region which was obtained from the General Directorate for Agricultural Production Development of Turkish Ministry of Agriculture. The potential yield of wheat and dry bean, the most important crops grown in study site is on average about 5.5 and 3.18 t ha^{-1} respectively. Crop yield results for drained conditions which were simulated by the model were given in Table 8. It also presents the relative yield caused by excess water and salinity stresses, and the overall relative yield. With optimum drainage design, slightly excess water stress was found to be a significant cause of wheat yield reduction. However, excess water and salinity stresses in the growth season were the main causes of bean yield reduction. If the narrower drainage system parameters were designed in the model in order to reduce excess water stress, drought stresses would be a serious problem because of the over drainage in soil profile. A comparison of data on crop yields of un-drained and drained soils revealed a positive influence of installing proper drainage system. Relative yields of the wheat and bean for drained and un-drained conditions were presented in Figure 4. In the experimental area, the yields are generally far below potential yield levels and show a declining trend as can be seen from district statistics. The reason for this is most probably due to aggravated problems of waterlogging and salinity. During simulation period, average wheat and dry bean yields in drained and un-drained areas of the basin were about 4.6 and 2.0 tons per ha, respectively. The average wheat yields were given in Table 9 indicating a significant increase in wheat and bean yields due to the subsurface drainage system. Average total production of winter wheat and bean was 600 and 700 kg ha^{-1} higher on drained than un-drained conditions respectively.

On the drained soils the relative yield of the winter wheat was higher by 11.4%, on the average, whereas that of bean was higher by 24.7%. Overall, the net impact of yield enhancement due to drainage was about 36%. This shows the positive impact of drainage system on crop yields in this area.

Conclusions

Based on the performed research, the following conclusions can be given:

1) The level of the water in soil profile for un-drained condition reached 32 and 54 cm below the surface at bean and wheat planting locations respectively which are crops suffering from waterlogging problem. However, the depth of the water table decreased rapidly to 68 and 98 cm for bean and wheat respectively after installing proper drainage system.
2) After growing season; average soil salinity level

Table 8. Simulated crop yields for well drained soil conditions.

		Stress day index			Relative yields (%)				
Loc. No*	**Land use**	**Excess**	**Drought**	**Delay**	**Excess**	**Drought**	**Delay**	**Salinity**	**Overall**
1	Wheat	1.58	0.00	0.00	96.9	100	100	100	96.9
3	Bean	1.26	0.00	0.00	95.5	100	100	87.5	83.6
4	Bean	1.30	0.00	0.00	95.3	100	100	88.6	84.4
7	Bean	0.92	0.00	0.00	98.6	100	100	97.6	96.2
8	Wheat	1.14	0.00	0.00	98.9	100	100	100	98.9
9	Wheat	0.00	0.00	0.00	100	100	100	100	100
11	Wheat	0.32	0.00	0.00	97.5	100	100	100	97.5
12	Wheat	0.00	0.00	0.00	100	100	100	100	100
16	Wheat	0.12	0.00	0.00	99.7	100	100	100	99.7
17	Wheat	0.00	0.00	0.00	100	100	100	100	100
18	Wheat	1.17	0.00	0.00	98.3	100	100	100	98.3
19	Bean	1.06	0.00	0.00	97.5	100	100	96.2	93.8
20	Wheat	0.00	0.00	0.00	100	100	100	100	100
21	Wheat	1.04	0.00	0.00	97.8	100	100	100	97.8
22	Bean	1.28	0.00	0.00	94.6	100	100	95.6	90.4
23	Wheat	0.52	0.00	0.00	96.8	100	100	100	96.8
25	Bean	2.18	0.00	0.00	94.8	100	100	91.6	86.8
26	Wheat	1.13	0.00	0.00	97.5	100	100	100	97.5
27	Bean	2.04	0.00	0.00	96.4	100	100	92	88.7
28	Wheat	1.74	0.00	0.00	97.1	100	100	90.5	87.9
30	Bean	0.24	0.00	0.00	98.7	100	100	81.3	80.2
31	Wheat	0.85	0.00	0.00	99.2	100	100	97.4	96.6
32	Bean	0.18	0.00	0.00	99.4	100	100	78.9	78.4
33	Bean	1.02	0.00	0.00	97.6	100	100	64.9	63.3
34	Bean	0.00	0.00	0.00	100	100	100	79.4	79.4
35	Wheat	1.16	0.00	0.00	95.2	100	100	100	95.2
37	Wheat	0.10	0.00	0.00	98.9	100	100	100	98.9
38	Bean	1.04	0.00	0.00	95.6	100	100	90.2	86.2
39	Bean	0.92	0.00	0.00	94.8	100	100	91.5	86.7
40	Wheat	1.44	0.00	0.00	90.7	100	100	100	90.7

*Locations; 2, 5, 6, 10, 13, 14, 15, 24, 29 and 36 were fallow (no yield).

increased to 3.4% in poorly drained location according to initial soil salinity. On average, 23.7% decrease in salt content occurred when compared with the earlier growing season. Percentage of salt decreases in soil profile occurred in 24.1, 37.9 and 14.4% for wheat, bean and fallow locations respectively with adequate drainage conditions. These results indicate the possibility of further improvements in soil salinity, soil properties, and crop yields in ensuing years, indicating that subsurface drainage system is a viable management option for waterlogged saline lands in irrigated semi-arid lands.

3) During simulation period, average wheat and dry bean yields in drained and un-drained areas of the basin were about 4.6 and 2.0 tons per ha, respectively. The average wheat yields were given in Table 9, indicating a significant increase in wheat and bean yields due to the subsurface drainage system. Average total production of winter wheat and bean was 600 and 700 kg ha^{-1} higher on drained than un-drained conditions respectively. On the drained soils, the relative yield of the winter wheat was higher by 11.4%, on the average, whereas that of bean was higher by 24.7%. Overall, the net impact of yield enhancement due to drainage was about 36%. This shows the positive impact of drainage system on crop yields in this area.

4) Results of this study 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 as a component of water management system and that design of each component should depend on the others.

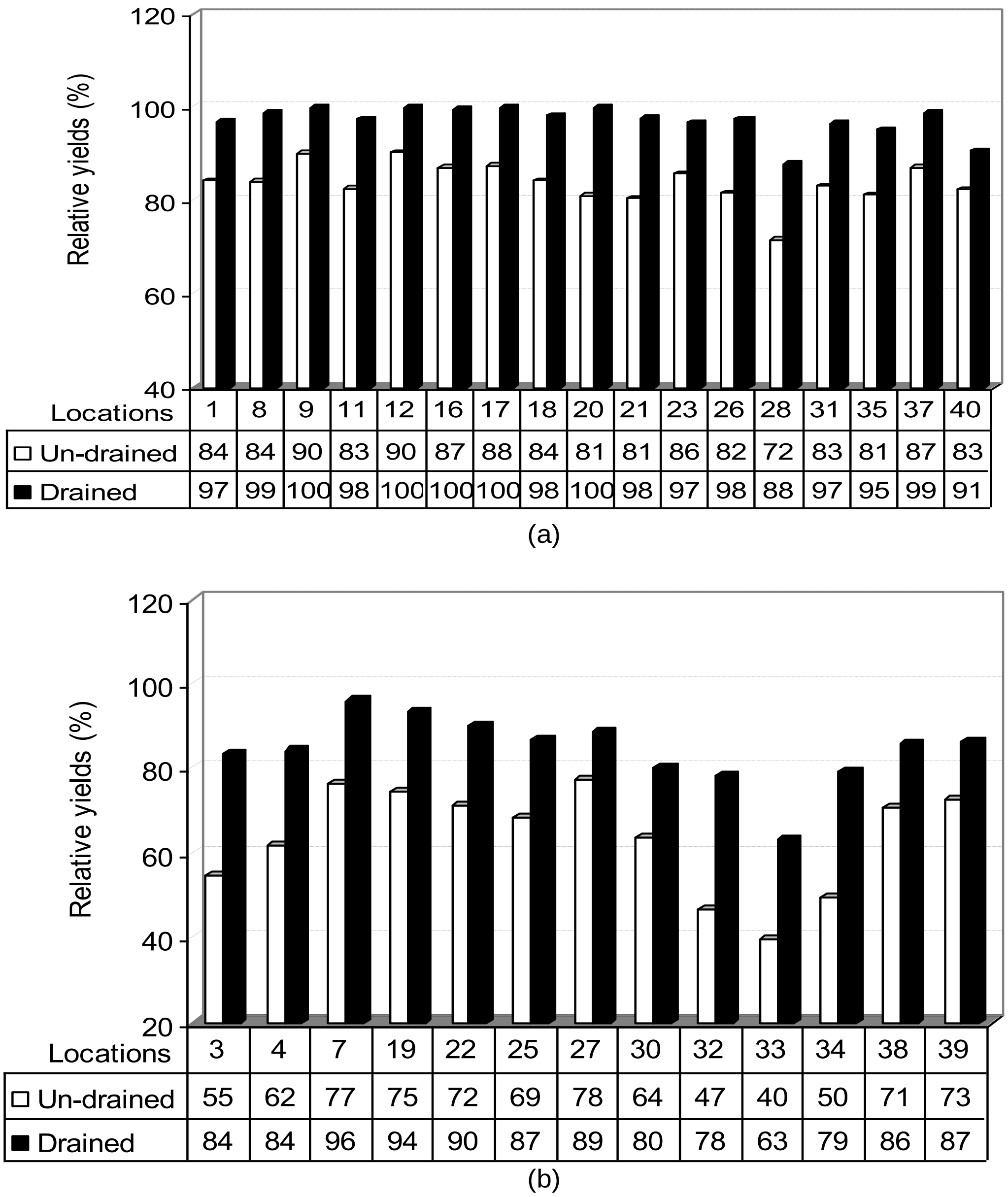

Figure 4. Relative yields of winter wheat and dry bean under un-drained and drained soil conditions. *Locations: 2, 5, 6, 10, 13, 14, 15, 24, 29 and 36 were fallow (no yield).

Table 9. Impact of subsurface drainage system on crop yield (ton ha^{-1}).

Area	Average yields (t ha^{-1})		Percentage of yield increases
	Un-drained	Drained	
Winter wheat	4.6	5.2	+ 11.4
Dry bean	2.0	2.7	+ 24.7

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