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TARIM BİLİMLERİ DERGİSİ — JOURNAL OF AGRICULTURAL SCIENCES 24 (2018) 394-402

Drainage Water Salt Load Variations Related to the Salinity and Leaching Ratios of Irrigation Water

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ARTICLE INFO
Research Article DOI: 10.15832/ankutbd.456667
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Received: 16 March 2017, Received in Revised Form: 18 July 2017, Accepted: 17 September 2017

ABSTRACT

Solubility of salts and leaching fractions have different effects on drainage water quality. Knowing the quality of drainage water is extremely important in terms of environmental factors and quality of water resources for the reason that this water is transferred to various sources.

In this study, were studied the changes of drainage water salinity and salt load under lyzimeter (soil columns) conditions using different irrigation water salinity and with different leaching fractions. The study was carried out with sunflower in PVC soil columns with 40 cm diameter and 115 cm length with 3 different irrigations and 5 irrigation waters with different salinity level. The three irrigation treatments were 75%, 115% and 135% of the required irrigation water. The irrigation water salinities were 0.25 dS m^{-1} as control treatment, 1.5 and 3.0 dS m^{-1} with $NaCl+CaCl_2$ salts and 1.5 and 3.0 dS m^{-1} with $NaCl+CaSO_4$ salts as saline treatments.

In this study investigated drainage water quality variations and salt load with irrigation water and some individual ions load and their leaching by drainage water as well. Drainage water salinities variated with both irrigation water salinity and leaching fractions. It was higher under the effect of soluble salts and with the 15% leaching fraction. However, salt load was higher at 35% leaching fractions level. When discuss the individual ions; while Cl^-, ($CO_3^{-2}+HCO_3^-$) and Ca^{+2} were accumulated in the soil profile, SO_4^{-2}, Na^+ ve Mg^{+2} were leaced from the profile, and all these ions variated by interaction for irrigation waters, and by leaching fractions for the drainage water.

Keywords: Irrigation water quality; Drainage water quality management; Solubility of salts; Leaching fraction; Salt load; Lysimeter experiment

1. Introduction

In most of the world's irrigated lands, there occur salinity and drainage problems due to irrigations and today it is known that irrigation is almost impossible without adequate drainage. Drainage is also significant in controlling salinity problems. The fact that accumulated salts can only be leached from the profile via leaching water, requires the absence of drainage problems in the area. Drainage water returns to natural resources or gets used in irrigating lower plains. Therefore, the quality of drainage water become important for water resources, for irrigation practices and also for the environmental point of view.

Salts affect soil water salinity according to their solubility. High solubility salts are highly concentrated salts that are easily soluble and harm the growth of plants. Conversely, low solubility salts are ones that never reach a high enough concentration to harm the plants (Ayers & Westcot 1988; van Hoorn & van Alpen 1988).

The estimation of drainage water below root zone is essential for evaluating risks of soil salinity in dry areas, developing irrigation management and tracking damage of agricultural chemicals in the ecosystem (Bond 1998; Walker et al 2002). The quality of drainage water reflects the quality of water table and the components of the drained water. Drainage water in irrigated dry places contains salts such as NaCl and $CaSO_4$ and may include elements such as Se, B and Ar. The core of sustainable irrigated agriculture is plant root zone salinity management and the requirement for controlled drainage implements to this end (Ayars et al 2006).

Regarding sustainable irrigated agriculture, leaching is a necessary procedure in order to avoid the accumulation of soluble salts in the root zone. The salinity of drainage water is increased with the leaching of salts from the root zone. Therefore, despite an increase in irrigation efficiency, that is to say, a decrease in leaching ratio might mean an increase in below root zone salinity concentration, it would also mean a decrease in drainage water salt load (Oster & Rhoades 1978). Northey et al (2006) have stated that there is a relation between the changes in salinity of the water table and depth. Generally, as depth increases, salinity in irrigated areas increases.

The increase of world's population and expansion of irrigated areas on one hand, and global warming and decrease of clean water resources on the other, make it unfortunately obligatory for poor quality water to be used in certain irrigation areas (Şener 1993). In the long run, 50% of the irrigation water needs will be met with rotational drainage water usage (Rhoades 1983). In Egypt, drainage water is diluted before usage. Therefore, additional water resources are created and as inhomogeneous water distribution becomes balanced, irrigation efficiency rises significantly (Wolters & Bos 1990). In a study done in Konya, where irrigation agriculture is common, 22% of farmers use irrigation water from drainage canals (Çiftçi et al 1995). Heng et al (1991) have carried out an experiment to determine the leaching losses of Cl^-, SO_4^{-2}, NO_3^{-1}, K^+, Mg^{+2}, Ca^{+2} and Na^+, and found that Cl^- was the dominant anion in the drainage water, with losses total concentration of 100 kg ha^{-1} per year. The leaching loss of $S0_4$ was concentration of 13 kg S ha^{-1} per year from the paddock fertilized with superphosphate compared with 3 kg ha^{-1} per year from the elemental S-fertilized paddock.

Irrigation with saline water and applying leaching fractions affected the mass balance of soil salinity constituents. Yurtseven at al (2014) stated that increasing leaching fractions in relation with the irrigation water salinity, caused to change soil Cl^-, SO_4^{-2}, HCO_3^-, Ca^{+2}, Mg^{+2}, and Na^+ balances; while Cl^-, SO_4^{-2}, Mg^{+2} and Na^+ washed out with leaching water, HCO_3^- and Ca^{+2} accumulated in SCL soil profile.

In this study, the leaching tendency of individual ions and salt loads have been analyzed in regards to irrigation water containing different solubility salts as well as drainage water salinity under varying leaching fractions, in homogeneous soil in lysimeters.

2. Material and Methods

The experiment was held in Ankara University Agricultural Faculty at Dışkapı Campus, as an outdoors cultivation between June 9th-September 16th 2015 with sunflower. Lysimeters were set up with corruge PVC tubes of 40 cm diameter and 115 cm height. The soil, was provided from the top 20-60 cm profile of the surrounding cultivated area and sieved and put into lysimeters in equal amounts according to their bulk density. The soil used was sandy-loam and its bulk density 1.35 g cm^{-3}, pH 8.03, EC_p (at 1:2 saturation) 1.92 dS m^{-1}, field capacity 25.1%, and wilting point 15.2%. The sunflower used was "Meriç", an original variety from Thrace Agricultural Research Institute of Turkey.

As treatments 5 salinity levels (S) and 3 irrigation amounts (L) have been used in a total of 45 lysimeters. Experiments were done as a factorial experiment in fully randomized design with 3 replications. Irrigations were done with water containing at various rates of NaCl, $CaCl_2$ and $CaSO_4.2H_2O$ salts. Irrigation water salinity levels were S_1= top water (0.25 dS m^{-1}), S_2= 1.5 dS m^{-1} NaCl+$CaCl_2$, S_3= 3 dS m^{-1} NaCl+$CaCl_2$, S_4= 1.5 dS m^{-1} NaCl+$CaSO_4.2H_2O$ and S_5= 3 dS m^{-1} NaCl+$CaSO_4.2H_2O$. Irrigation water was applied with leaching fractions as 115% (L_{15}) and 135% (L_{35}). Field experiments also had a treatment of limited irrigation, i.e. 75% of the required amount (L_{075}) but, this treatment was not included to this drainage water quality evaluation since it didn't produce drainage water. Drainage waters were collected from the leaching treatments of L_{15} and L_{35}.

This experiment implemented 8 irrigations during growing season and these were dated according to TDR (Trace) and gravimetric soil water analyses, considering of 40% usage of available soil water. After each irrigation, drainage water was collected from plastic cups previously put at the bottom of soil columns. EC measurements were taken with ECmeter (YSI-3000) according to USSL (1954). The anion and cation analysis were taken via ion chromatography (DIONEX IC-1600) apparatus according to Anonymous (1993).

Salt load values of drainage waters were calculated by multiplying the total drainage volume (mm) and drainage water salinity (EC, dS m^{-1}) and denoted as ECmm (van Hoorn & van Alpen 1988). Salt load values regarding ion concentrations were denoted as mmol as the multiplication of water volume (liter) and appropriate ion concentration (Yurtseven et al 2014).

3. Results and Discussion

During the growing season, irrigation was done 8 times and the average salinity levels were 0.27, 1.58, 3.12, 1.95 and 3.45 dS m^{-1} for S_1, S_2, S_3, S_4 and S_5 treatments, respectively. The S_4 and S_5 treatments had higher salinity than predicted. It was because the added salts had various solubilities and jips solved in a different manner than chloride salts. Anyway the differences of the water salinity levels than predicted weren't extremely high to effect the design of the experiment.

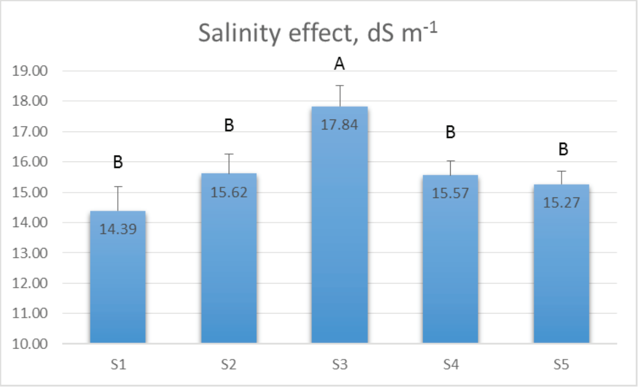
3.1. Drainage water salinity

Examined drainage water salinity resulted in L_{15} having salinity between 15.11 dS m^{-1} (S_5) and 17.84 dS m^{-1} (S_3) and for L_{35} treatment having salinity between 12.81 dS m^{-1} (S_1) and 17.47 dS m^{-1} (S_3). The changes in drainage water salinity is statistically significant for both treatments irrigation water salinity and leaching fractions (Figure 1). Drainage water salinity has been highest (17.84 dS m^{-1}) for treatment S_3 which was containing the highest level of soluble salts. This value is approximately 17% higher than the average of other treatments. The reason behind this, is the fact that chloride salts are highly soluble and easily leachable (Yurtseven et al 2003). Though salinity level in S_5 treatment was high and same as S_3, NaCl+$CaSO_4.2H_2O$ salt composition inhibited the effect of drainage water salinity and provided the salinity level similar to that S_2 and S_4 treatments which were low salty irrigation waters.

The leaching fraction affected the salinity of drainage water (Figure 1). The average drainage water salinity in L_{15} treatment was higher than L_{35} treatment of about 10%. Lower level of leaching fractions resulted in average a more concentrated drainage water because of highly soluble salts. Since soil was sandy-loam and 15% of leaching fraction was enough to provide an efficiently leaching the profile, drainage water became more concentrated for treatments with lower leaching fractions (Oster & Rhoades 1978; Yurtseven et al 2011).

3.2. Salt load

As salt load, salts that were added to soil columns with irrigation water and the salts that were collected from the profiles as leached water via drainage were evaluated.



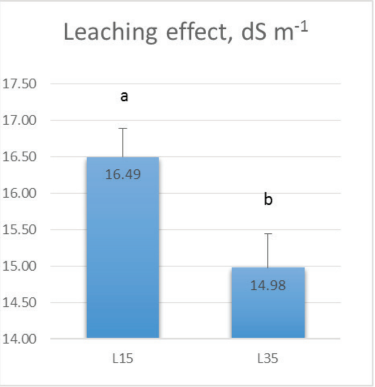


Figure 1- Salinity and leaching effects on drainage water EC values (dS m^{-1})

Salt load values varied between 2370 ECmm (S_1) and 3918 ECmm (S_3) for L_{15}, and between 5434 ECmm (S_1) and 6900 ECmm (S_5) for L_{35}. S_3 and S_5 had higher irrigation water salinity (3 dS m^{-1}) and caused the highest drainage water salt load. As previously explained, the EC values of drainage water from the L_{15} treatment had higher average drainage water salinity with lower leaching fraction. However, when looking at salt loads, L_{35} having a higher leaching fraction, had the highest salt load values, i.e. highest total salt leached from the profile occurred. Even having low salinity level of irrigation water, providing a higher volume of drainage water related with the high level of leaching, consequently resulted a higher level of salt loads (Figure 2). Increase in leaching fractions from 15% to 35% resulted in an average increase of 84% in salt load. Results are consistent with which were given in Yurtseven et al (2014).

While in drainage water only leaching fraction was significantly important, interaction was significantly important for irrigation water salt load.

When examining salt load values of irrigation water (ECmm), the variation was between 281 for S_1L_{15} and 6367 for S_5L_{35} treatments. For all treatments except for S_3L_{15} and S_5L_{15} the total salt load leached with drainage was higher than loaded with irrigation water. The difference in salt load between irrigation water and drainage water was proportionally lower for treatments with higher salt and lower leaching fractions (Figure 3). Considering the total salt load,

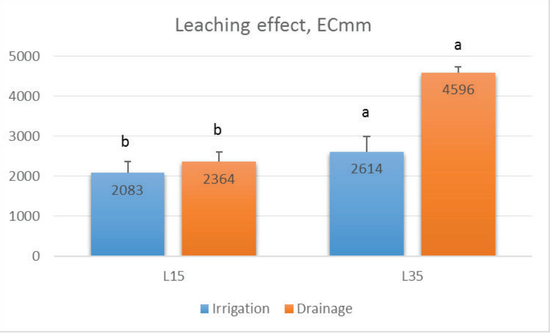


Figure 2- The effect of leaching fractions on drainage water salt load (ECmm)

leaching has been high in all treatments except S_3 and S_5. This proved that it is possible to obtain high enough leaching with irrigation water salinity till 1.5 dS m^{-1} salinity level. For high leaching at 3 dS m^{-1} salinity level, 35% leaching fraction is needed. In general says, 15% leaching fraction is enough to able to leach salts from the soil and which are loaded with irrigation water as well (Ayers & Westcott, 1988). In this study it has been seen that the low level of leaching fraction was quietly not enough for high salinity levels (S_3 and S_5), but was noticeably enough for all of other treatments.

Salt load values were considered in concentration (mmol$_c$) form for the salinity components as well. Therefore, highly active ion chloride and some of ions and components such as Na^+, Ca^{+2}, Mg^{+2}, SO_4^{-2} and CO_3^{-2} were examined (Yurtseven et al 2014).

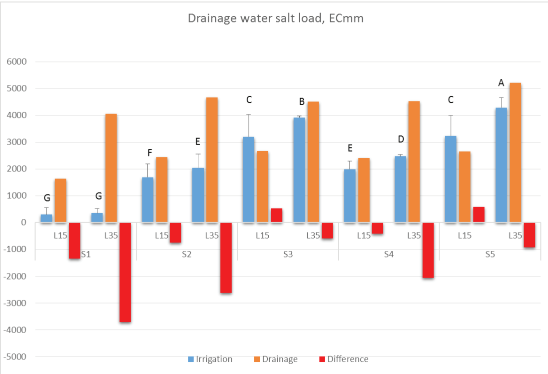


Figure 3- Changes in salt load (ECmm) values in drainage water in relation with irrigation water salinity and leaching

3.2.1. Chloride load

Figure 4 shows the interaction of chloride with the treatments. Leaching of chloride was insufficient and chloride has accumulated in all treatments. Chloride load by the irrigation water were greatly affected by the interaction between irrigation water salinity and leaching fractions (Yurtseven et al 2014). S_2 and S_3 treatments had the highest irrigation chloride levels because of the highest level of chloride salt addition (Heng et al 1991). These values were 1448 $mmol_c$ for S_2L_{15} while 4170 $mmol_c$ for S_3L_{35}. As a higher volume of water was applied to L_{35} treatments, they had a higher level of Cl^- compared to L_{15} treatments. Drainage Cl^- levels however, were affected by irrigation water salinity and leaching ratios individually (Figure 5).

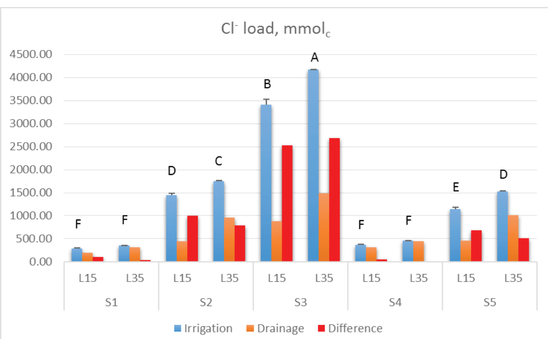


Figure 4- Chloride accumulation as $mmol_c$ related to irrigation water salinity and leaching ratio

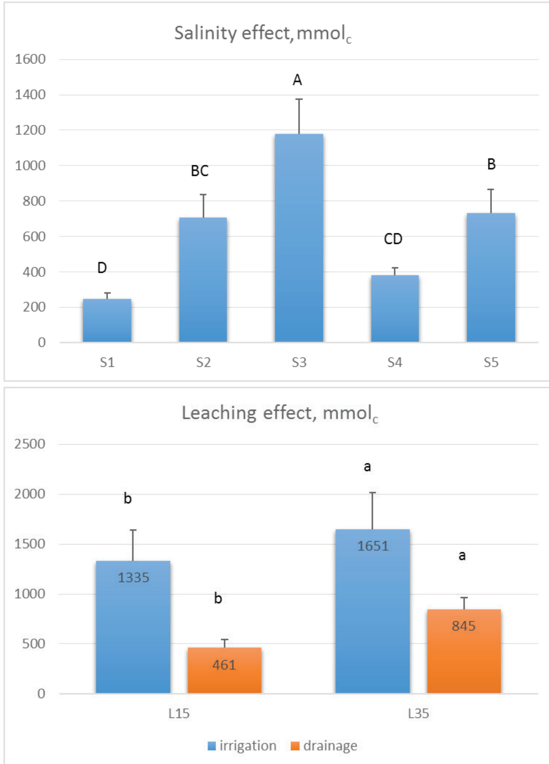


Figure 5- Salinity and leaching effects on drainage water Cl^- load ($mmol_c$)

S_3 treatment had the highest level of Cl^- in drainage water (1177 $mmol_c$) followed by S_5 and S_2 treatments. In other words, S_3, which was loaded with highest level of Cl^- by irrigation water, caused drainage water with the highest level of Cl^- load as well. For the experimental conditions, add more Cl^-, led to the highest level of leaching. L_{35}, with the highest level of leaching fraction, had the highest leaching of Cl^-. Cl^- load levels of L_{15} and L_{35} treatments are 461 and 845 $mmol_c$, respectively and the difference is at a level of 83%. Chloride coming with irrigation is approximately 2.8 times the Cl^- load leached with drainage.

3.2.2. Sulphate load

Drainage water SO_4^{-2} load variations are shown in Figure 6. All treatments had a high level of SO_4^{-2} load leached from the profiles via drainage water.

It can be said that SO_4^{-2} leaching was the case for all treatments (Yurtseven et al 2014). S_1, S_2 and S_3 treatments had higher leaching sulphate load rates. This is the result of the sulphate that originally have in the soil, and leached out from the soil with leaching water. In S_4 and S_5 because of the sulphate salt loading, the sulphate leached by the drainage water was relatively less or not leached at all (S_5L_{15}). That is, SO_4^{-2} loaded by irrigation water for S_4 and S_5 was high so at the end the total SO_4^{-2} leached (loaded with irrigation-leached with leaching fraction) became relatively small but, in fact the total sulphate leached from the soil were the highest.

There is an interaction effect on irrigation water sulphate loads. While salinity (S) has no effect on sulphate that was being leached with drainage water, leaching ratios were significantly important and L_{35} had higher sulphate load (Figure 6). As the leaching fraction increased from 15% to 35%, the increase in the sulphate loads of the irrigation water were 15.7% while on the drainage water was 85.4%. Leaching ratios for L_{15} and L_{35} treatments sulphate loads are 1177 and 2948 $mmol_c$ respectively. In average for all treatments SO_4^{-2} leached with drainage were 2.7 times the SO_4^{-2} that came with irrigation.

3.2.3. Alkalinity load

As the soil profile alkalinity, CO_3^{-2}+HCO_3^- leaching was analyzed. It was seen that drainage masses were insufficient for the leaching of the alkalinity. When analyzing alkalinity leaching, the interaction between CO_3^{-2}+HCO_3^- load in irrigation treatments is important (Figure 7). Drainage water alkalinity load showed significant changes depending on leaching

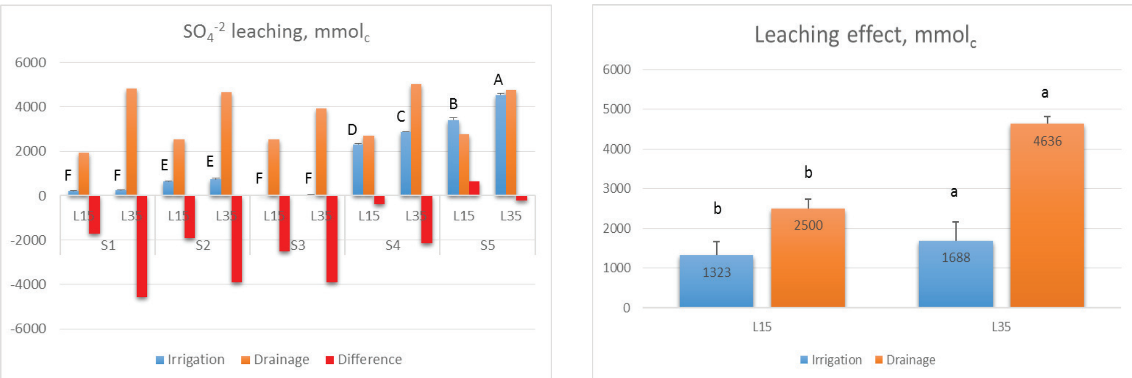


Figure 6- Sulphate leaching related to the irrigation water salinity and leaching ratio as $mmol_c$

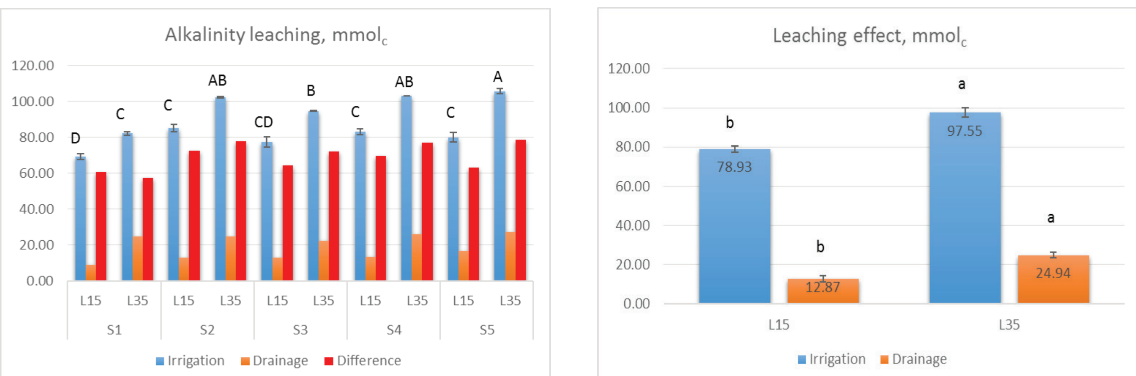


Figure 7- Irrigation and drainage water alkalinity variations related with treatments ($mmol_c$)

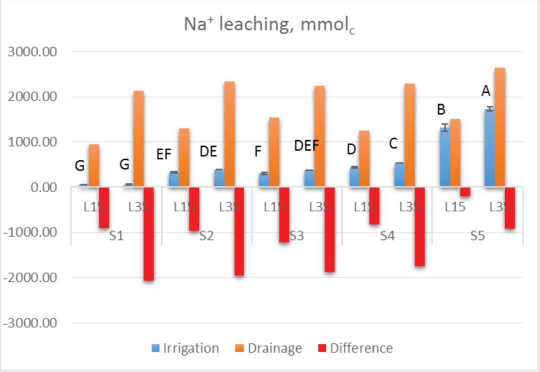
fraction in all treatments. Alkalinity that washed away was lower than the amount carried to the profiles with irrigation, and this result is compatible with Yurtseven et al (2014). Hence, there was alkalinity accumulation in the profiles. Naturally, a higher leaching ratio causes higher alkalinity and leaching. As leaching ratio increased from 15% to 35%, alkalinity load increased 24% in irrigation water and 94% in drainage water. Accumulation in L_{15} and L_{35} treatments were respectively 66.1 and 72.6 $mmol_c$ in average. CO_3^{-2}+ HCO_3^- added with irrigation were approximately 4.7 times to that leached away with drainage.

3.2.4. Sodium load

Sodium loads showed interaction in irrigation water, while in drainage water only leaching fractions effected significantly (Figure 8). As leaching ratio increased from 15% to 35%, irrigation water Na^+ load increased by 28%, and drainage water Na^+ load increased by 78%. In all treatments it has been seen that sodium leached out from the soil profile were higher than added with irrigation. Total leached out sodium were 825 $mmol_c$ for $L_{15,}$ and 1713 $mmol_c$ for L_{35}. Na^+ leached away with drainage water were approximately 3.3 times the total amount of loaded.

3.2.5. Ca^{+2} load

Calcium was one of the ion that were added to all irrigation waters except S_1. It has been seen that Ca^{+2} accumulated in all treatments. The highest level Ca^{+2} loads were detected at S_3 and S_5 treatments for irrigation waters due to the adding Ca^{+2} at highest level. Interaction is statistically important for irrigation treatments (Figure 9). Small variations



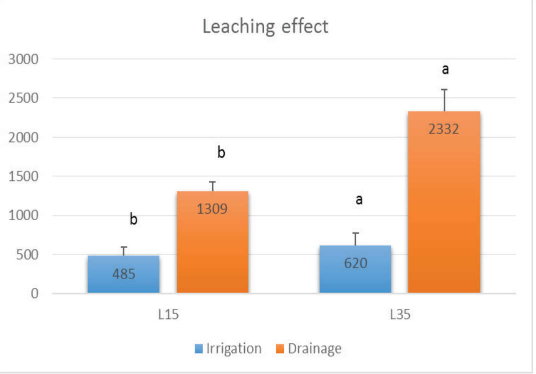
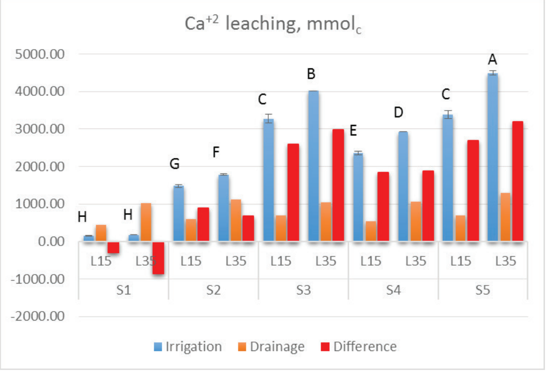


Figure 8- Na^+ load variation as $mmol_c$ of Irrigation and drainage water related with the treatments



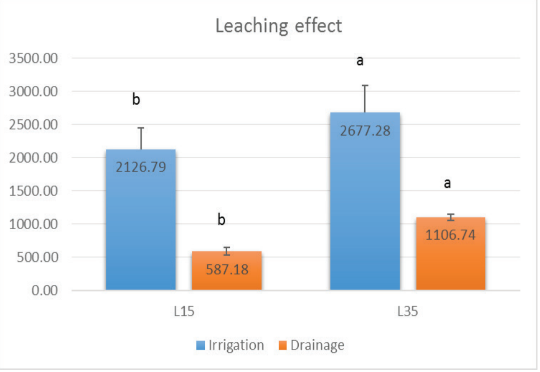


Figure 9- Ca^{+2} load variation of irrigation and drainage water as $mmol_c$ related with the treatments

were detected for leaching Ca^{+2} with the drainage water but higher at L_{35} level than L_{15} for leaching treatments and the difference is 88.4%. However for the irrigation waters the same difference is 26%. Ca^{+2} loads that were carried with water were approximately 2.8 times the total amount of Ca^{+2} leached away with drainage.

3.2.6. Mg^{+2} load

Since no extra Mg^{+2} were added to the soil with irrigation water, Mg^{+2} was the ion that washed away the most. In all treatments, level of leaching was higher than the level of initially added Mg^{+2} (Yurtseven et al 2014). While irrigation water Mg^{+2} loads showed interaction effect, leaching fractions showed an important effect on drainage water Mg^{+2} loads. For the leaching fractions in L_{35} Mg^{+2} loads increased by 24.5% in irrigation, while Mg^{+2} leached away with drainage increased by 87% (Figure 10). Mg^{+2} leached away with drainage were approximately 18 times the initial Mg^{+2} carried by irrigation water.

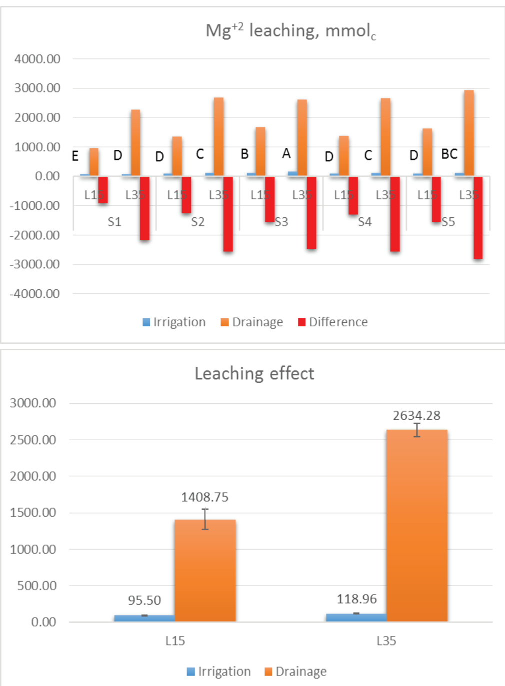


Figure 10- Mg^{+2} load variations as $mmol_c$ due to the experimental treatments

4. Conclusions

In this experimental conditions with SL soil, it can be said that drainage water became more saline with 15% of leaching fraction than with 35%. It means that the salinity could be leached out easily, with this percentage (15%) of leaching water, as Ayers & Westcot (1988) stated, under drip irrigation. It is concluded that, under effective leaching conditions, drainage water concentration can be increased due to the fact that leachable salts in the soil contributed easily to the leaching water. So drainage water became more concentrated, and drainage water salinity was concluded to be highest in treatment with most soluble salts added (S_3).

High level of chloride salts, i.e. NaCl and $CaCl_2$, having a high solubility led to high levels of salinity (S_3) in drainage water. Gypsum (S_4, S_5) has limited effect to drainage water salinity.

When it is considered the salt load; in almost all treatments drainage water salt load was high and was not affected by salinity treatments but rather by the increase in leaching fraction. The higher the leaching fraction caused the higher the drainage water salt load. The salt leached from the lyzimeters at almost the same for the treatments, varying with the leaching fractions. Although no salt were added to the S_1 treatment, it has seen that the most salt leached from the soil of S_1. This is because of the effects of added salt to the other treatments. Added salts caused that relatively the less leaching has been occured. Consequently more salt were leached with the higher level of leaching fraction.

Since chloride is easily move in the soil with water, more Cl^- added treatments in irrigation water caused more concentrated drainage water. Also increasing leaching ratio caused to increase drainage water Cl^- load.

Sulphate, leached to all treatments and leaching SO_4^{-2} increased with increasing leaching fraction. However, since sulphate has limited solubility and motion with water, there was no difference in drainage water between various salinity levels as it was for chloride.

Alkalinity (CO_3^{-2}+HCO_3^{-}) values lead to accumulation in the profiles under the effect of leaching fractions.

The analysis of Na^+, Ca^{+2} and Mg^{+2} loads concluded that while Na^+ and Mg^{+2} showed leaching, Ca^{+2} showed accumulation. All three ions concluded in increased total leached ion levels due to the increase in leaching fractions.

Acknowledgements

This study has been supported by TUBİTAK (The Scientific and Technological Research Council of Turkey) (TOVAG 114O554)

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