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Research Article

Introducing the Importance of Mass Balance Works for Soil Salinity in a Large Scale Irrigation Scheme in the Eastern Mediterranean Region of Turkey

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ABSTRACT

Irrigation is the most important practice that guarantees high agricultural production in arid and semi-arid regions. Notwithstanding, various problems may arise in irrigation practices. These problems result from the imbalance among soil, plant and water relations. The fact that the farmers do not know how much water, when and which irrigation method to apply causes inappropriate irrigation practices. In addition, the use of primitive irrigation methods of low efficiency by the farmers is also very common. This does not only hinder sustainable irrigated farming but also leads to salinity and alkalinity problems, thus resulting in the loss of fertile soils. Monitoring and evaluation of groundwater (GW) depths as well as salinity of GW and soil to ensure the sustainability of irrigated agriculture and water management is a necessity in agriculture. Because GW depth and salinity, and soil salinity are among the most important factors that negatively affect production in agricultural areas. Poor irrigation water management, low irrigation efficiency, the inadequacy of in-field drainage systems etc. are the main reasons for drainage and salinity problems in irrigation areas. This study aimed at monitoring changes in soil salinity by conducting the salt balance work in a large irrigation scheme (9 495 ha), located in the Lower Seyhan Plain, in southern Turkey. Field studies were carried out in the hydrological year 2008. Research results showed that the salt balance equation resulted in a closure error of $\Delta S = -2.84$ Mg ha^{-1}. Results indicated that the amounts of salts exported by drainage flows were greater than the salts imported by precipitation and irrigation water. In turn, not only precipitation in the winter but also irrigation applications in the summer season are effective in leaching salts out of the root zone. This is due to poor irrigation efficiency and high drainage fraction in the District.

Keywords: Drainage, irrigation management, salinity, salt balance, closure error.

Türkiye'nin Doğu Akdeniz Bölgesi'nde Büyük Ölçekli Bir Sulama Şebekesinde Toprak Tuzluluğu İçin Kütle Dengesi Çalışmalarının Önemini Tanıtmak

ÖZ

Sulama, kurak ve yarı kurak bölgelerde yüksek tarımsal üretimi garanti eden en önemli uygulamadır. Bununla birlikte, sulama uygulamalarında çeşitli sorunlar ortaya çıkabilmektedir. Bu sorunlar toprak, bitki ve su ilişkileri arasındaki dengesizlikten kaynaklanmaktadır. Çiftçilerin ne kadar su, ne zaman ve hangi sulama yöntemini uygulayacağını bilmemeleri, uygun olmayan sulama uygulamalarına neden olmaktadır. Ayrıca çiftçiler tarafından düşük randımanlı ilkel sulama yöntemlerinin kullanılması da oldukça yaygındır. Bu sadece sürdürülebilir sulu tarımı engellemekle kalmaz, aynı zamanda tuzluluk ve alkalilik sorunlarına da yol açarak, verimli toprakların kaybına neden olur. Sulu tarımın ve su yönetiminin sürdürülebilirliğini sağlamak için yeraltı suyu (GW) derinliklerinin yanı sıra GW ve toprağın tuzluluğunun izlenmesi ve değerlendirilmesi tarımda bir zorunluluktur. Zira, GW derinliği ve tuzluluğu ile toprak tuzluluğu tarım alanlarında üretimi olumsuz etkileyen en önemli faktörler arasındadır. Yetersiz sulama suyu yönetimi, düşük sulama randımanı, tarla içi drenaj sistemlerinin yetersizliği vb. sulanan alanlarında drenaj ve tuzluluk sorunlarının başlıca nedenleridir. Bu çalışma, Türkiye'nin güneyinde Aşağı Seyhan Ovası'nda bulunan geniş bir sulama birliğinde (9 495 ha) tuz bütçesi çalışması yaparak, toprak tuzluluğundaki değişimleri izlemeyi amaçlamıştır. 2008 hidrolojik yılında saha çalışmaları yapılmıştır. Araştırma sonuçları, tuz bütçesi denkleminin $\Delta S = -2.84$ Mg ha^{-1} kapatma hatasıyla sonuçlandığını göstermiştir. Sonuçlar, drenaj akışları tarafından ihraç edilen tuz miktarlarının yağış ve sulama suyu ile ithal edilen tuzlardan daha fazla olduğunu göstermiştir. Buna karşılık, sadece kışın yağışlar değil, aynı zamanda yaz mevsiminde yapılan sulama uygulamaları da tuzların kök bölgesi dışına sızmasında etkili olmuştur. Bunun nedeni, Bölgedeki düşük sulama randımanı ve yüksek drenaj fraksiyonudur.

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Introducing the importance of mass balance works for soil salinity in a large scale irrigation scheme in the eastern Mediterranean region of Turkey

Anahtar kelimeler: Drenaj, sulama yönetimi, tuzluluk, tuz dengesi, kapatma hatası

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Introduction

The Earth might seem like it has abundant water, but in fact, less than one per cent is available for human use. The rest is either saltwater found in oceans, fresh water frozen in the polar ice caps, or too *inaccessible for practical usage* (EPA, 2022). However, as in all water demanding sectors, there is an ever-increasing trend in the need for water in agriculture. Furthermore, agriculture is the only sector that uses almost 74% of water withdrawals in Turkey (Çetin et al., 2008; Cetin, 2020).

In arid and semi-arid regions where water resources are generally scarce, efficient use of irrigation water has become an important issue. Problems such as demand for good quality water, climate change, drought, contamination of underground and surface water resources (İbrikçi et al., 2016), the high cost of irrigation services, low efficiency in irrigation management for agriculture and household purposes negatively affect the sustainability of irrigated agriculture (Büyükcangaz and Değirmenci, 2002). Even though the water resources of the world have not changed much yet, the agricultural sector has been required to reduce water use in irrigated agriculture for the sake of saving water in favor of other water demanding sectors.

The need for water is expected to increase considerably due to the increase in the temperature and the decrease in water resources together with climate change. On the other hand, drought is one of the factors significantly limiting agricultural production in areas under rain-fed or irrigation agriculture (Abukar 2004; Soula, 2021). Drought, salinity, nutrient imbalance and extreme temperatures are the main environmental factors limiting efficiency and productivity in agriculture.

Today, drought and water shortage are among the main problems to be taken precautions against yield loss. For example, 45% of the agricultural areas where 38% of the world's population lives are threatened by drought (Ashraf and Foolad 2007). Nonetheless, drought accelerates the process of soil salinization.

Regrettably, soil salinity affects plant yield significantly. As a result of the increase in the salt concentration in the soil, the ion balance in the root zone deteriorates and as a result, the plant's nutrient uptake is adversely affected (Öktüren Asri et al., 2013). In turn, salinity is one of the most important problems of irrigated agriculture and it is mostly due to the improper management of irrigation and drainage systems. Malpractices in irrigation applications and the use of more or less water reduce the efficiency of water and lead to decreases in production. Excessive irrigation practices cause an increase in the groundwater table and thus soil salinity may also increase accordingly (Cetin and Kirda, 2003). However, present irrigation practices in many areas are inefficient and inadvertently provide excessive leaching for the sake of accessible drainage. Nonetheless, poor drainage mostly hinders anticipated leaching, resulting in salt accumulation in the root zone. Significant reductions in plant yield can occur depending on the level of salt accumulation in the soil. Therefore, the amount of irrigation water and the irrigation method used should meet the need of the plant but does not cause any accumulation of salt in the root zone.

Monitoring and evaluation of groundwater depths and groundwater salinity levels is a necessity in agriculture for sustainable agricultural production and water management. With the precautions taken into consideration, monitoring and evaluation of irrigation schemes can help practitioners solve the irrigation related problems (Büyükcangaz and Değirmenci, 2002; Cetin, 2020; Kaman et al., 2022). The level of groundwater and its salt content, and soil salinity are considered to be among the most significant factors affecting agricultural production. If the groundwater levels increase up to the root zone in dry spells, it can be concluded that the source of the high water table is closely related to the irrigation practices, of low-efficiency rates, such as furrow, border and wild irrigation methods (DSİ, 1982; Çetin and Diker, 2003).

Lower Seyhan Plain (LSP), in which a large large-scale irrigation scheme has been constructed since 1942, constitutes one of the most important large-scale irrigation projects in Turkey. Seyhan Dam which was constructed in 1956 has provided irrigation water to the LSP since then (Çetin and Özcan, 1999). However, as expected, the problems such as low soil fertility, waterlogging, drainage, high soil salinity and alkalinity in the irrigated and non-irrigated fields have started to emerge since the introduction of irrigation (Çetin and Özcan, 1999).

This study aims to: a) introduce the importance of mass balance works in a large scale irrigation scheme of Akarsu Irrigation District in the LSP in Adana province, Turkey, and b) address the changes in soil salinity during a period of the hydrological year.

Materials and Methods

This study was carried out in the Akarsu Irrigation District (9 495 ha) in Adana province, which is located in the eastern Mediterranean region of Turkey. The Akarsu Irrigation District has significant agricultural potential in the national economy of Turkey. The region where this study was carried out is one of the most densely cultivated regions in Turkey, and it is located at 36º 57′ 32″ – 36º 50′ 43″ North latitude and 35º 40′ 22″ – 35º 28′ 42″ East longitude (Figure 1).

The most common soil series in the study area are Arikli (30%), İncirlik (27%) and Yenice (14%) (Dinç et al., 1995). The other soil types/series available in the region are Ismailiye (0.9%) and Golyaka (0.5%) and Innapli (0.4%).

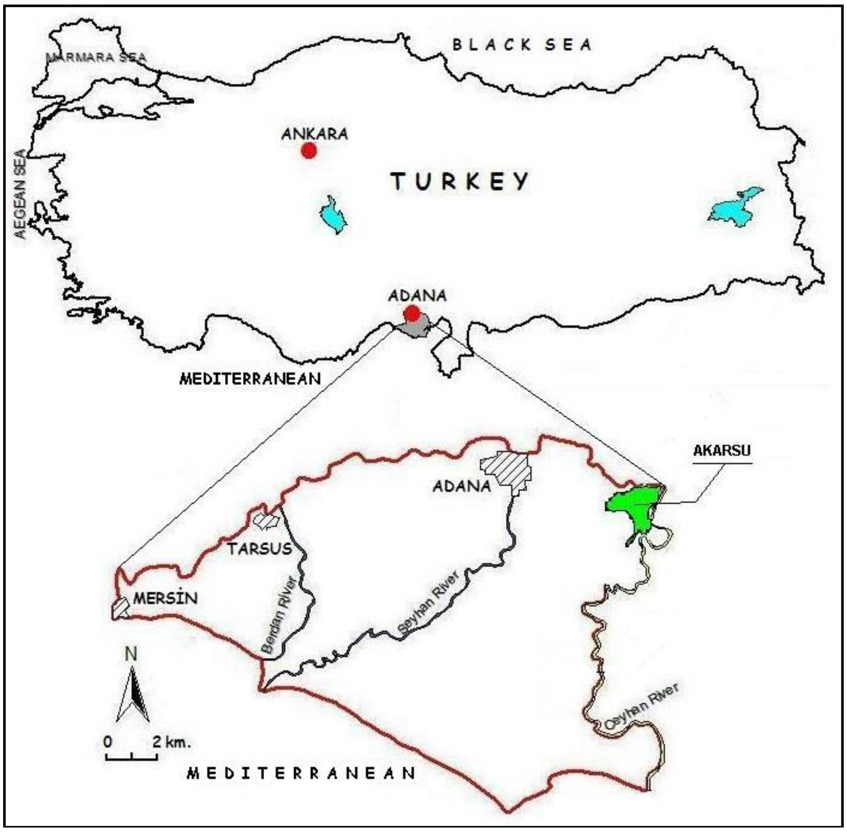

Figure 1. Map of the study area in Turkey (Kaman et al., 2011).

The study area is under the influence of the Mediterranean climate, winters are warm and rainy, and summers are dry and hot. The average temperature over long years in the region was found to be 18.8 °C. As for the temperature extremes, August is the hottest month (28.1 °C), and January is the coldest month (9.9 °C). Almost all of the rainfall falls in the winter months in the form of rain. The average rainfall is 650 mm in the region. However, the distribution of rainfall throughout the year is not homogenous. Relative humidity increases up to high values in summers (sometimes over 95%) as a consequence of the increase in the temperature and the irrigation practices. In the winter months, relative humidity surprisingly decreases.

The necessary examination was done on the maps of 1 to 25 000 scale to determine soil sampling locations and to locate groundwater observation wells. Incoming (L6, L3, L7, L9 for irrigation; L2 and L11 for drainage inputs in Figure 2) and outgoing (L4 for drainage and L5 for irrigation in Figure 2) water flow rates were measured daily; and daily water samples from irrigation and drainage gauging station in Figure 2 were taken to determine total dissolved salts (*TDS, mg l*$^{-1}$). Furthermore, rainwater samples were taken whenever precipitation was observed at the meteorological station (L8 in Figure 2). A total of 108 drainage observation wells were taken under review (Figure 2).

Water samples from the ground water wells were taken at the beginning and end of the hydrological year 2008. All the water samples were analyzed at the lab and determined their TDS concentrations by following the procedure given in USSLS (1954). Concurrently with the groundwater sampling schedule, soil samples from 0-30, 30-60 and 60-90 depths (i.e. root zone) were taken from the immediate vicinity of the groundwater observation wells. The *ECe* (*dS m*$^{-1}$) and total dissolved salts (*TDS, mg l*$^{-1}$) of the soil samples were determined in the laboratory by USSLS (1954) and Kaman et al. (2006). In order to determine the salinity change in the crop root zone (Cetin et al., 2008), soil saturation, porosity and bulk density maps for 0-0.9 m soil profile were produced using GIS media. Then, a general salt balance equation was employed to quantify salinity dynamics at the catchment level.

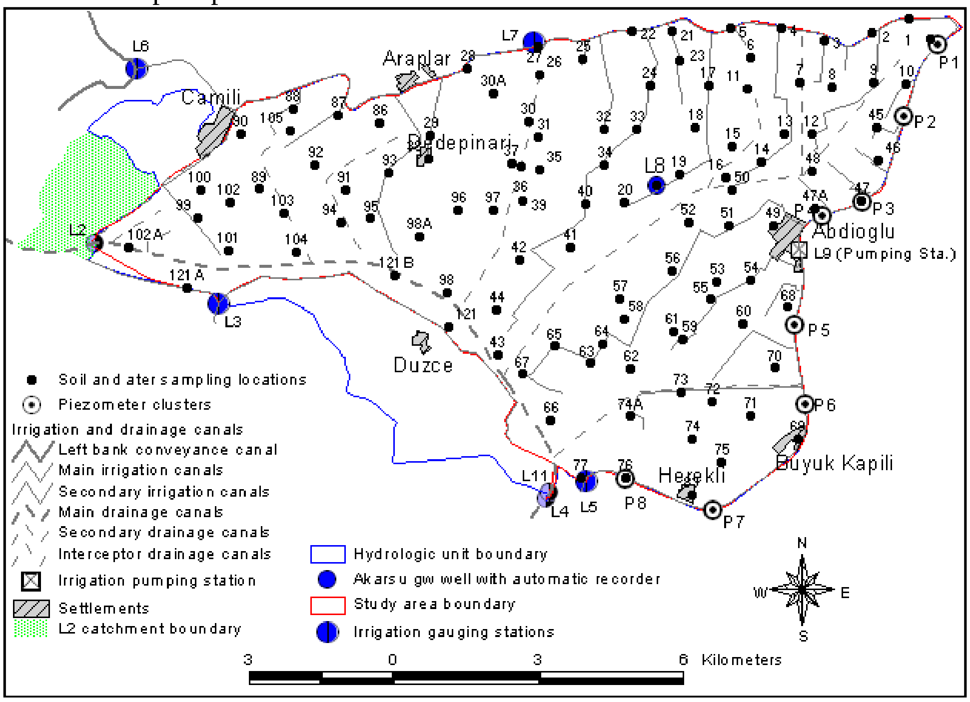

Figure 2. Locations of irrigation and drainage gauging stations; spatial distribution of groundwater observation wells over the study area

Results and Discussion

The plant types, commonly grown in the study area in 2008, are corn with 39.6%, citrus with

29.2%, and vegetables with 0.3%. In the LSP, corn is generally cultivated as the first crop, but it is also grown as the second crop, particularly in the wheat, onion and/or potatoes planted areas in the winter season.

Although the research area has had an open drainage and surface irrigation system for more than 60 years, the drainage system in some parts of the study area does not function efficiently as expected. Therefore, in the regions where irrigation applications have been densely performed, the problems related to the waterlogging, high water table and salinity may emerge both during the winter season by heavy precipitation events in excess of the water storage capacity of the soils and peak irrigation season by excess water application. Inadequate drainage facilities might have contributed highly to the aggravated drainage problems in the research area. In this context, although the research area has had a drainage and irrigation system for 60 years or more, the problems related to the groundwater quality and quantity as well as soil salinity have been continually observed in some specific areas where irrigation applications have been densely performed. However, the severity of soil salinization problems is negligible to some extent because the maximum soil *ECe* observed in the root zone has been ever less than 2.0 $dS\ m^{-1}$ during the study period. It should be expressed explicitly that research results regarding soil salinity degree were found to be compatible with the results of Aragüés et al. (2011). They pointed out that soil salinity in the Akarsu district, a sub-catchment of the LSP, has been negligible, for areas of $ECe>0.54\ dS\ m^{-1}$ covered only 13.9 per cent of the District.

The total unitary salt load imported by precipitation and irrigation was about 4.863 $Mg\ ha^{-1}$ in 2008. It should be kept in mind that drainage is the only source to export salts from the study site. In this context, the salt load of drainage flows is found to be 7.714 $Mg\ ha^{-1}$ in the observation period. This indicates that the salt load imported to the study area is less than the salts exported from the study area, indicating leaching salts from the soil profile. After taking the salt loads of the hydrologic water budget equation, it is important to highlight that the salt balance equation resulted in a closure error of $\Delta S= -2.84\ Mg\ ha^{-1}$. This figure indicates clearly that the amounts of salts exported by drainage flows were noteworthy greater than the salts imported by precipitation and irrigation water. In turn, not only precipitation in the winter but also irrigation applications in the summer season are effective in leaching salts out of the root zone. This result may be interpreted that present irrigation practices in the research area are inefficient and inadvertently provide excessive leaching, indicating no salt accumulation in the root zone. In other words, this is due to poor irrigation efficiency and high drainage fraction in the District.

Further study was done to justify the supposition of no salt accumulation in the root zone. To this end, TDS maps for 0-0.9 m soil depth produced for early October/07 and late September/08 were converted to the unitary salt loads of $Mg\ ha^{-1}$ by utilizing soil saturation, porosity and bulk density maps in GIS media. Map algebra calculations and zonal statistics of GIS showed that the net change in soil salinity (ΔSTDS) over 0-0.90 m soil depth was $\Delta STDS= -0.026\ Mg\ ha^{-1}$, indicating a small decrease in soil salinity which is desirable in irrigated agriculture. The negative sign in the ΔSTDS suggests explicitly the soils in the study are subject to salt leaching. Under these circumstances, there exists no salinization risk in the rooting depth.

Conclusion

The total unitary salt load imported by precipitation and irrigation was about 4.863 $Mg\ ha^{-1}$ in 2008. Drainage waters were the only source to export salts from the study site. In this context, the salt load of drainage flows was about 7.714 $Mg\ ha^{-1}$ in the observation period. This indicates that salts imported to the study area are less than the salts exported from the study area, indicating leaching salts from the soil profile. After taking the salt loads of the hydrologic water budget equation into consideration, it was concluded that the salt balance equation resulted in a closure error of $\Delta S= -2.84\ Mg\ ha^{-1}$.

In this study, the salt contribution of fertilizer applications to the soil and shallow water table system was ignored; furthermore, the salinity change in the soil layers between the shallow water table and the rooting depth was not considered in the mass balance calculations. These two potential factors may be the primary source of closure error in salt balance work.

In the regions where irrigation applications have been densely performed, the problems related to the waterlogging, high water table and salinity emerged both during the winter season by heavy precipitation events in excess of the water storage capacity of the soils and during peak irrigation season by excess water application.

This result may be interpreted that present irrigation practices in the research area are inefficient and inadvertently provide excessive leaching, indicating no salt accumulation in the root zone. This process causes normal soil salinity profiles in the study area to remain and indicates undoubtedly a net downward flux of water and salts.

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