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The Effect of Different Depths of Salty Groundwater on Yield and Soil Salinity of Some Pasture Crops

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ABSTRACT

Salinity is one of the most serious environmental factors limiting the yield of plants. Because many crops experience yield losses due to the harmful effects of high salt content in soil and water. The increase in the area of land affected by salt has the potential to create problems in terms of food safety. In this context, it is necessary to develop some cultural practices to prevent or reduce the harmful effects of salinity. This study investigated the effects of salty groundwater at different depths on the yield and soil salinity of some forage crops grown in semi-arid regions for three years. The experiment was conducted using the randomized block split-plot design. The effect of water table depths on the yields of the cultivars in the first year was found to have a statistically significant ($p<0.01$) effect while it was insignificant in the second year. According to the Duncan test results, it was determined that the H1 (40 cm groundwater depth) treatment in the first year provided the highest yield in all three cultivars and formed the first group ($p<0.01$) in the Duncan test. The interaction between water table depths and plant species was statistically significant at the $p<0.05$ level. At the end of the experiment, the salt concentration of the topsoil (40 cm depth) increased significantly ($p=0.025$) at all water table depths. Moreover, although the sodium adsorption ratio of the inlet water was low, it was determined that the exchangeable sodium percentage of the soils increased significantly at all groundwater levels at the end of the trial.

Keywords: Forage crops, Pasture lands, *Festuca elatior, Lotus strictus, Puccinella distans*, Groundwater salinity

1. Introduction

Flatlands in arid and semi-arid regions and alluvial plains on the coasts have inadequate drainage due to topographic and soil structure. These lands have been salted by high groundwater levels and insufficient drainage. This type of land that covers extremely large areas of the world, is in the form of pastures or abandoned lands with low, and poor-quality grass yields. These unproductive pastures were degraded by negative factors such as overgrazing, erosion, drainage, and barrenness. These lands have reduced plant diversity due to the high-water table and excessive salt, and natural vegetation has become poor-quality pastures dominated by barren-halophyte plants of low nutritional value that are not liked by animals.

In many countries where livestock is based on meadow and pasture farming, it is aimed at producing cheap and healthy food by growing salt-resistant forage plants and their mixtures in meadows and pastures under the influence of high groundwater (Dieleman 1977). Establishing artificial pastures consisting of acceptable forage crops, currently used as pastures, may significantly increase the agricultural potential of these lands.

Another way to benefit from these lands is to rehabilitate them. However, although salt-affected soils are chemically recovered, it takes a long time to restore the physical properties of these soils. Therefore, by cultivating some salt-tolerant forage crops during this period, both the recovery of the physical properties of the soil and the farm income will be contributed.

In this context, halophytes are important because of the prevalence around the Lake Tuz and arid soils in central Anatolia (Birand, 1961). For example; *Puccinella distans* can provide a good yield of up to 26 dS m^{-1} salinity in salty soils (Öztan 1965; Akhazari et al. 2012). Bennett & Barrett-Lennard (2013) reported that samphire (*Tecticornia pergranulata*) and *Puccinellia* (*Puccinellia ciliata*) grow in areas with a salinity of 16 dS m^{-1}. The increased salinity causes only a decrease in plant height (Ashkan & Jalal 2013; Kuşvuran et al. 2014). *A. elongatum* species are less damaged by salinity conditions than other *Agropyron* species because it is more adaptable to salinity conditions in morphological terms (Koç & Acar 2017).

In addition, *Agropyron* species (*Agropyron* spp.) can naturally grow in areas with salinity issues in the Central Anatolia rangeland (Acar et al. 2016). The grass yield of 70% of the natural pastures in the Konya plain is very low, and the average dry grass yield is approximately 200 kg ha^{-1}. High-quality forage plants with high grass yields have been replaced by sour marsh plants such as *Carex* and *Juncus* (Tosun 1967).

Tall wheatgrass (*A. elongatum*) and crested wheatgrass (*A. cristatum*) from *Agropyron* spp. give a yield with a 50% loss in high salinity levels, which is not available to grow other plant species. (Akhazari et al. 2012; Ashkan & Jalal 2013). The presence of saline groundwater at 25 cm depth had a detrimental effect on the production of biomass and its components on Rhodes grass (*Chloris gayana*), whereas the effect at 125 cm and greater depths was neutral (Chiacchiera et al. 2016). *Leptochloa fusca*, *Spartina patens*, and *Sporobolus virginicus* (Smyrna) have been reported to be promising halophytic plants for feeding goats and sheep in desert areas (Ashour et al. 1997).

For the reasons mentioned above, this study was carried out to determine the effects of salty groundwater at different depths on the yield and soil salinization of some forage crops in pasture areas in semi-arid regions and to contribute to the determination of forage plant varieties suitable for semi-arid conditions.

2. Material and Method

2.1. Trial site

The trial site is the salty lands in Konya Plain with a high-water table. These lands are widely located in different parts of the Central Anatolia (Figure 1), especially around Lake Salt, in Aslım pastures, in the plains of Karapınar, Ereğli plain, and around Lake Hotamış (Meester 1970).

Figure 1- The geographical location of the research site

The trial site soils are in the hydromorphic soil group, with medium depth, it is flat land (Atalay & Secerli 1971). The upper soil is silty loam, and the lower soil is silty and organically rich. Its lime content is high, it is excessively salty and salt content decreases with depth (Table 1). The water conductivity of light sodium soils is in the middle group of the upper layers and the medium-slow group of the lower layers (Meester 1970).

Table 1- Some physical and chemical properties of trial soils

Soil depth cm	*Texture*				*pH*	*EC_e*	*NaX*	*CEC*	*ESP*	*Lime*	*OM*
	S	*Si*	*C*			*dS m^{-1}*	*$cmol^+$*	*kg^{-1}*	*%*	*%*	*%*
0-20	24.5	68.7	6.7	Si	7.8	17	3.1	13	24	22.0	4.35
20-40	20.7	70.3	9.0	Si	7.0	15	2.3	10.9	21	23.3	2.90
40-70	8.0	87.9	4.0	Si	6.5	12	1.4	11.4	13	41.7	2.56
70-110	13.3	87.0	0.0	Si	6.4	6.9	0.3	8.5	3.5	43.1	2.04

EC_e: Electrical conductivity of soil extract, NaX: Exchangeable Na, CEC: Cation exchange capacity, ESP: Exchange Na percentage, OM: Organic material, S: Sandy, Si: Silty, C: Clay

2.2. Climate

The Konya Plain has the typical characteristics of the continental climate; the summers are dry and hot, and the winters are snowy and cold. The highest annual temperature average is 11.6 ºC, the annual precipitation is 327.7 mm and the average relative humidity is 63% (Anonymous, 2018). During the trial, precipitation was 386 mm in the first year, and 277.8 mm in the second year, the evaporation was 1,171 in the first year and 1,243 mm in the second year and the average temperature was 11.1 in the first year and 10.5 ºC in the second year.

2.3. Method

Trials were carried out with 3 forage plants, A- *Lotus sitrictus*, B- *Puccinella distans*, C- *Festuca elatior* and 4 groundwater depth levels, H1=40 cm H2=60 cm H3=80 cm H4=110 cm.

2.3.1. Setting up the experiment

The experiment was carried out in 3 replicated, randomized blocks split plots trial design. The experiment was conducted in cylindrical steel barrels with a depth of 120 cm and with a diameter of 56 cm. The plot areas are 0.2462 m^2 for planting and harvesting.

In the first place, the volume weights of the soils at the trial site were determined by the layers of 20 cm. The soils were dug, stored, and allowed to dry in the shade, depending on the soil layers. Ten cm thick sand gravel was laid on the bottoms of the barrels. To measure the depth, 10 cm of soil was placed on the top of the sand-gravel layer. It was compacted until the original bulk weight was achieved with a mallet. Then the second 10 cm layer was laid, and the same operations continued until the barrel was full.

To create a water table in the barrels, holes in the specified depth are drilled and the outlet drainage pipes were located. Groundwater was pumped through inlet pipes placed under the tanks to a 4 m high water tank. The salt content of the water entered and discharged from the barrels was measured every month.

2.3.2. Properties of the plants used in the experiment

Festuca elatior, Puccinellia distans, and *Lotus strictus*, which are under the shallow water table around Konya in the natural vegetation of Aslım pasture lands, were used in the experiment (Figure 2).

Festuca elatior; high meadow ball, salt resistant, 40-60 cm tall, also called meadow ball (Tosun 1974). Its multi-sibling, bundles are 30 cm in diameter, growing vertically upwards, between 20 cm and 1 meter in length. Leaves are curled, cylindrical leaf sheathed. The underside of the leaf is brightly colored. Flowers are unique with many large and elongated spikelets together to form compound clusters**.**

Puccinellia distans is a green-colored forage crop with wheatgrass spikes resistant to salt (Werner & Senghas 1973). Five-forty cm in length with body characteristics of herbaceous plants native to Turkey. It is common in semi-marshy areas around inland salty lakes. It generally grows in sandy loam, silty loam, and loamy soils and has a strong root system and anti-erosion feature, which is important for grazing in salty areas.

Lotus strictus is a salt-resistant, yellow-flowered forage plant that reproduces with the rhizome and is 50-100 cm tall and highly branched (Kyell Vist 1971). Glabrous, with short hair only on top, perennial, erect, thick, woody below, with umbrella-like inflorescences bloom in August - September.

2.3.4. Sowing, fertilizing, and harvesting

The seeds were sown by hand, but as there was not adequate germination, the *Lotus strictus* plots were replanted. Before planting, 40 kg N, and 100 kg P_2O_5 were given per hectare and mixed into the soil. During the summer, the trial plots were irrigated 3 times with groundwater.

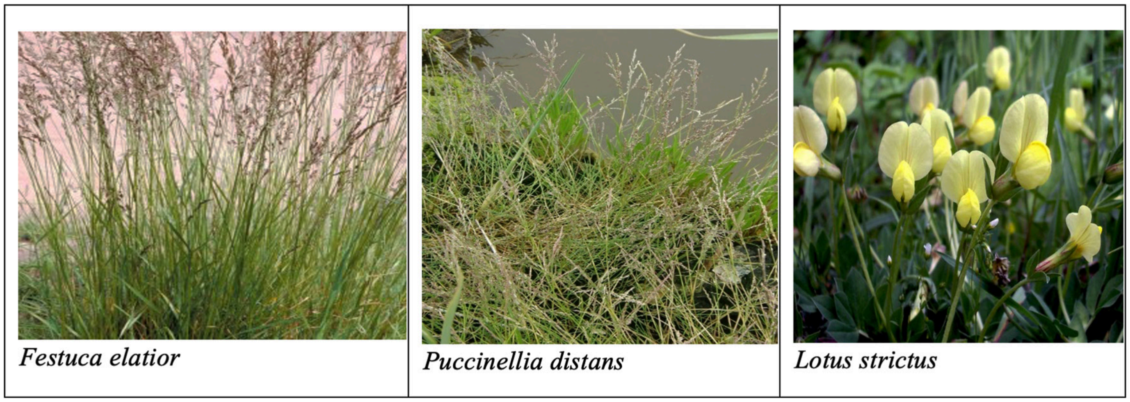

Figure 2- Pasture plants used in the experiment

When the plants reached grazing maturity, *Festuca elatior*, and *Agropyron elongatum* 20 cm, *Puccinella distans*, and *Lotus strictus* 15 cm in length, were harvested, and wet and dry grass weights were determined.

In order to determine the dry grass yield, the wet grass samples were dried in an oven at 65 ºC until they reached a constant weight, and their moisture content was determined.

2.3.5. Statistical analysis

Grass yields of the cultivars were analyzed in randomized blocks with a split-plot design. The effect of groundwater on salt accumulation was evaluated through regression analysis and pairwise comparisons (Yurtsever 1984).

3. Results and Discussion

3.1. Grass yields of crop varieties

The highest yield was obtained for 40 cm water table depth. The dry grass yields of *F. elatior, P. distans*, and *L. strictus* are 744, 642, and 615 kg da^{-1}, respectively. When the groundwater level fell to 60 cm depth, the hay yields decreased to 407, 383, and 454 ka da^{-1}, respectively. The effect of water table levels on plant yield was found to be significant, and H1=40 cm water table depth formed the first group ($F_{0.01}=34.57^{**}$ and $p<0.01$) in both years, and also the interaction between water table and plant species ($p=0.05$) was found to be significant (Table 2) and crop varieties (A, B, C).

Table 2. Dry grass yields versus different water table depths (kg da^{-1})

Groundwater depth, cm	*Crop varieties: 1st year*			*Average*	*Crop varieties: 2st year*			*Average*
	A	*B*	*C*		*A*	*B*	*C*	
40	744	642	615	667a	816	173	494	494a
60	407	383	454	415ab	543	72	378	331b
80	214	318	334	289b	792	125	209	375b
110	224	270	314	269b	509	99	206	271c

However, while *L. strictus* regenerated itself with rhizome and maintained its productivity at all water levels, the decrease in the yield of *P. distans* and *F. elatior* was significant statistically (Figure 3). Due to a decrease from 60 cm to 110 cm in the water table, the efficiency decrease continued, but the decrease was not statistically significant.

In these pasture areas, a groundwater depth of 40 cm should be considered a critical level. It should be noted that increasing the depth of the water table, in addition to damaging the existing vegetation due to water stress, may also accelerate the oxidation of organic matter in the upper soil layers.

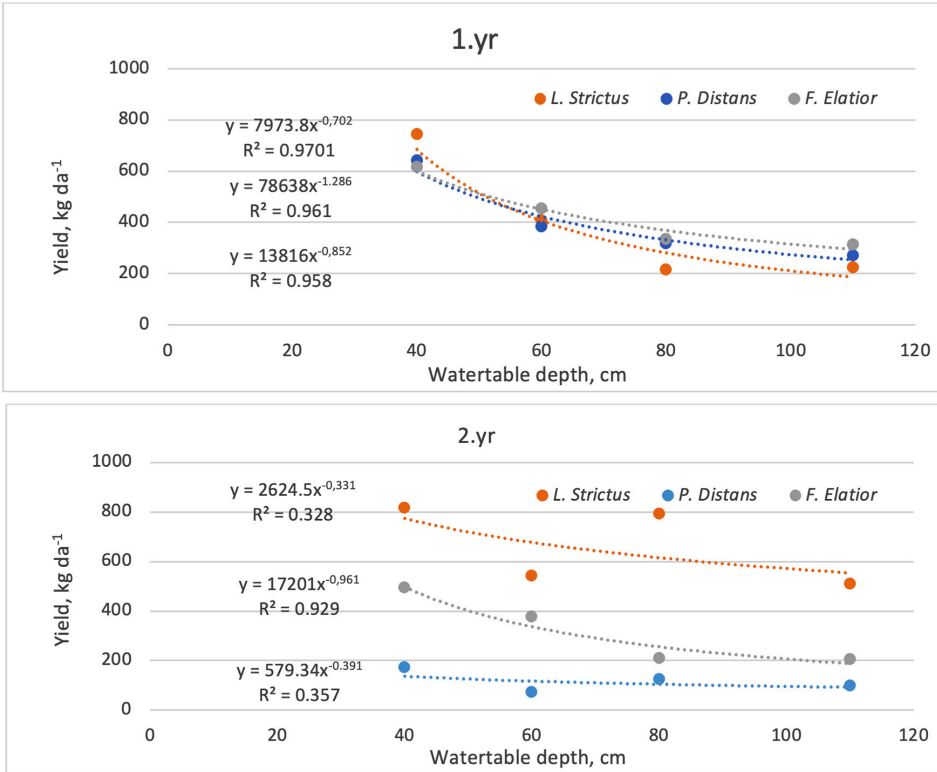

Figure 3- Dry grass yields versus water table depths in different years

The high correlation coefficients of the relationship between the decrease in the water table level and the grass yields indicated that the main reason for the decrease in the crop was water stress. Although similar results were obtained in the second year of the trial, the negative effects of the increase in soil salinity were also observed. However, although *L. strictus* regenerated by rhizome and maintained its productivity at all water levels, there were significant decreases in the yield of *P. distans* and *F. elatior* (Figure 3).

Many halophytic plants thrive optimally at 20 to 25 g l^{-1} soil salinity, and at 30 to 40 g l^{-1} show 25% to 50% growth reduction but they can sustain their lives in soils containing 60 to 90 g l^{-1} salt (Miyamoto et al. 1994). *Leptochloa fusca*, *Spartina patensand*, *Sporobolus virginicus* (Smyrna) are shown as promising halophytic plants for feeding goats and sheep in desert lands using available saline water for irrigation areas (Ashour et al. 1997). In a land with a drainage problem, 85% of the yield from tall wheatgrass was obtained from forage plants irrigated with saline drainage water, while the yield for alfalfa was 43%. (Suyama et al. 2007). Tall wheatgrass has less tolerance to salinity, and the yield is severely reduced (by 55%) under high salinity (Grattan et al. 2004, Robinson et al. 2004). To maintain high bermudagrass yields, it is recommended that soil salinities should not exceed Ec_e 12 dS m^{-1} (Kaffka et al. 2004).

Many salt-tolerant forage crop species, such as the forage crops discussed in this study, can be grown successfully in semi-arid conditions dominated by shallow groundwater. On lands with similar conditions, artificial pastures can be established before improvement. *Puccinellia distans* is a perennial cool-season salty grass, that can adapt to arid climates and extremely saline-alkaline soil conditions (Hughes 1972; Brotherson 1987; Scalia et al. 2009; Ehsani et al. 2016), and, spread in salty meadow-pasture areas. This plant produces between 4 and 10 tons of hay per hectare per year (Warren et al. 1994) and this delicious species (Shidaei & Namati 1978) is generally consumed by sheep [Peng et al. 2004; Akhazari et al. 2012, Ashkan & Jalal 2013], but, it has been reported that increasing salinity causes a decrease in plant height (Acar et al. 2016). Considering that 0.4 hectares of artificial pasture per sheep provides the most economical live weight gain in the shallow water table conditions of *A. elongatum*, *P. capillaris* and *F. elatior* in this research area (Uçar 1982), the usefulness of such an application can be easily understood that it can make a significant contribution to increasing feed production.

3.2. Change in soil salinity and sodium

The salt distribution in the soil profile was similar for all groundwater levels. The distribution of salts in the soil profile was typical, as in soils under the influence of a high water table. That is, the salt concentrations were decreased from the upper layers to the lower layers. Statistical analysis after the experiment showed that the interaction of soil layers and water levels was significant ($F_{0.01}=34.57^{**}$ $p<0.01$) in the first year. Analysis by year showed that the effect of water levels on salinization was insignificant ($F_{0.01}=124.44^{**}$ $p<0.01$), but salt accumulation in soil layers was significantly different.

In other words, the water levels were effective in the salinization of the soil layers. In the beginning, the topsoil layer had the highest salt content and the salinity have been decreased with increasing depth (Table 3, Figure 4). Differences in soil salt contents between treatments were insignificant ($p=0.202>0.05$). However, there was a statistically ($p<0.05$) significant difference between the salt contents of the soil layers.

Table 3- Variation of salinity in soil layers versus different water table depths and crop varieties (A, B, C)

Groundwater depth, cm	*Soil depth,*	*Before trial*				*After trial*			
		ECe, dSm-1				*ECe, dSm-1*			
		A	*B*	*C*	*Mean*	*A*	*B*	*C*	*Mean*
40	0-40	15.3	14.8	15.4	15.2	18.3	21.2	24.7	21.4
	40-70	10.8	6.9	8.5	8.6	7.9	9.9	12.4	10.1
	70-110	5.9	9.0	9.4	8.1	4.9	6.7	6.4	6.0
60	0-40	14.7	16.7	14.5	15.3	20.3	28.8	23.4	24.2
	40-70	8.8	14.3	12.9	12.0	13.1	14.0	16.6	14.6
	70-110	6.7	10.0	6.0	7.6	8.1	7.8	9.2	8.4
80	0-40	16.7	16.4	16.4	16.5	13.9	17.3	12.4	14.5
	40-70	11.1	10.9	12.0	11.3	13.3	9.7	11.0	11.3
	70-110	6.3	7.0	6.3	6.5	6.4	6.9	8.9	7.4
110	0-40	16.5	15.8	16.6	16.3	19.3	16.7	17.7	17.7
	40-70	10.8	7.7	9.2	9.0	14.3	9.6	11.5	11.8
	70-110	7.1	6.7	6.7	6.8	10.4	6.7	8.1	8.4

Before and after the trial all soil layers and all treatments, $p=0.0036<0.01$
Before and after the trial topsoil layer and all treatments, $p=0.025<0.05$

Although the salt accumulation in the upper soil layers was slightly higher than the water table at 80 and 110 cm in the treatments where the water table was kept at a depth of 40 and 60 cm, there was no significant difference observed between them.

On the other hand, when we consider all trial treatments, the salt concentration of the top layer increased significantly at the end of the trial ($p=0.025$). In comparison to the baseline, salt accumulation at depths of 40-70 and 70-110 cm is insignificant ($p=0.326$, $p=0.715$).

It was determined that there was a significant difference ($p=0.006$-0.04) between the salt load of the incoming water and the salt load of the drained water, while there was no difference between the effects of the water table levels on the salt load of the drainage water (Table 4).

Table 4- The salinity of entering and drainage water

Water table depth, cm	*March*	*April*	*May*	*June*	*July*	*March*	*April*	*May*	*June*	*July*
	Inlet water, dS m^{-1}									
	3.3	***3.6***	***4.4***	***4.1***	***4.0***	***3.6***	***3.6***	***3.1***	***4.4***	***4.4***
	Drainage water (1st year)					*Drainage water (2st year)*				
40	5.2	4.3	5.1	4.2	4.0	5.1	5.2	6.0	8.5	5.2
60	6.3	6.1	6.5	6.7	5.5	4.7	8.1	5.4	4.8	
80	4.1	3.6	3.6	4.1	4.1	6.8	6.4	6.7	6.6	4.5
110		10.2	10.2	5.6	5.6	7.50	.	.	.	.

As shown in Table 5, before the experiment, the soil exchangeable sodium percentage (ESP) was 24% in the upper layer and decreased to 4% at 110 cm in depth. At the end of the trial, the ESP values in the topsoil increased significantly in all treatments compared to the initial values and reached 50-60%. In plots with a water table level of 80-110 cm, the ESP values are closer to each other in the entire profile. Crop varieties have not been shown affect ESP change.

Table 5- ESP status before and after trial according to groundwater depths

Groundwater depth, cm	*Soil depth*	*L. sitrictus*	*P. distans*	*F. elatior*	*Soil depth*	*Groundwater depth, cm*	*L. sitrictus*	*P. distans*	*F. elatior*
	ESP status before trial, (%)								
Before trial	0-40	24	24	24					
	40-60	21	21	21					
	60-80	13	13	13					
	80-110	4	4	4					
	ESP status after trial, (%)								
40	0-40	68	61	51	80	0-40	39	94	42
	40-60	22	20	81		40-60	61	53	35
	60-80	16	12	25		60-80	24	74	36
	80-110	13	14	16		80-110	18	29	33
60	0-40	55	50	68	110	0-40	53	60	31
	40-60	38	12	15		40-60	39	53	56
	60-80	28	9	43		60-80	28	21	50
	80-110	21	15	17		80-110	26	23	24

Since there was no difference between the ESP values according to the crops ($p=0.970^{ns}-0.470^{ns}$), the average values are taken and the changes in ESP according to the depths of the water table and soil layers are shown in Table 5 and Figure 5.

Whether there was a difference between the ESP values of the soils before the trial and the ESP values at the end of the trial was determined in the form of pairwise comparisons, taking into account the water table levels.

A statistically significant difference ($p<0.01$; ($0.000-0.007^{**}$) was found between the initial ESP values of all soil layers and the ESP values at the end of the experiment at different water table levels. However, the effect of different water table levels on ESP in soil layers was found to be statistically insignificant ($p>0.05$; $0.95-0.719^{ns}$).

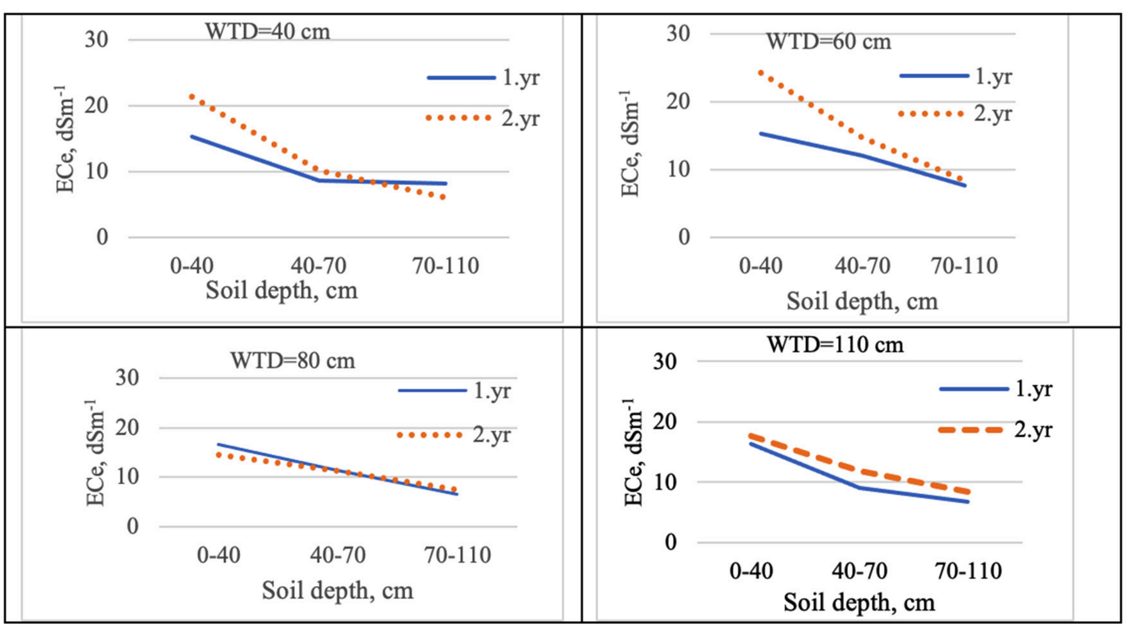

Figure 4- Change of soil salinity at different water table depths

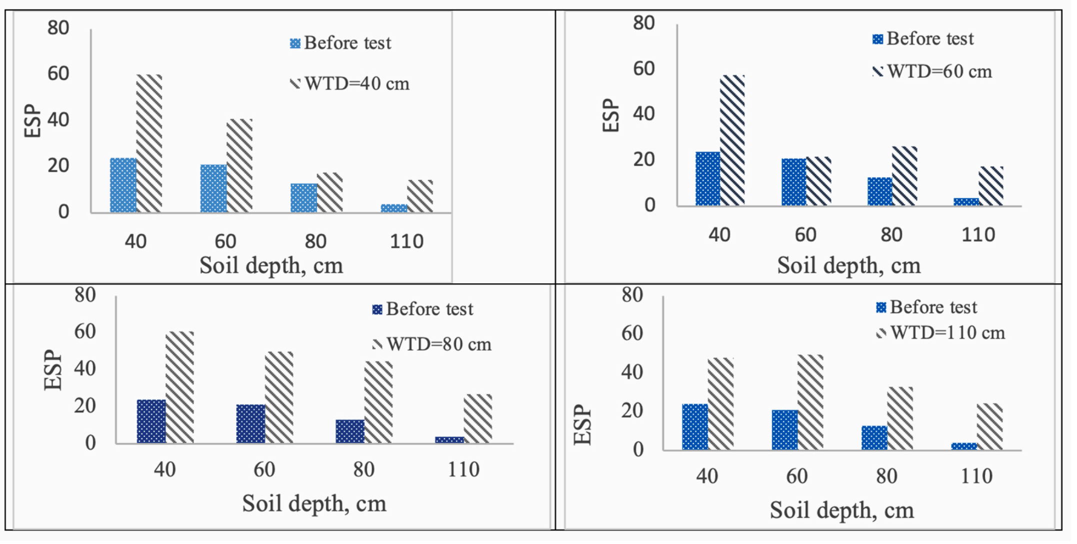

Figure 5- ESP status before and after trial according to different groundwater depths

4. Conclusion

The high groundwater level significantly increased the yield of pasture crops used in the experiment. Significant differences have been found between salt concentrations before and after the experiment in the trial soils. On the other hand, no difference was found between the effects of water table levels on salt and sodium accumulation in the soil.

Even if the high-water table increases the grass yield in the artificial pastures planned to be created, salt and sodium accumulation should be controlled for a sustainable yield. In such areas, it seems possible to create sustainable pastures if managed drainage and groundwater are provided as leaching water at the end of the season and salt-resistant forage crops are grown.

In arid and semi-arid areas under the influence of shallow groundwater for many years, uncontrolled lowering of the water table will accelerate the oxidation of organic matter as well as cause a loss of yield in these pastures. The irrigation and drainage systems in these regions should therefore be planned together, and the drainage systems to be built should be controlled drainage rather than free-flowing.

Data availability: Data are available on request due to privacy or other restrictions.

Authorship Contributions: Concept: İ.B., Design: İ.B., Data Collection or Processing: İ.B., Analysis or Interpretation: B.B., A.F.T., Literature Search: B.B., A.F.T., Writing: B.B., A.F.T.

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