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The Effect of Plant Density and Irrigation Regime on Net Income of Sweet Corn

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ABSTRACT

This study was conducted to determine the effect of two plant density (low: 57000 and high: 95000 plant ha^{-1}) and three irrigation levels (all of the water evaporated from a class A pan (Epan): 3/3 Epan, 2/3 Epan, and 1/3 Epan) on the net income of sweet corn. Field experiments were carried out with the Challenger F1 sweet corn (*Zea mays saccharata* Sturt) variety in Bursa conditions in the Marmara region of Turkey in 2017. As a result of study, the amount of irrigation water applied to the experimental treatments via a drip irrigation system varied between 148 and 444 mm. Relatively higher average fresh ear yield (20.76 t ha^{-1}) was obtained at high plant density under different irrigation levels. On the other hand, the average yield of 3/3 Epan irrigation treatment (22.59 t ha^{-1}) under different plant density was found to be statistically higher ($P<0.05$) compared to other irrigation levels. With the decrease in irrigation level, the fresh ear yield also decreased. The total production costs, including the application of water by drip irrigation system were determined to vary between 2743 and 3000 US$ ha^{-1}. The highest net income per unit area was obtained from the treatment 3/3 Epan irrigation at high plant density with 1846 US$ ha^{-1}, followed by the treatment 2/3 Epan. Net income per unit area at low plant density ranged from 350 to 1292 US$ ha^{-1}. The decrease in the irrigation level decreased the income per unit area. The net income values obtained in return for the unit irrigation water amount were determined as the lowest being 0.24 US$ m^{-3} for 1/3 Epan irrigation treatment and low plant density, while the highest was determined as 0.50 US$ m^{-3} for 2/3 Epan irrigation treatment and high plant density. According to the results obtained from the experiment, under 95000 plant ha^{-1} when there is a land restriction, the irrigation regime in which all the evaporated water from the A class pan is taken as a reference, and in the areas with irrigation water restriction, 2/3 Epan irrigation regime can be recommended.

Keywords: Drip irrigation, Net return, Water productivity

INTRODUCTION

Sweet corn (*Zea mays saccharata* Sturt.) is a subspecies of the corn plant grown in Turkey and the world, and used in its fresh or processed form in human and animal nutrition. The USA is the largest sweet corn producer in the world with a production area of 650 thousand hectares. Approximately 40% of the product obtained in the USA is consumed fresh, while 60% is consumed by processing. After the USA, Nigeria with (7%), France (6%), Hungary (6%) and Peru (4%) are other important countries producing sweet corn in the world. The country that exports the most sweet corn products (fresh, canned, frozen) in the world is the USA, and the most important importing country is Canada. Although sweet corn, which is of great importance among corn varieties, was introduced in Turkey in the 1930s, a great increase in production and consumption has not been achieved (Akman 2015). In the USA, a total of 6.9 kg of sweet corn is consumed, including 3.4 kg of fresh ear, 2.7 kg of canned and 0.8 kg of frozen per capita per year (Çetinkol 1989). Although there is not enough statistical information about the cultivation of this corn in Turkey, its cultivation is increasing in Bursa and some other provinces (Turgut 2000; Sönmez et al. 2013). Considering that horse tooth and hard corn varieties are generally offered to the consumer for fresh consumption, it can be said that the consumption and production potential of sweet corn in Turkey is high (Sencar et al. 1997).

In agricultural production, having sufficient moisture in the root zone of the plant during the production season is extremely important for plant growth, yield and product quality. The first source of this moisture is natural precipitation. In arid and semi-arid regions, the rainfall during the crop production season is insufficient in terms of both quantity and distribution and cannot meet the plant water needs. Therefore, the lack of moisture is met by irrigation (Rasool et al. 2020).

The majority of Turkey has a semi-arid climate, and some regions have a sub-humid climate. In both climatic regions, irrigation is required due to insufficient and irregular rainfall during the production season. However, the availability of water in many parts of the world is economically and technically limited (James 1994, Fereres and Soriano 2007). Insufficient rainfall in terms of optimum plant growth and irregular distribution in

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areas located in arid, semi-arid and sub-humid climatic regions pose a great risk in corn agriculture and make irrigation the most important yield factor.

Water is one of the most important resources for agricultural production. However, today, rapid population growth, pollution of natural resources, global warming and climate change are increasing the pressure on water resources. In order to ensure the food security of the increasing population, agricultural production should be increased in a sustainable way and the limited available water resources should be used in the most efficient way. The limited availability of water resources and the increasing pressures on its use by other sectors (domestic, urban and industrial) makes the effective use of water even more inevitable.

In order to achieve the expected benefit from irrigation, the use of pressurized irrigation systems, which save water and energy, minimize water losses, do not pollute the environment, and increase the amount and quality of products, together with the correct irrigation time planning is required. Thus, effective use of water resources and water savings can be achieved in agricultural irrigation, where water is used the most. Surface drip irrigation is a modern irrigation technique that has advantages such as saving water and energy, increasing efficiency and quality, requiring less labor, allowing the application of fertilizer together with irrigation water.

In agriculture, deficit irrigation is the most effective application in order to save water. Controlled deficit irrigation practices allow savings in water consumption while minimizing the negative effects on yield (Pandey et al. 2000). In addition, with deficit irrigation programs it is possible to eliminate the drainage problem that may occur as a result of excessive application of water through irrigation (Tülücü 1985).

Deficit irrigation is an optimization approach where certain levels of water shortage and crop yield reduction are allowed. The main purpose of this irrigation is to increase the efficiency of water use by saving water from the irrigation water applied in optimum irrigation and to avoid irrigation that affects the yield at the minimum level. Irrigation of more areas with the same amount of water and enabling more income per unit of water are the most important features of deficit irrigation (English et al. 1992, Yıldırım et al. 1995).

Demir et al. (2006), according to their research, Bursa is located in a sub-humid climate zone with limited surface and subsurface water resources. Although it varies from year to year, according to the average data for many years, approximately 100 mm of precipitation falls between the months of May and August when corn is grown in the province. Since the corn plant needs high irrigation water, it is seen that this amount of precipitation is insufficient.

In order to obtain high yield from the corn plant, it is necessary to determine the most appropriate crop density and irrigation level. In addition to the efficiency obtained under these applications, the economic aspect should also be investigated. Although there have been many studies on the effects of different crop density and irrigation levels on maize, there are very limited studies on economic evaluations. For this reason, the effects of different crop density and irrigation levels on net income were investigated in sweet corn irrigated by drip irrigation method in Bursa region.

MATERIALS AND METHODS

This research was carried out in Agricultural Application and Research Center, Faculty of Agriculture, Bursa Uludağ University in 2017. The research site is at 40° 13' north latitude and 28° 51' east longitude. The height of the experimental area above sea level is approximately 113 m. Soil samples were taken and analyzed from every 0-30 cm depth up to 90 cm soil depth in the research area before the experiment was established and the results indicating some physical properties of the soils of the experimental area are shown in Table 1. The soil texture is clayey in the soil layer within 90 cm depth in the research area. The total available water holding capacity for 90 cm soil depth of the experimental area was determined as 163.3 mm. The soils of the study area are slightly acidic at an average of pH=6.25 levels for 0-60 cm soil layer, neutral at 60-90 cm depth, alkaline at 90-120 cm layer, lime-free at 0-60 cm layer, a bit limey at 60-90 cm and in the 90-120 cm layer it is very calcareous and low salty. With these properties, the soils of the experimental area are suitable for sweet corn cultivation.

Table 1. Some physical properties of the soils at the experimental area.

Soil depth (cm)	Clay (%)	Sand (%)	Silt (%)	Soil texture	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})
0-30	49.5	24.32	26.18	Clay	38.17	27.07	1.35
30-60	50.5	23.28	26.22	Clay	40.01	27.03	1.36
60-90	53.5	21.88	24.62	Clay	43.01	26.75	1.34
90-120	40.5	21.64	37.86	Clay	40.05	23.18	1.38

The region has temperate climatic conditions where the winters are cool and rainy and the summers are hot. According to the long-term average climate data and 90 years of observation period, the annual average precipitation is 707.6 mm, and the average temperature is 14.6 °C. In the period between May and July of 2017, when the experiment was conducted, the average temperature, average relative humidity and total precipitation values were measured as 18-26 °C, 62-73% and 108.6 mm, respectively.

Irrigation water was taken from a hydrant approximately 350 m away from the experimental area. The EC (electrical conductivity) value of the irrigation water was determined as 310 µS cm^{-1}, the SAR (sodium adsorption rate) value was determined as 0.23, indicating that the water was in the C_2S_1 class according to the diagram prepared by the United States Salinity Laboratory. The salt tolerance EC threshold value of the corn plant is 1.7 dS m^{-1} making it among the plants with high salt tolerance (Arıcan and Kale 2016). For this reason, it can be said that the water source in question does not have a limiting effect on the cultivation of the sweet corn plant.

In the research, Challenger F1 sweet corn variety, which is recommended as the main product with high yield potential for Bursa, was used. First of all, the experimental area was plowed with a plow, after the soil aeration was ensured, the clods were cut by pulling the disc harrow and a rotary tiller, and then the field was made ready for planting. Irrigation system was established in accordance with the experimental pattern. Before sowing the seeds, soil samples were taken from 3 different soil depth, 0-30, 30-60, 60-90 cm, of the experimental area in order to determine the existing soil moisture was measured by gravimetric method. Corn seeds were sown by hand at a depth of 5 cm in 70 cm row spacing on 25 May 2017. On the same day, all plots were irrigated up to field capacity for 0-90 cm soil layer. Weed control was done every other day in all crop development stages of corn and the weeds were cleared by hoeing method. No diseases or pests were encountered during plant cultivation. The fertilization was 400 kg per hectare of 15-15-15 NPK.

Experiments were carried out according to the split plot design with 3 replications. Two different plant densities (57000 and 95000 plants ha^{-1}) were applied to the main plots and three different irrigation levels (all of the evaporated water (Epan) from a class A pan: 3/3 Epan, 2/3 Epan and 1/3 Epan) are placed in sub-plots. Irrigation was applied to plots when the amount of water evaporated from the pan was 20-25 mm.

Experimental plots were prepared with dimensions of 5.25 m×2.80 m = 14.70 m^2, with 0.7 m row spacing for low plant density, 0.25 m row spacing, and 0.7 m row spacing for high plant density, and 4 rows of plants in 0.15 m row planting plan. A 2 m gap was left between all plots.

Irrigation water was applied to the root zone of the plant with a drip irrigation system. For this purpose, 1 lateral pipe (Ø16 × 20 cm × 2 L h^{-1}) was drawn approximately 10 cm near each plant row. The laterals were connected to the manifolds with a mini valve, where as in the transition from the main pipe to the manifolds a water meter was used to control the water on the basis of volume with a ball valve.

In determining the amount of irrigation water applied, the amount of water evaporated from the Class A evaporation pan was taken into account as the reference evapotranspiration. Accordingly, the amount of irrigation water applied in terms of volume was determined by using Equation 1 (Öktem et al. 2002).

$$IL = A \times Ep \times kp \times kc \times P \quad (1)$$

In the equation, IL is the amount of irrigation water applied (liter), A is the area of a plot (m^2), Ep is the cumulative pan evaporation amount in the time between two irrigations (mm), kp is the pan coefficient, kc is the plant coefficient, and P is the wetted area ratio (%). P was determined to be equal to the percentage of vegetation by measuring before each irrigation during the experimental and was never taken below 30%. In this study, different irrigation levels were created by taking the plant coefficient and the pot coefficient together. The plant-pan coefficient (kpc) was taken as 1.00, 0.66 and 0.33 according to the experimental treatments. Irrigation was continued until the plants reached physiological maturity and irrigation was stopped when they reached physiological maturity.

Harvest of fresh ears; in the period when the grain moisture in the ear was 70-75% (El-Hendawy et al., 2008), all the ears except the two rows in the middle and one plant at the beginning and end of these rows, after leaving one row on the right and left of each plot as an edge effect, were collected by hand (Öktem and Öktem, 2006). All harvested ears were weighed and their weights were determined and converted into yields per hectare.

To determine the economic indicators, the following equations (Equations 2-5) were used (Kuşçu et al., 2014).

$$Gross\ income\ per\ unit\ area\ (US\$\ ha^{-1}) = \frac{Gross\ return\ (US\$)}{Unit\ area\ (ha)} \quad (2)$$

$$Net\ income\ per\ unit\ area\ (US\$\ ha^{-1}) = \frac{Net\ return\ (US\$)}{Unit\ area\ (ha)} \quad (3)$$

$$Net\ income\ to\ irrigation\ water\ (US\$\ m^{-3}) = \frac{Net\ return\ (US\$)}{Irrigation\ water\ applied\ (m^3)} \quad (4)$$

$$Irrigation\ water\ productivity\ (kg\ m^{-3}) = \frac{Yield\ (kg)}{Irrigation\ water\ applied\ (m^3)} \quad (5)$$

The net income per unit area (US\$ ha^{-1}) is found by subtracting the total production costs from the gross income. Gross income was determined for each experimental treatment by multiplying the yield values by the local selling price of the sweet corn in the field (0.20 US\$ kg^{-1}). The total production cost was determined by adding the fixed and variable costs. Fixed costs were considered equal for all experimental treatments. The data obtained from the Bursa Provincial Directorate of the Ministry of Agriculture and Forestry of Turkey were used in the calculation of fixed costs (soil preparation, planting, fertilization, control of plant diseases and pests, harvesting and threshing). In addition, since the drip irrigation system was used in the irrigation of sweet corn, the system cost per unit area was determined as 4200 US\$ ha^{-1}. Since the lifetime of the drip irrigation system was considered to be 7 years, the annual cost of drip irrigation was determined as 600 US\$ ha^{-1}. In this study, since different crop density and irrigation levels are variables, seed costs, water price and costs related to irrigation were taken as variable costs. It is obtained by dividing the volumetric irrigation water (m^3 ha^{-1}) by the amount of water given in 1 hour (m^3 $hour^{-1}$ ha^{-1}) for the irrigation season, taking into account the total irrigation time (hour ha^{-1}), dripper flow rate and dripper spacing characteristics. Labor cost for irrigation (US\$ $hour^{-1}$) was determined by considering the average daily wage of an agricultural worker (1.2 US\$ $hour^{-1}$) in Bursa conditions. Total cost for irrigation labor (US\$ ha^{-1}) was determined by multiplying the irrigation duration for the irrigation season and the 1.2 US\$ $hour^{-1}$. In the study area, an energy cost has been taken into account, considering that an electrically powered pump (15 kW) would be used to pump the irrigation water into the drip irrigation system. Electric energy cost (US\$ ha^{-1}), taking into account the characteristics of the drip irrigation system used in this study, was calculated by multiplying irrigation duration (hour ha^{-1}) determined for each experimental treatment with the agricultural electrical energy cost (US\$ kW $hour^{-1}$) and 15 kW values. The cost of the water used (US\$ ha^{-1}) was found by multiplying the unit volume water price (0.017 US\$ m^{-3}) with the amount of irrigation water applied per unit area (m^3 ha^{-1}) according to the experimental treatment. Thus, the cost of the water used for each irrigation treatment, the irrigation labor cost, the energy cost and the water price were added to get the variable costs related to irrigation. Seed costs for the two different crop densities were treated as variable costs.

SPSS (Statistical Package Program for Social Science) 23.0 program was used in the variance analysis of the fresh ear yield values obtained from the study.

RESULTS AND DISCUSSION

Irrigation water applied

The amount of irrigation water applied to the experimental treatments varied between 148 and 444 mm (Fig. 1). Total precipitation was measured as 108.6 mm in the growing season. Similarly, Gündüz and Beyazgül (1998) determined the amount of irrigation water applied to the corn plant in Balıkesir conditions as 586 mm, Çamoğlu et al. (2011) reported the amount of seasonal irrigation water in sweet corn irrigated by drip irrigation in Çanakkale region as 50-389 mm.

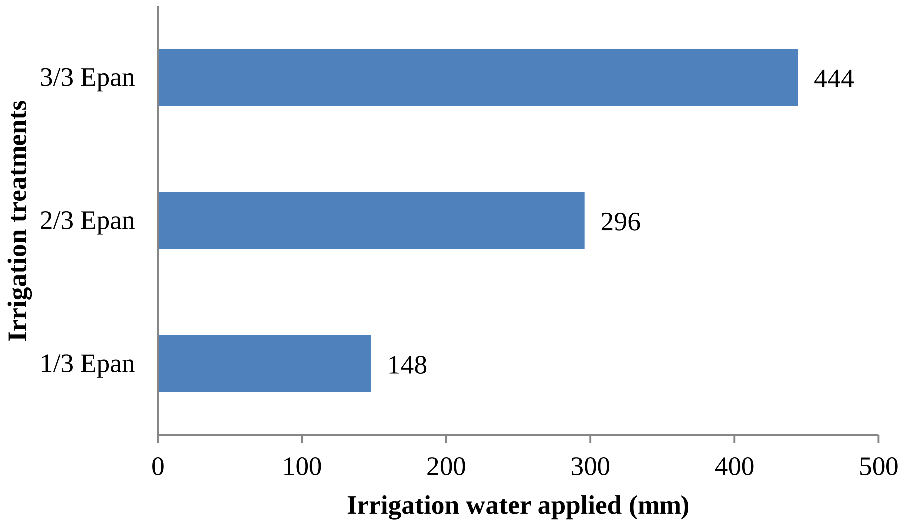

Figure 1. Seasonally applied irrigation water amounts.

Fresh ear yield

The fresh ear yield values obtained according to different plant density and irrigation levels are given in Table 2. According to ANOVA results, the effect of different plant density (PD) and irrigation levels (IL) on fresh ear yield was statistically significant ($p<0.01$). On the other hand, the effect of PD × IL interaction on yield was insignificant.

In the grouping made according to Duncan's multiply range test, higher yield was obtained at high crop density (95000 plant ha^{-1}). With the increase in the amount of irrigation, the fresh ear yield also increased. While the highest yield was obtained from 3/3 Epan application as 22.59 t ha^{-1}, the lowest yield was determined from 1/3 Epan application. The average yield from the 2/3 Epan application was 9% less than the 3/3 Epan application. Öktem et al. (2002) reported that the highest fresh ear yield in sweet corn irrigated with drip irrigation in a semi-arid region, the irrigation interval was two days, and the irrigation water amount was obtained from the treatment where all evaporation from the Class A evaporation pan was applied. In the study conducted by Vural and Dağdelen (2008) in Aydın region in 2006; the highest yield was obtained from the full irrigation water application, and the lowest yields were obtained from the dehydrated treatments. The results obtained from the above-mentioned studies show parallelism with the findings obtained from this study.

Table 2. Fresh ear yield (t ha^{-1}).

Treatments	**Plant density (plant ha^{-1})**		
Irrigation level	**57000**	**95000**	**Mean**
1/3 Epan	15.47	16.03	15.75 c
2/3 Epan	19.21	22.01	20.61 b
3/3 Epan	20.95	24.23	22.59 a
Mean	18.54 b	20.75 a	19.65

Note: According to Duncan's multiply range test at a significance level of $P<0.05$, lowercase letters indicate differences in yield in terms of irrigation or crop density.

Economic indicators

Table 3 shows the fixed and variable costs of sweet corn grown under drip irrigation with different irrigation levels and crop densities. Total cost for 1 year ranged from 2743.2 to 3000.5 US$ ha^{-1}. The highest total cost was obtained at 9500 plant ha^{-1} crop density at 3/3 Epan irrigation level, while the lowest was obtained from 57000 plant ha^{-1} and 1/3 Epan applications. Generally, with the decrease in crop density and irrigation level, total costs have also decreased.

Table 3. Fixed and variable costs.

Plant density (plant ha^{-1})	**Irrigation level**	**Total cost for irrigation labor (US$ ha^{-1})**	**Water pumping cost via electrical motor pump (US$ ha^{-1})**	**Water cost (US$ ha^{-1})**	**Yearly cost of drip irrigation system (US$ ha^{-1})**	**Seed cost (US$ ha^{-1})**	**Crop production cost (US$ ha^{-1})**	**Total cost for 1 year (US$ ha^{-1})**
95000	3/3 Epan	74.6	78.4	75.5	600	262	1910	3000
	2/3 Epan	49.7	52.2	50.3	600	262	1910	2924
	1/3 Epan	24.9	26.1	25.2	600	262	1910	2848
57000	3/3 Epan	74.6	78.4	75.5	600	157	1910	2895
	2/3 Epan	49.7	52.2	50.3	600	157	1910	2819
	1/3 Epan	24.9	26.1	25.2	600	157	1910	2743

Gross income per unit area values were calculated to be lower in parallel with yield values at high plant density and 3/3 Epan irrigation level (Table 4). The highest net income to unit area (1845.5 US$ ha^{-1}) was obtained from 95000 plant ha^{-1} plant density and 3/3 Epan irrigation, followed by 2/3 Epan, and the lowest value was obtained from 57000 plant ha^{-1} plant density and 1/3 Epan irrigation treatment. On the other hand, the highest net income to irrigation water was obtained with high plant density and 0.50 US$ /m^3 under 2/3 Epan irrigation level, followed by 3/3 Epan application. When the irrigation levels are examined under both plant densities, 2/3 Epan application provides higher return per unit irrigation water, while 1/3 Epan application provides lower return. According to these results, if the aim is to maximize the income, 1/3 Epan application is not recommended since it provides low returns per unit area and unit water. High plant density and 3/3 Epan irrigation level should be preferred to maximize net income in areas with sufficient irrigation water but land constraints. However, if it is aimed to maximize the net income in regions where irrigation water needs to be reduced, 2/3 Epan irrigation can be recommended. In this study, irrigation water productivity values increased with the decrease in irrigation level (Table 4). In a similar study conducted on silage maize, it was determined that net income per unit area according to varieties and net income differ according to unit irrigation water volume (Karaer et al. 2021). On the other hand, Okursoy (2009) reported that the highest net income was achieved when 443 mm of irrigation water was applied to the corn plant. Yolcu et al. (2016) reported that the most appropriate irrigation scheduling and nitrogen fertigation were application of irrigation water (447 mm) consisting of 100% cumulative evaporation from Class A pan (Ep) and equal amounts of nitrogen at each irrigation cycle (5 days), and net return per unit area and net return per volumetric water values were 305.4 TL da^{-1} and 1.78 TL m^{-3}, respectively.

Table 4. Economic indicators

Plant density (plant ha^{-1})	**Irrigation level**	**Gross income per unit area (US$ ha^{-1})**	**Net income to unit area (US$ ha^{-1})**	**Net income to irrigation water (US$ m^{-3})**	**Irrigation water productivity (kg m^{-3})**
95000	3/3 Epan	4846	1845.5	0.42	5.5
	2/3 Epan	4402	1477.7	0.50	7.4
	1/3 Epan	3206	357.8	0.24	10.8
57000	3/3 Epan	4188	1292.5	0.29	4.7
	2/3 Epan	3840	1020.7	0.34	6.5
	1/3 Epan	3094	350.8	0.24	10.5

CONCLUSIONS

The effect of different irrigation levels on yield and net income in sweet corn grown in Turkey's sub humid climatic conditions and soils with clay soil texture, under different crop density and different irrigation levels, based on the evaporation data from Class A pan under drip irrigation, were investigated. Relatively higher fresh ear yields were obtained with the increase in irrigation levels and higher plant density. According to the results of the study, in order to obtain a higher net income per unit area, it can be recommended to grow sweet corn at a crop density of 95000 plant ha^{-1} and to irrigate with reference to all the water evaporated from the Class A pan. In conditions where irrigation water is insufficient and its cost is high, it can be recommended to grow it at a crop density of 95000 plant ha^{-1} and under 2/3 Epan conditions.

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