AGROKÉMIA ÉS TALAJTAN 72 (2023) 1, 64–80
DOI: 10.1556/0088.2023.00135

Effect of irrigation and fertiliser doses on sweet corn yield, water consumption and water utilization

[1]Ildikó SZALÓKINÉ ZIMA

[1]Department of Irrigation and Land Improvement, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Szarvas, Hungary

(Received: 23 Sep 2022; Accepted: 01 Jan 2023)
(First published online: 08 Feb 2023)

Original article

Abstract

The experiment was conducted within a framework of a two-factor long-term trial at the Research Institute for Fisheries, Aquaculture and Irrigation, in Szarvas, Hungary. This was a special field experiment, in which lysimeters have been installed in the middle of 32 m^2 field plots. The main factor was the water supply with 4 levels: i_1: non-irrigated control; i_2: irrigated with one third of the optimal water supply; i_3: irrigated with two thirds of the optimal water supply; i_4: optimum irrigated plot, according to the requirement of sweet corn test plant. The amount of released irrigation water was 0, 54, 106 and 158 mm per year on average over 5 years. Within every water supply treatment there were 4 nutrient supply rates (N): N1, N2, N3, N4 = 100, 200, 300 and 400 kg ha^{-1} NPK fertiliser substance in ratio 2:1:1. The number of replications was 4, and the experiment was arranged in split-plot design. In the studied years, the amount of precipitation varied between 92 and 264 mm from sowing to harvesting.

The effect of fertiliser was less in the non-irrigated treatments compared to that of the irrigated ones, and the yield was increased only up to 200 kg ha^{-1} NPK treatment level. The NPK dose of 300 kg ha^{-1} proved to be optimal in the irrigated treatments in which the utilization of fertilizer doses increased parallel to the improving water supply. In addition, the ratio of first class products (cobs longer than 20 cm) increased to a greater extent than the yield as a result of irrigation and fertilization. *Water requirement* of sweet corn proved to be between 400-450 mm resulting in an average yield of 20-24 t ha^{-1}, of which 18-20 t ha^{-1} came from marketable cobs. *The amount of evapotranspiration* fluctuated between 270-440 mm during the five years, depending on the quantity of water supply, but it changed to a lesser extent than the amount of the yield. Increasing the fertilizer dose practically did not affect ET in non-irrigated plants, but increased it by 20-30 mm in irrigated ones. The change was not significant.

Corresponding author: Ildikó SZALÓKINÉ ZIMA, Department of Irrigation and Land Improvement, Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences 5540 Szarvas, Szabadság u. 1-3., Hungary
*E-mail:*szalokine.zima.ildiko.zsuzsanna@uni-mate.hu

The *productivity of ET* was only 30-45 kg ha^{-1} mm^{-1} in the non-irrigated treatment, while it was 50-55 kg ha^{-1} mm^{-1} in the irrigated treatments, with higher values at the higher fertiliser rates. The *productivity of irrigation water* exceeded far over the productivity of ET at adequate nutrient supply. The yield increase per 1 mm of irrigation water was on average 60 kg ha^{-1} mm^{-1}, which was considerably higher than the productivity of ET of non-irrigated plants (39 kg ha^{-1} mm^{-1}). There was a positive correlation between the yield and ET, and a negative correlation between the yield and specific water consumption. Irrigation and fertilization increased the average yield to a greater extent than evapotranspiration, so as the average yield increased, the ET per unit of yield decreased, i.e. the productivity of evapotranspirated water increased.

Keywords: evapotranspiration, water supply, nutrient supply, sweet corn, yield

Introduction

Sweet corn is an important food plant not only in Hungary but also worldwide. Its cultivation requires much more attention than fodder corn, because its production costs are higher, and its profitability depends not only on the quantity of the crop, but also on its quality. In addition, crop safety and the timing of harvesting are also very important for the food industry. In Hungary with exception of precipitation, the environmental conditions for sweet corn cultivation are good. The quantity and distribution of precipitation over the season often falls markedly short of the needs of sweet corn, which makes its production risky in the Hungarian Great Plain, so its cultivation is increasingly concentrated in irrigated areas.

Though the water requirement of sweet corn is lower than that of fodder maize due to its shorter growing period (around 100 days), nevertheless it needs much more irrigation, because on the one hand, initial irrigation is often necessary due to the intermittent sowing, and on the other hand, in order to achieve first-class cob yield sizes and to keep the kernels tender until harvesting, it is essential to ensure adequate water supply. In numerous studies, it was found that better water supply increased not only the yield but also the amount of the marketable sweet corn ears (NOEIN & SOLEYMANI, 2022; NEMESKÉRI et al., 2019; ILLÉS et al., 2022; FARSIANI et al., 2011).

ZSOMBIK & DARÓCZI (2008) experienced an increase in sweet corn yield every year as a result of irrigation, which was 5 t ha^{-1} on average for the Jubilee variety. The average yield of sweet maize was 14.9 t ha^{-1} in the non-irrigated treatment and 19.6 t ha^{-1} in the irrigated ones. The maximum yield in the irrigated treatment was achieved with 159-197 kg ha^{-1} of N+PK fertilizer, while without irrigation the increase in crop yield ended with a much lower dose of fertilization, and the dose of 120 kg ha^{-1} of N+PK caused even a decrease in yield. Also according to LENTE (2012), the success of sweet corn cultivation is largely determined by the amount of water available to the plant. In his experiments, the effect of different years (mainly water supply) was the most decisive factor in the development of crop yield. In the studies of ROSA et al. (2016), the more uniform distribution of precipitation, combined with the cooler month of July resulted in a higher average yield and longer ears for sweet corn. The agrotechnical factors were also more effective in the favourable years and help the utilization of water (LENTE & PEPÓ, 2011). Several studies have investigated the effect of nutrient supply and seed number on the development of sweet corn ear yield (KAR et al., 2006; JAT et al., 2009; KUMAR 2009). At the same time, irrigation increases the absorption and utilization of nutrients by plants, thereby reducing their accumulation in the soil and their leaching towards the deeper layers.

Irrigation, on the other hand, changes the water and nutrient circulation of the soil and it is not only the economic but also the environmental impact that must be taken into account.

In relation to these, although there are many research results in the world literature (ZWART, 2004) and there are also results in Hungary (RUZSÁNYI, 1974), there are still many questions for future research and one of the most important is the regulation of water- and nutrient circulation and utilization that corresponds both economic and ecological requirements.

This study presents the following results for sweet corn: the quantity and size distribution of the crop, the amount of actual evapotranspiration (ET), the productivity of ET and the irrigation water, the tendency and closeness of the regression relationships between the quantity of the crop and the ET, the relationships between the quantity of the crop and the productivity of water.

Materials and methods

The experiments have been carried out at the Lysimeter Station of the Research Institute for Fisheries, Aquaculture and Irrigation, Szarvas, Hungary, which is situated in the south-east of Hungary (lat. 46°8', long. 20°5', 86 m a.s.l.). The experiment was carried out in three blocks, each with 64–64 lysimeters, the size of which was 1×1×1 m (1 m^3), built in the middle of the 32 m^2 field plots. The lysimeters were closed from each side, so they made measurements of water balance easier, faster and more accurate, as in field plots.

In the base there was a discharge hole, which was connected through pipelines to dishes placed in the cellar, where the amount of leachate was collected and measured. The two-factor long-term experiment has been conducted since 1971, in 16 treatment-combinations, i.e. at 4 water levels multiplied by 4 nutrient supply levels in 4 replications arranged in split-plot design.

The water supply treatments of the main plots consisted of the following 4 irrigation levels: i_1: non-irrigated control; i_2: irrigated with one third of the optimal water supply; i_3: irrigated with two thirds of the optimal water supply; i_4: optimum irrigated plot (according to the requirement of plants). The irrigation according to the requirement of plants means, that the available part of the water capacity was maintained always above 50% in the upper 30 cm soil layer.

The soil moisture content was continuously measured with tensiometers placed at a depth of 20 cm. The irrigation was performed by dripping pipelines. The main plots were split into subplots that included 4 nutrient supply rates (N): N1, N2, N3, N4 = 100, 200, 300 and 400 kg ha^{-1} of a 2:1:1 NPK fertiliser active agent, respectively.

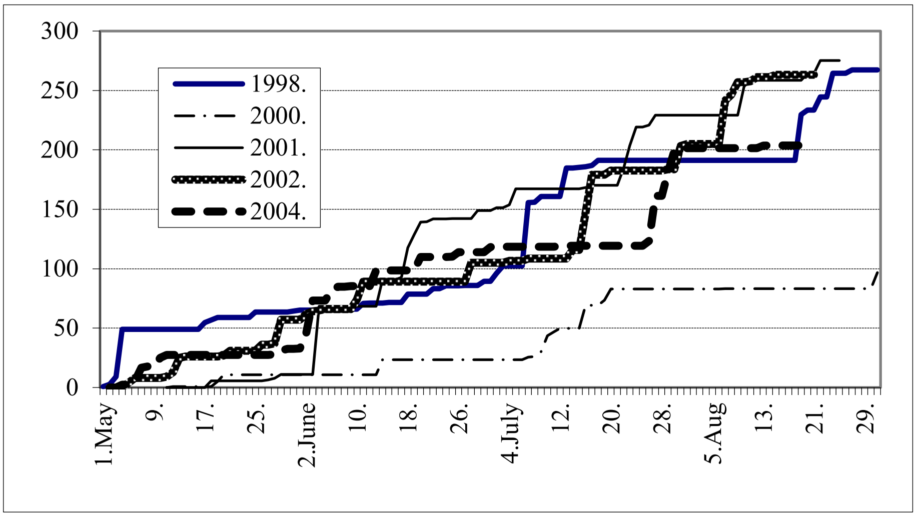

Figure 1
Accumulated precipitation amounts from sowing to harvest (mm). Szarvas, Hungary

Treatments are marked with a 2-digit number, the first digit indicates the water supply level, the second the nutrient supply level (e.g. 44 = water level 4, and nutrient supply level 4).

Table 1
Annually applied irrigation water, mm

Years	i_1	i_2	i_3	i_4
1998	0	40	80	120
2000	0	100	200	300
2001	10	40	70	100
2002	0	50	100	150
2004	0	40	80	120

The trials with the sweet corn were carried out in crop rotation of the long-term experiment in 1998, 2000-2002 and 2004. The variety was Jubilee, which was planted with a row and stem spacing of 0.5×0.29 m, having a plant density of 60 000 plants ha^{-1}. The previous crop was red pepper in 1998, potato in 2004, and onion in the other three years. The time of sowing was between 2nd-11th May, and the harvesting was between 10th-19th August. The length of the vegetation period varied between 95-105 days. In this season, the amount of precipitation varied between 92-264 mm *(Figure 1).* The released irrigation water per year ranged between

40-100 mm in treatment i2, 80-200 mm in treatment i3 and 100-300 mm in treatment i4 *(Table 1)*.

The soil texture was clay loam with an average pH of 7.5, and with a humus content of 2.5%. Its natural water capacity was 39% by volume, half of which is disposable water. Its total salinity in the upper 30 cm layer was 0.05% on average. The soil was very well supplied with phosphorus and potassium. Because of this, only nitrogen has a decisive role in shaping the yield average. The nitrogen content was originally medium, but differences developed in the soil depending on the treatments *(Table 2)*

Table 2
Soil test results from the plots, Lysimeter station, Szarvas, 2000

Treatment	*Soil layer cm*	*pH H_2O*	*$CaCO_3$ %*	*NO_3-N ppm*	*NH_4-N ppm*	*P_2O_5 ppm*	*K_2O ppm*	*Na ppm*
				1 n KCl			*1 n AL*	
11	0-200	8.19	5.79	3.89	2.85	1247	945	69
12	0-200	8.36	7.97	4.93	3.69	820	1210	62
13	0-200	8.42	8.57	7.86	4.23	751	1465	71
14	0-200	8.37	6.39	8.54	5.31	797	1418	73
	i_1 (mean)	*8.33*	*7.18*	*6.31*	*4.02*	*904*	*1259*	*69*
21	0-200	8.38	7.56	3.11	2.74	528	1553	94
22	0-200	8.12	5.66	3.32	3.26	672	1373	89
23	0-200	8.10	6.84	6.17	2.66	625	1439	101
24	0-200	8.09	11.44	6.36	3.54	550	1134	101
	i_2 (mean)	*8.17*	*7.88*	*4.74*	*3.05*	*594*	*1375*	*96*
31	0-200	8.14	9.26	2.06	3.13	280	1184	86
32	0-200	8.18	7.89	2.63	2.69	495	1370	92
33	0-200	8.06	6.17	4.54	3.56	506	1293	88
34	0-200	8.06	6.83	4.71	3.67	165	1298	82
	i_3 (mean)	*8.11*	*7.54*	*3.49*	*3.26*	*362*	*1286*	*87*
41	0-200	8.28	7.44	1.63	2.57	178	1743	77
42	0-200	8.24	9.17	2.59	2.53	319	1567	80
43	0-200	8.23	9.20	3.43	4.26	131	1459	87
44	0-200	8.26	9.09	4.41	3.67	166	1631	81
	i_4 (mean)	*8.25*	*8.73*	*3.01*	*3.26*	*198*	*1600*	*81*

According to the soil test results of spring 2000, the average NO_3-N content of the 2 m layer of the plots was twice as much (6.00 ppm) in the N4 treatments as it was in the N1 treatments (2.67 ppm). At the same time, the amount of nitrate in the i4 treatments was half as much as the average of the i1 treatments (e.g. 8.54 ppm in the case of 400 kg ha^{-1} NPK application in the i1 and 4.41 ppm in the i4 treatment), that is, fertilization doubled and irrigation halved the amount of nitrate. Thus, it was almost identical in the i1N1 and i4N4 treatments, only the depth distribution showed a difference *(Figure 2)*.

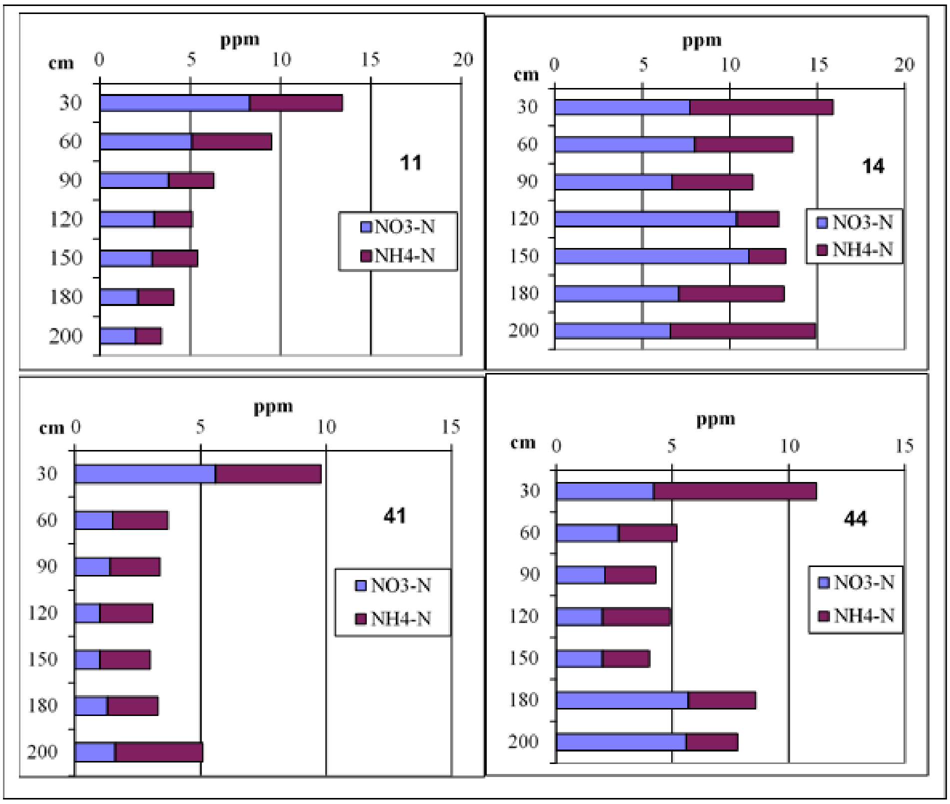

Figure 2.
Depth distribution of the amount of NO_3-N and NH_4-N (ppm) in the irrigation and fertilization treatment combination. Long-term experiment (treatments: i1N1, i1N4, i4N1, i4N4). Szarvas, 2000

The actual evapotranspiration was calculated in the lysimeters by the water balance method according to the following equation: ET = P + I - Inf ± Smd, where P: precipitation, I: irrigation water, Inf: infiltration, Smd: soil moisture difference between sowing and harvesting.

Hungary has a continental climate, the annual average precipitation is 500-600 mm, and in the growing season it ranges from 130 mm to 550 mm, of which the average is 300 mm in the Hungarian Great Plain. The mean temperature over the whole year is 10.5°C, and in the growing period it is 17.5°C.

The statistical evaluation of the results for a two-factor, split-plot design experiment was carried out using the analysis of variance recommended by SVÁB (1973). For the regression analyses, the Microsoft Office Excel 98 software package was used.

Results

1998 was a wet year, but the distribution of precipitation was not suitable for sweet corn. In the critical vegetation period, from 18th July to 19th August there was no rain. Irrigation was carried out only during this dry period, a total of 40, 80 and 120 mm of water was dispensed per treatment, four times, in 10, 20, 30 mm portions. The effect of irrigation was significant even in the average of the nutrient treatments: i_2, i_3 and i_4 resulted in 2.3; 6.5 and 7 t ha^{-1} yield surplus, respectively, compared to the i_1 control, and the yield was increased by 7-8 t ha^{-1} when combined with higher nutrient supply (*Table 3*).

Table 3
The raw cob yield of sweet corn, t ha^{-1}

Treatment		*1998*	*2000*	*2001*	*2002*	*2004*	*mean*
	11	12.1	10.6	13.8	11.9	13.9	*12.5*
	12	12.8	12.1	14.7	11.7	15.8	*13.4*
	13	13.1	8.5	12.8	12.7	15.1	*12.5*
	14	13.5	8.0	11.0	10.1	13.5	*11.2*
i_1 (mean)		*12.9*	*9.8*	*13.1*	*11.6*	*14.6*	*12.4*
	21	13.1	16.2	16.0	13.1	14.9	*14.7*
	22	14.5	17.5	18.3	14.6	16.4	*16.3*
	23	16.7	19.9	18.3	16.9	17.0	*17.8*
	24	16.5	17.5	16.8	16.7	15.5	*16.6*
i_2 (mean)		*15.2*	*17.8*	*17.4*	*15.3*	*16.0*	*16.3*
	31	17.7	18.1	15.2	15.2	14.1	*16.1*
	32	19.7	22.3	18.4	17.1	17.2	*18.9*
	33	20.1	24.0	19.3	20.3	18.5	*20.4*
	34	20.1	24.4	18.7	20.3	17.9	*20.3*
i_3 (mean)		*19.4*	*22.2*	*17.9*	*18.2*	*16.9*	*18.9*
	41	18.1	19.3	14.1	15.4	14.1	*16.2*
	42	19.0	22.0	18.0	21.3	17.8	*19.6*
	43	20.9	23.4	20.0	22.9	20.4	*21.5*
	44	21.6	24.5	19.6	23.1	20.5	*21.8*
i_4 (mean)		*19.9*	*22.3*	*17.9*	*20.7*	*18.2*	*19.8*
N1 (mean)		15.2	16.1	14.8	13.9	14.2	*14.8*
N2 (mean)		16.5	18.5	17.4	16.7	16.9	*17.3*
N3 (mean)		17.7	19.0	17.6	17.6	17.6	*17.9*
N4 (mean)		17.9	18.6	16.5	17.6	16.8	*17.5*
i x N (mean)		*16.8*	*18.0*	*16.9*	*16.9*	*16.9*	*17.2*
LSD5% (i)		1.12	2.04	0.81	0.79	0.81	1.11
LSD 5 % (N)		0.96	2.12	0.56	0.51	0.56	0.51
LSD 5% (i*N)		1.37	3.14	1.12	0.97	1.12	0.97

Table 4
Sweet corn water consumption (ET), mm

Treatment	*1998*	*2000*	*2001*	*2002*	*2004*	*mean*
11	316	291	319	302	347	*315*
12	324	296	333	305	351	*322*
13	326	279	336	311	356	*322*
14	322	272	334	310	358	*319*
i_1 (mean)	*322*	*284*	*331*	*307*	*353*	*319*
21	342	362	332	330	364	*346*
22	363	361	376	351	370	*364*
23	366	372	379	366	376	*372*
24	365	374	375	378	386	*376*
i_2 (mean)	*359*	*367*	*366*	*356*	*374*	*364*
31	372	376	380	369	368	*373*
32	389	399	385	382	381	*387*
33	396	419	392	412	395	*403*
34	395	437	390	420	400	*408*
i_3 (mean)	*388*	*408*	*387*	*396*	*386*	*393*
41	398	400	392	396	372	*391*
42	411	430	402	431	391	*413*
43	415	426	405	437	398	*416*
44	411	442	411	449	401	*423*
i_4 (mean)	*409*	*424*	*402*	*428*	*391*	*411*
N1 (mean)	357	357	356	349	363	*356*
N2 (mean)	372	371	374	367	373	*372*
N3 (mean)	376	374	378	382	381	*378*
N4 (mean)	373	381	377	389	386	*381*
i x N (mean)	*369*	*371*	*371*	*372*	*376*	*372*
LSD5% (i)	16	17	16	13	16	16
LSD 5 % (N)	12	15	12	11	12	11
LSD 5% (i*N)	19	20	19	16	19	16

The evapotranspiration was 322 mm in i_1 control treatment (*Table 4*). Only 13 t ha^{-1} cob yield was produced with the amount of natural precipitation without irrigation. The productivity of ET without irrigation was relatively low, 40 kg ha^{-1} mm^{-1}. Among the applied irrigation water doses, the i_3 (80 mm) proved to be the most effective. This increased yield by 6.5 t ha^{-1}. The amount of increased yield per 1 mm of the irrigation water was 82 kg ha^{-1}. This value is two-times more than the efficiency of ET in the non-irrigated treatment. The yield increase was not significant by the effect of 120 mm irrigation water compared to the 80 mm. Increasing the fertilizer doses without irrigation increased the average yield only slightly, but with adequate water supply it increased the average yield significantly from 2.84 to 3.46 t ha^{-1}. The treatments this year increased only the size of cobs and kernels, not the number of cobs, since the irrigations were done in the post-flowering period. As a result of the treatments, the weight of the more valuable cobs over 20 cm increased from 7.06 t ha^{-1} to 19.56 t ha^{-1}, while the number and weight of the small cobs decreased from 5 t ha^{-1} to 2 t ha^{-1}.

At the beginning of the vegetation period in *2000,* the soil was saturated – in some places oversaturated, but only 96 mm fell during the growing season from sowing to harvesting (*Figure 1*). This year, without irrigation, due to the rapid drying of the top layer of the soil, the emergence of the plants was hindered, and later the moisture content of the deeper layers of the soil was also greatly reduced, and the water supply of the plants was severely limited from flowering to harvest. During the growing season, instead of the water demand of around 440 mm, the sweet corn was able to use only 284 mm of water from precipitation and soil moisture reserves *(Table 4).* Because of this neither the cobs, nor the kernels developed properly. The abundant supply of nutrients in N3 and N4 treatments was not beneficial either, and even had a depressing effect. In the irrigated treatment, however, as a result of 100; 200; 300 mm of water supply, the water consumption increased to 360-440 mm, and the average yield in these lysimeters more than doubled (from 10.6 t ha^{-1} to 22 t ha^{-1}), and the weight of the valuable, large cobs increased 5-10 times. The precipitation – as usual in drought years – was poorly utilized. In the control treatments, the evapotranspiration productivity was only 30-44 kg ha^{-1} mm^{-1}, however in the irrigated treatments, due to better utilization of the irrigation water, it was 45-60 kg ha^{-1} mm^{-1}. 100 mm of irrigation water together with a favourable supply of nutrients in N3 treatment increased the yield by an average of 10 t ha^{-1} compared to the non-irrigated one, which means an average yield increase of 100 kg ha^{-1} per 1 mm of irrigation water. The 200 mm irrigation increased the average yield even further, by 4-6 t ha^{-1}, with a productivity of 78-82 kg ha^{-1} mm^{-1}. At low NPK doses, however, also the irrigation water was poorly utilized (36-22 kg ha^{-1} mm^{-1}). The i_4 treatment with 300 mm water supply did not result in further increase compared to the previous level. Irrigation improved the quality and also the proportion of larger cobs from 15-25% to 80-95%.

In the year *2001,* the winter semester and the beginning of the growing season (April-May) had poor rainfall. Within this, a total of 10 mm of precipitation fell between May 1 and June 4, during the period of emergence and the beginning of development, while the temperature was well above normal values. In this period 40, 70 and 100 mm irrigation water was applied to the irrigated treatments. After June 4, no more irrigation was needed, because sufficient precipitation fell until the end of the month, and the amount of precipitation in July was 80 mm. However, the impact of the developmental retardation caused by the early drought could not be corrected by the later rainfall. This is why irrigation increased the cob yield on average by 35-40% compared to the baseline level (i1–i2–i3-i4 = 13.1–17.4–17.9–18 t ha^{-1}) averaged over the fertilizer treatments, and by 50-78% in the case of good nutrient supply (i1N4:11 t ha^{-1}, i2N4:16.8, i3N4:18.7, i4N4: 19.6 t ha^{-1}) (*Table 3).* The amount of the first class cob yield (over 20 cm in length) increased to a higher proportion contrary to the small cobs. However, the water supply above 70 mm did not result in further increase. The evapotranspiration in the non-irrigated treatment was around 331 mm *(Table 4),* with an average raw cob yield of 13 t ha^{-1}. At the same time, the irrigated sweet corn stands used 370-400 mm of water, with which they were able to produce 18-20 t ha^{-1} of ear crop. The yield per unit of evapotranspiration (Y/ET) was 40 kg ha^{-1} mm^{-1} in the control treatments, and 47 kg ha^{-1} mm^{-1} in the case of 70 mm water supply. The favourable water and nutrient supply significantly increased the proportion of the first-class cob yield this year as well. In treatment 11, the marketable yield was 8.8 t ha^{-1}, which rose to 17.6 t ha^{-1} in treatment 44.

In the year *2002*, the winter precipitation was extremely low, of the 104 mm that fell, only 40-50 mm was stored in the soil. This was followed by a dry, warm April, and then, between 10th June and 14th July there was a period almost without rainfall combined with very high temperatures, so the non-irrigated sweet corn suffered badly, and the setting of kernels was also hindered. Thus, in these treatments, almost no cobs suitable for eating were formed. The yield was in the non-irrigated treatment 11 t ha^{-1} on average, and in the irrigated treatments it varied between 13-23 t ha^{-1} *(Table 3)*. In *Table 4* it can be seen that the evapotranspiration in the non-irrigated treatments was 307 mm on average, but increased to 330-449 mm in the irrigated plant stands. The utilization of ET without irrigation was low, and only 36.1 kg ha^{-1} fresh ear crop of poor-quality was reached per 1 mm of ET. The productivity of irrigation water combined with the N3 and N4 nutrient supply was also 2-3 times higher this year (75-130 kg ha^{-1} mm^{-1}) than the utilisation of the precipitation.

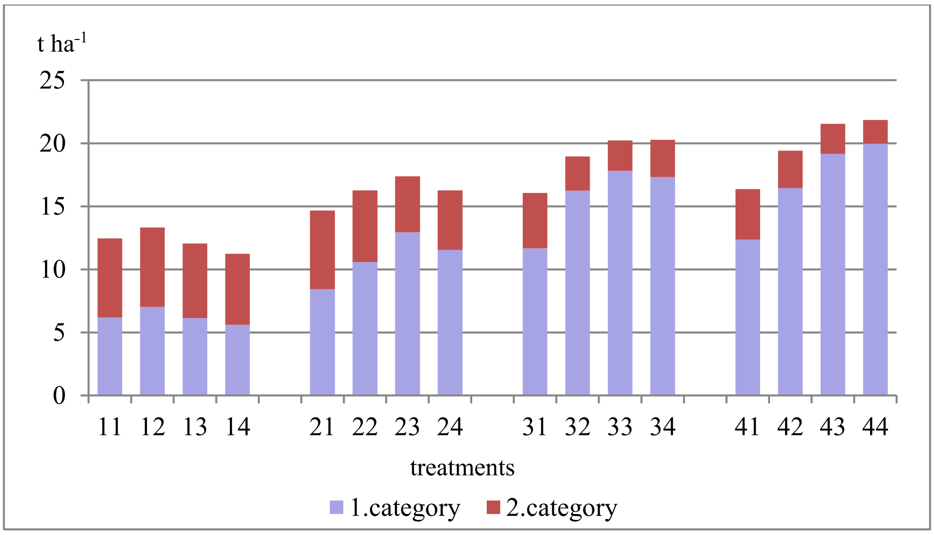

Figure 3
The distribution of sweet corn raw cob yield according to quality in a 5-year average, Szarvas

In *2004*, the distribution of precipitation was also unfavourable, as only 10 mm of precipitation fell between June 21 and July 25. During this period, 40, 80 and 120 mm of irrigation water increased the average yield by 2, 4 and 7 t ha^{-1} in the N4 treatments, but irrigation had no effect in treatment 41 *(Table 3)*. Later on, irrigation was not necessary because 88 mm of rain fell at the end of July. The productivity of ET and irrigation water this year was mainly influenced by the level of nutrient supply. The size of cobs increased by the combined application of fertilizers and irrigation this year and as a result the ratio of the first class products increased as well. The amount of first class ear yield was 9.87 t ha^{-1} in treatment 11, and 19.06 t ha^{-1} in treatment 44.

Table 5
The effect of irrigation and nutrient supply on the water consumption, yield and water utilization of sweet corn in the average of 5 years (1998, 2000–2002, 2004), Szarvas

Irrigation (i)	*NPK (N)*	*Yield (Y)*	*ET*	*Y/ET*	*Yield increment ($Y_{inc.}$). t ha^{-1}*		*$Y_{inc.i}$ / i*
mm	*kg ha^{-1}*	*t ha^{-1}*	*mm*	*kg mm^{-1}*	*$Y_{inc.i}$*	*$Y_{inc.N}$*	*kg mm^{-1}*
0	100	12.5	315	39.6	0	0.00	0
0	200	13.6	322	42.3	0	1.15	0
0	300	12.5	322	38.7	0	0.00	0
0	400	11.2	319	35.2	0	-1.23	0
i_1 (mean)		*12.4*	*319*	*38.9*	*0*	*-0.03*	*0*
54	100	14.7	346	42.4	2.2	0.00	41
54	200	16.3	364	44.7	2.7	1.61	49
54	300	17.8	372	47.8	5.3	3.12	99
54	400	16.6	376	44.2	5.4	1.95	100
i_2 (mean)		*16.3*	*364*	*44.8*	*3.9*	*2.23*	*72*
106	100	16.1	373	43.1	3.6	0.00	34
106	200	18.9	387	48.9	5.3	2.88	50
106	300	20.4	403	50.7	8.0	4.37	75
106	400	20.3	408	49.6	9.0	4.21	85
i_3 (mean)		*18.9*	*393*	*48.1*	*6.5*	*3.82*	*61*
158	100	16.2	391	41.4	3.7	0.00	24
158	200	19.6	413	47.5	6.0	3.41	38
158	300	21.5	416	51.7	9.1	5.33	57
158	400	21.8	423	51.7	10.6	5.65	67
i_4 (mean)		*19.8*	*411*	*48.1*	*7.4*	*4.80*	*47*
N_1 (mean)	100	14.8	356	41.7	3.2	0.00	33
N_2 (mean)	200	17.3	372	46.4	4.7	2.41	46
N_3 (mean)	300	17.9	378	47.4	7.5	3.06	77
N_4 (mean)	400	17.5	381	45.8	8.3	2.64	84
i x N (mean)		16.9	372	45.3	5.9	2.70	60
LSD 5%: (i)		*1.114*	*16*	*1.91*	*0.62*	*0.73*	*2.30*
LSD5%: (N)		*0.51*	*11*	*1.72*	*0.51*	*0.48*	*2.10*
LSD5%: (i x N)		*0.97*	*16*	*2.09*	*0.97*	*0.88*	*2.50*

Notes: The meaning of the abbreviations is the following: Y_{inc}: yield increment, $Y_{inc.i}$.: yield increment by the effect of irrigation, $Y_{inc.N}$: yield increment by the effect of nutrient supply.

In *Table 5* and *Figure 3* the averages of the *5-years results* are shown. From sowing to harvest the vegetation period was round 100 days in an average of 5 years, during which mean precipitation was 200 mm, the accumulated mean temperature was 1960ºC, and the amount of released irrigation water was 54, 106, 158 mm. As a result of irrigation, the increase in the sweet corn yield in i_2, i_3 and i_4 treatments were 3.9; 6.5 and 7.4 t ha^{-1} compared to the non-irrigated i_1, averaged over the fertilizer treatments.

The ET in the non-irrigated treatments was 319 mm, with a yield of 12.4 t ha^{-1}. The irrigated plants, on the other hand, evaporated 346-423 mm of water, thus achieved 14.7-21.8 t ha^{-1} fresh ear yield. In the average of 5 years irrigation increased the cob yield by a value of between 2.2 and 10.6 t ha^{-1}. ET productivity was the lowest (38.9 kg ha^{-1} mm^{-1}) in treatment 14 and the highest (51.7 kg ha^{-1} mm^{-1}) in treatment 43-44.

The yield-increasing effect of fertilizer doses was not significant for non-irrigated plants, but in irrigated treatments it was the greater, the more favourable the water supply was. The yield-increasing effect of nutrient supply in the i4 treatment was 3.41; 5.33 and 5.65 t ha^{-1} in N2, N3 and N4 treatments, respectively, compared to N1 control.

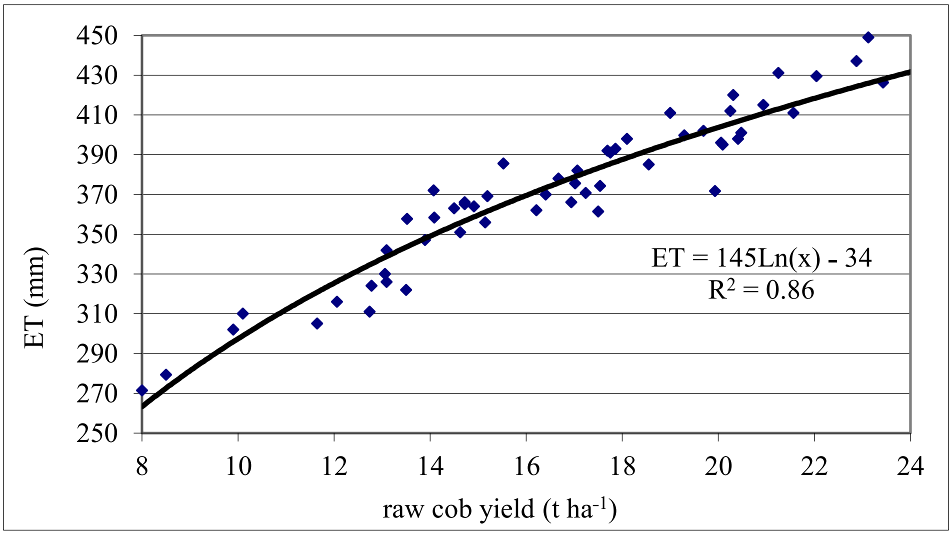

Figure 4.
Correlation between the fresh cob yield and the evapotranspiration (ET) of sweet corn

The quantitative relationship between the ET and yield is shown in *Figure 4* and between water productivity and yield in *Figure 5*. These functions undoubtedly prove the trends, which were discussed in the yearly evaluation of the results, thus there is a strong positive correlation between the average yield and the increase in ET, which can be described by a logarithmic function. However, with the improvement of water and nutrient supply, the ET increases at a lower rate than the yield average. The natural consequence of these is that as the average yield increases, the ET per unit of yield decreases, i.e., the productivity of evapotranspirated water increases *(Figure 5).*

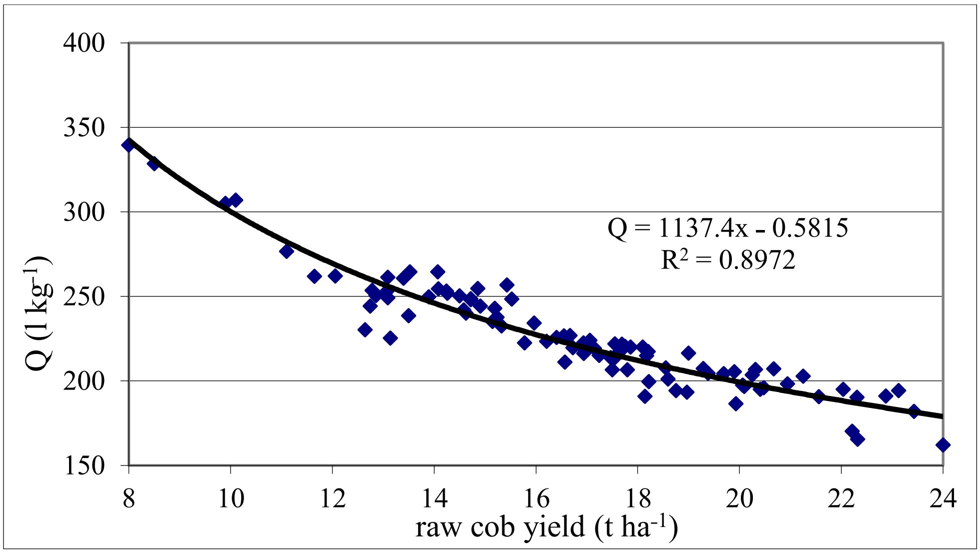

Figure 5
Correlation between average yield and specific water consumption (Q) of sweet corn

Discussion

The crop water productivity originating from different countries in the world ranges between very large limit values, even for the same plant. ZWART (2004) found 0.22-3.99 kg m^{-3} crop water productivity range of values for maize in 26 literature sources from 10 countries. The opinions usually agree that the productivity of evapotranspiration is increased by the effect of increasing nutrient supply (OLSON, 1964; RUZSÁNYI, 1974*),* but in dry years the highest N levels can cause depression in yield, and thereby reduce the productivity of precipitation and evapotranspiration (PANDEY et al., 2000).

These views are also supported by our results. Namely the utilisation of ET was reduced from 42 to 35 kg ha^{-1} mm^{-1} in the non-irrigated treatment that received more than 100 kg ha^{-1} nitrogen doses. Although in the irrigated treatments the productivity of ET increased at i2, i3 and i4 irrigation levels to 47.8; 50.7 and 51.7 kg ha^{-1} mm^{-1}, respectively, by the impact of the 150 kg ha^{-1} nitrogen dose.

Regarding the productivity of increasing or decreasing precipitation, irrigation water and evapotranspiration, more contradictions can be found in the literature. In arid and semi-arid areas the utilisation of the precipitation, irrigation water and evapotranspiration is improving by the effect of the increasing amount of precipitation and irrigation water (ECK, 1986; PANDEY et al., 2000; BENNIE & HENSLEY, 2001; AL-JAMAL et al., 2001; OGOLA et al., 2002; FAN et al., 2005;

OKTEM, 2008; RIVERA-HERNÁNDEZ et al., 2010; AYDINSAKIR et al., 2013; MOTAZEDIAN et al., 2019). According to other reports the changes of the ET and yield are parallel to each other, and the productivity of evapotranspiration is relatively steady (DE WIT, 1958; KIPKORIR et al., 2002; ZHANG et al., 2004). In some cases, with an increase in rainfall or water supply, ET increased in a larger proportion than the amount of the yield, and the efficiency of water use decreased (CAVAZZA 1963; GULATI & MURTI, 1979; ORGAZ et al., 1992; VISWANATHA et al., 2002; KIRDA et al., 2005; STONE et al., 2021).

Fertilization field experiments also clearly prove that in the case of a favourable nutrient supply, plants make better use of natural precipitation (if there is enough) and irrigation water (DEBRECZENI, 1987; BERZSENYI, 1993; RUZSÁNYI, 1974; SZALÓKINÉ & SZALÓKI, 2002).

It was proved by our experimental results that with improving water supply, the proportion of the main product increases at a higher rate than ET, as a result, ET productivity increases in treatments with better water and nutrient supply

The productivity of irrigation water and precipitation was also influenced essentially by its quantity and distribution over time, whether it coincides with the requirements of the plants, and the amount used by plants, leached out or stayed in the soil (SZALÓKINÉ & SZALÓKI, 2002). According to our experimental results the increase of ET – in average of 5 years – was less (45, 74 and 92 mm) than the quantity of the released irrigation water (54, 106 and 158 mm), and the productivity of increasing irrigation water was also decreasing (72, 61, 47 kg ha^{-1} mm^{-1}), but still significantly higher than the productivity of ET in the non-irrigated treatment (38.9 mm). Because of this, increasing the irrigation water increases the productivity of ET (39, 45, 48 kg ha^{-1} mm^{-1}). Precipitation or irrigation water that exceeds the needs of the plants can even be harmful to the plants and the environment.

Conclusions

The experimental results clearly prove that with the improvement of the water supply and nutrient supply, the amount of the main product increases at a higher rate than the ET, as a result, the productivity of the ET increases in the treatments with better water- and nutrient supply.

Based on the results, it can be generally concluded that all factors that result in an increase in the average yield increase evapotranspiration, as characterized by the saturation function, and decrease the specific water consumption as characterized by a hyperbolic function, that is, it increases the productivity of ET.

The productivity of irrigation water and precipitation is also significantly influenced by how much their quantity and temporal distribution is in line with the needs of the plants, how much of it is used by the plants, and how much remains in the soil or flows away.

The favourable water and nutrient supply is the basic condition for the safe achievement of a marketable quality and evenly high yield.

The water requirement of sweet corn is between 400–450 mm, depending on the length of the growing season and the weather, especially the temperature. This requirement can only be satisfied by soil with a relatively high moisture content: the absorbable part of the water capacity must be over 60% at least in part of the upper 10-30 cm layer. Irrigation is preferably done more often, with smaller (10-30 mm) doses. Precipitation or irrigation water that exceeds the needs of the plants can even be harmful to the plants and the environment.

Acknowledgements

The research was supported by the Ministry of Agricultural and Regional Development of Hungary.

References

AL-JAMAL, M S., BALL, S., & SAMMIS, T. W., 2001. Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. Agricultural Water Management. **46**. 253-266.

AYDINSAKIR, K., ERDAL, S., BUYUKTAS, D., BASTUG, R., TOKER, R., 2013. The influence of regular deficit irrigation applications on water use, yield, and quality components of two corn (*Zea mays* L.) genotypes. Agricultural Water Management. **128**. 65-71.

BENNIE, A. T. P. & HENSLEY, M., 2001. Maximizing precipitation utilization in dryland agriculture in South Africa – a review. Journal of Hidrology. **241**. 124-139.

BERZSENYI, Z., 1993. A N-műtrágyázás és az évjárat hatása a kukoricahibridek (*Zea mays* L.) szemtermésére és N-műtrágyareakciójára tartamkísérletben az 1970-1991. években. Növénytermelés. **42**. (1) 49-62.

CAVAZZA, D., 1963. L'irrigatione fisiologica. Teoria razionale dell' irrigatione. L' Italia Agricola, Roma. **100**. (2) 115-135.

DE WIT, C. T., 1958. Transpiration and crop yield. Wageningen University, Wageningen.

DEBRECZENI, B., 1987. A tápanyag- és vízellátás kapcsolata. Időjárás. **91**. (2-3) 104-113.

ECK, H.V., 1986. Effects of water deficits on yield, yield components, and water use efficiency of irrigated corn. Agronomy Journal. **78**. (7) 1035-1040.

FAN, T., STEWART, B. A., YONG, W., JUNJIE, L. & GUANGYE, Z., 2005. Long-term fertilization effects on grain yield, water-use efficiency and soil fertility in the dryland of Loess Plateau in China. Agriculture Ecosystems & Environment. **106**. 313-329.

FARSIANI, A., GHOBADI, M. E., & HONARMAND, S. J., 2011. The effect of water deficit and sowing date on yield components and seed sugar contents of sweet corn (*Zea mays* L.). African Journal of Agricultural Research. **6**. (26) 5769-5774.

GULATI, H. S. & MURTY, V. V. N., 1979. A model for optimal allocations of canal water based on crop production functions. Agricultural Water Management. **2**. (1) 79-91.

ILLÉS, Á., SZABÓ, A., MOUSAVI, S. M. N., BOJTOR, CS., VAD, A., HARSÁNYI, E., SINKA, L., 2022. The influence of precision dripping irrigation system on the phenology and yield indices of sweet maize hybrids. Water. **14**. (16) 2480.

JAT, V., TUSE, B.P., JAWALE, S.M., SHAIKH, A.A. & DALAVI, N.D., 2009. Effect of fertilizer levels and dates of sowing on growth and yield of sweet corn (*Zea mays* Saccharata). Journal of Maharastra Agricultural University. **34**. (1) 109-111.

KAR, P.P., BARIK, K.C., MAHAPATRA, P.K., GARNAYAK, L.M., RATH, B.S., BASTIA, D.K.& KHANDA, C.M., 2006. Effect of planting geometry and nitrogen on yield, economics and nitrogen uptake of sweet corn (*Zea mays*). Indian Journal of Agronomy. **51**. (1) 43-45.

KIPKORIR, E. C., RAES, D. & MASSAWE, B., 2002. Seasonal water production functions and yield response factors for maize and onion in Perkerra, Kenya. Agricultural Water Management. **56**. 229-240.

KIRDA, C., TOPCU, S., KAMAN, H., ULGER, A. C., YAZICI, A., CETIN, M. & DERICI, M. R., 2005. Grain yield response and N-fertiliser recovery of maize under deficit irrigation. Field Crops Research. **93**. 132-141.

KUMAR, A., 2009. Production potential and nitrogen-use efficiency of sweet corn (Zea mays) as influenced by different planting densities and nitrogen levels. Indian Journal of Agricultural Sciences, **79**. (5) 351-355.

LENTE, Á., 2012. A legfontosabb agrotechnikai tényezők hatása a csemegekukorica hibridek agronómiai tulajdonságaira és termésére. Egyetemi doktori (PhD) disszertáció, Debreceni Egyetem Hankóczy Jenő Növénytermesztési, Kertészeti és élelmiszertudományok Doktori Iskola, Debrecen.

LENTE, Á., PEPÓ, P., 2011. Effect of year and technological factors on the yield and agronomic traits of sweet corn (*Zea mays* L. convar. saccharata Koern.) varieties in a long-term experiment. Acta Agronomica Hungarica. **59**. 143-152.

MOTAZEDIAN, A., KAZEMEINI, S. A., BAHRANI, M. J., 2019. Sweet corn growth and Grain Yield as influenced by irrigation and wheat residue management. Agricultural Water Management. **224**. 105748

NEMESKÉRI, E., MOLNÁR, K., RÁCZ, C., DOBOS, A.C., HELYES, L., 2019. Effect of water supply on spectral traits and their relationship with the productivity of sweet corns. Agronomy. **9**. 63.

NOEIN, B., SOLEYMANI, A., 2022. Corn (*Zea mays* L.) physiology and yield affected by plant growth regulators under drought stress. Journal of Plant Growth Regulation. **41**. 672-681.

OGOLA, J. B. O., WHEELER, T. R. & HARRIS, P. M., 2002. Effects of nitrogen and irrigation on water use of maize crops. Field Crops Research. **78**. 105-117.

OKTEM, A., 2008. Effect of water shortage on yield and protein and mineral compositions of drip-irrigated sweet corn in sustainable agricultural systems. Agricultural Water Management. **95**. 1003-1010.

OLSON, R. A., THOMPSON, C. A., GRABOUSKI, P. H., STUKENHOLTZ, D. D., FRANK, K. D. & DREIER, A. F., 1964. Water requirement of grain crops as modified by fertilizer use. Agronomy Journal. **56**. (4) 427-432.

ORGAZ, F., MATEOS, L. & FERERES, E., 1992. Season length and cultivar determine the optimum evapotranspiration deficit in cotton. Agronomy Journal. **84**. 700-706.

PANDEY, R. K., MARANVILLE, J. W. & ADMOU, A., 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment, I. Grain yield and yield components. Agricultural Water Management. **46**. 1-13.

RIVERA-HERNÁNDEZ, B., CARRILLO-ÁVILA, E., OBRADOR-OLÁN, J.J., JUÁREZ-LÓPEZ, J.F., ACEVES-NAVARRO, L.A., 2010. Morphological quality of sweet corn (*Zea mays* L.) ears as response to soil moisture tension and phosphate fertilization in Campeche, Mexico. Agricultural Water Management. **97**. 1365-1374.

ROSA, R., KOSTERNA-KELLE, E., FRANCZUK, J., ZANIEWICZ-BAJKOWSKA, A., 2016. The influence of weather conditions of eastern Poland on sweet corn yields and length of growing season. Journal of Ecological Engineering. **17**. 273-279.

RUZSÁNYI, L., 1974. Effect of fertilisation on several field crops water consumption and water utilisation. Növénytermelés. **23**. (3) 249-258. (in Hungarian with english summary).

STONE, P. J., WILSON, D.R., REID, J. B., GILLESPIE, R. N., 2001. Water deficit effects on sweet corn. I. Water use, radiation use efficiency, growth, and yield. Australian Journal of Agricultural Research. **52**. 103-113.

SVÁB, J., 1973. Biometriai módszerek a kutatásban. Mezőgazdasági Kiadó, Budapest.

SZALÓKINÉ, I. Z., & SZALÓKI, S., 2002. Relationships of Water-and Nutrient Supply, Yield and Evapotranspiration of Maize. Időjárás. **106**. (3-4) 197-213.

VISWANATHA, G. B., RAMACHANDRAPPA, B. K. & NANJAPPA, H. V., 2002. Soil-plant water status and yield of sweet corn (*Zea mays* L. cv. Saccharata) as influenced by drip irrigation and planting methods. Agricultural Water Management. **55**. (2) 85-91.

ZHANG, Y., KENDY, E., QIANG, Y., CHANGMING, L., YANJUN, S. & HONYONG, S., 2004. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China plain. Agricultural Water Management. **64**. (2) 107-122.

ZSOMBIK, L.; DARÓCZI, M., 2008. A csemegekukorica termesztésének helyzete és aktualitásai. Agrárágazat. **9**. (2) 24-26.

ZWART, S. J., & BASTIAANSSEN, WIM G. M., 2004. Review of measured crop water productivity values for irrigated wheat, rice cotton and maize. Agricultural Water Management. **69**. 115-133.