Effect of water and nutrient supply on the evapotranspiration, yield and on the quantity and quality of infiltration water

I. Z. SZALÓKI

Abstract

The effect of different water and nutrient supply on the evapotranspiration (ET), yield, as far as on the amount and concentration of infiltration water in lysimeters and on field plots was examined. It was established that the ET is increased-, and also even the yield to a higher extent by water supply, and thereby the utilisation of ET is improved.

The yield was increased significantly-, and the ET to a lesser extent, by the effect of raising doses of fertiliser in a positive interaction with water supply.

The amount of infiltration water changed mainly depending on the winter season precipitation, and to a lesser degree on the amount of irrigation water. The amount of leaching water was influenced the less by the fertiliser doses. The concentration of infiltration water was increased by the fertiliser, and decreased by the irrigation.

Introduction

The most frequent limiting factor of plant production is the water shortage in Hungary. Because of this the effectiveness of other factors is uncertain or low.

In our experiment the effect of different water and nutrient supply is examined, respectively the shortage on the evapotranspiration (ET), on the quantity and quality of yield, on the quantity and salt concentration of infiltration water, furthermore on the soil and on the nutrient balance.

The results are showed only in connecting the water consumption, water utilisation and yield of maize, as well as the infiltration water.

Examination of infiltration water-, and the dissolved materials in it can provide important information for implementation of sustainable agriculture.

Materials and Methods

The experiment has been made at the Lysimeter Station of the Research Institute for Fisheries, Aquaculture and Irrigation, Szarvas, Hungary, which has been built in 1971 with 320 lysimeters. The experiment is consisting of 5 blocks, in each with 64-64 lysimeters.

The size of lysimeters is 1x1x1m (1m^3), which are built into the middle of each plot, the area of which is 32 m^2. In three of the five blocks a long term experiment have been carried out with two factors, 16 treatment-combination, four replications, split-splot arrangement.

The main treatment is the ***water supply***:

a_1 - non-irrigated *control* (natural rainfall)

a_2 - irrigated with *one third* of optimum water supply

a_3 - irrigated with *two thirds* of optimum water supply

a_4 - *optimum* water supply (irrigated according to the demand of plants).

In the optimum water supply treatment the moisture content of the soil has been kept between 50-100 % of disposable water in the root zone.

Within the main treatment (water-supply) the ***nutrient supply*** levels are: b1, b2, b3, b4 = 100, 200, 300 and 400 kg/ha NPK substance in ratio 2:1:1. However in the two last years it were given only nitrogen with the following doses in lysimeters: 75; 150; 225; 300 kg/ha.

The marking of treatment combinations happens by two number. The first number means the water-, the second the nutrient supply treatments (between 11-44).

The type of the soil is chernozem rhetic, which is very well supplied with phosphorus and potassium, and has a medium nitrogen-content. It contains 2,5-3 % humus and 50 % clay. Its natural water capacity is 40 volume percent, half of which is disposable water.

The leaching water was collected separately at every lysimeter, its quantity was measured, and its quality was determined as well.

Results

The more important water balance and water utilisation results of maize in average of 20 years are summarized, and also the results of infiltration water. The last two years results of maize are introduced more in detail.

The precipitation was 212 mm in the winter season, 225 mm in the growing season and total was 437 mm in average of last 20 years. The average of irrigation water were the following in the 20 years: 0, 90, 192, 211 mm. The amount of leaching water was 33 mm in the winter season, and 25 mm in the summer season. The evaporation was in average 83 mm in winter season, and 331, 403, 471, 479 mm by treatments in the growing season.

The amount of evapotranspiration (ET) was differentiated also by the dose of fertiliser at well water supply, yearly in average by 20-40 mm.

Between the actual evapotranspiration and yield of 20 years average - at 400 kg/ha NPK and at four different water supply - was found the next relation:

$y = 13{,}97 \ln(x) - 76{,}78$; $R^2 = 0{,}79$, where x = ET (mm), and y = dry grain yield (t/ha). From this can be seen that the yield enhanced in a larger extent than the water consumption, due to this the evapotranspiration coefficient (water consumption getting on one unit of dry grain yield) decreased with raising yield. This relationship can be approached by

Autor: Ildiko Zima SZALÓKI, Research Institute for Fisheries, Aquaculture and Irrigation, P.O.Box 47, H-5541 SZARVAS, email: zimai@haki.hu

Table 1: **Effect of water- and nutrient supply on evapotranspiration (ET) and yield of maize in lysimeters, 2001. Szarvas, HAKI, Hungary**

treatment irrigation (a)	N (b)	yield (Y) t/ha	%	more yield, t/ha I effect	N effect	Y/Irrig.w. kg/mm	ET mm	Y/ET kg/mm
0	**75**	8,37	100	0,00	0,00	0,0	417	20,1
0	**150**	8,80	100	0,00	0,43	0,0	420	21,0
0	**225**	7,92	100	0,00	-0,45	0,0	421	18,8
0	**300**	7,81	100	0,00	-0,56	0,0	408	19,1
$\mathbf{a}_1$ (b. average)		**8,2**	**100**	**0,00**	**-0,14**	**0,0**	**417**	**19,7**
50	**75**	8,50	102	0,13	0,00	2,6	443	19,2
50	**150**	9,90	113	1,10	1,40	22,0	460	21,5
50	**225**	10,72	135	2,80	2,22	56,0	472	22,7
50	**300**	10,13	130	2,32	1,63	46,4	468	21,6
$\mathbf{a}_2$ (b. average)		**9,8**	**119**	**1,59**	**4,13**	**31,8**	**461**	**21,3**
100	**75**	8,42	101	0,05	0,00	0,5	480	17,5
100	**150**	10,77	122	1,97	2,35	19,7	498	21,6
100	**225**	11,19	141	3,27	2,77	32,7	506	22,1
100	**300**	11,11	142	3,30	2,69	33,0	515	21,6
$\mathbf{a}_3$ (b. average)		**10,4**	**126**	**2,15**	**1,95**	**21,5**	**500**	**20,7**
150	**75**	7,70	92	-0,67	0,00	-4,5	507	15,2
150	**150**	10,70	122	1,90	3,00	12,7	536	20,0
150	**225**	12,31	155	4,39	4,61	29,3	544	22,6
150	**300**	12,45	159	4,64	4,75	30,9	544	22,9
$\mathbf{a}_4$ (b. average)		**10,8**	**132**	**2,57**	**3,09**	**17,1**	**533**	**20,2**
SZD 5 %: **(a)**		*0,78*	*9*	*0,78*	*0,76*	*2,03*	*19,00*	*2,1*
$\mathbf{b}_1$ (a.átl.)	**75**	**8,25**	100	-0,12	0,00	-0,34	462	18,0
$\mathbf{b}_2$ (a.átl.)	**150**	**10,04**	122	1,24	1,80	13,59	479	21,0
$\mathbf{b}_3$ (a.átl.)	**225**	**10,54**	128	2,62	2,29	29,49	486	21,6
$\mathbf{b}_4$ (a.átl.)	**300**	**10,4**	126	2,57	2,13	27,58	484	21,3
a*b. (átl.)		**9,8**	**119**	**1,58**	**1,55**	**17,58**	**477**	**20,5**
SzD 5 %: **(b)**		*0,62*	*5,76*	*0,62*	*0,62*	*1,91*	*11,00*	*0,82*
SzD5 %: **(a*b)**		*1,21*	*10,81*	*1,21*		*2,43*	*27,70*	*2,44*
	0	50	100	150	t/ha	%		
75	8,37	8,50	8,42	7,70	**8,25**	100		
150	8,80	9,90	10,77	10,70	**10,04**	122		
225	7,92	10,72	11,19	12,31	**10,54**	128		
300	7,81	10,13	11,11	12,45	**10,38**	126		
	0	50	100	150				
50	9,76	10,09	10,42	10,63				
100	10,33	10,96	11,32	11,64				
150	9,84	11,51	11,87	12,41				
200	9,64	11,54	12,07	12,87				
átlag	**9,89**	**11,02**	**11,42**	**11,89**				

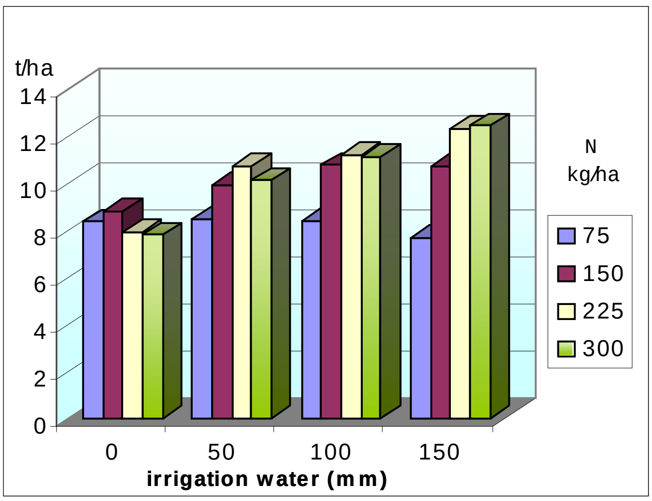

Figure 1: **Dry grain yield of maize in lysimeters, 2001**

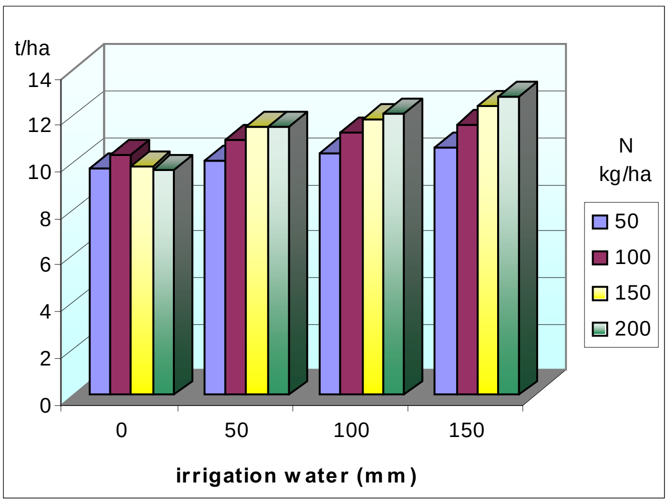

Figure 2: **Dry grain yield of maize on plots, 2001**

Table 2: **Effect of water- and nutrient supply on evapotranspiration (ET) and yield of maize in lysimeters, 2002. Szarvas, HAKI, Hungary**

treatment		yield (Y)		more yield, t/ha		Y/Irrig.w.	ET	Y/ET
irrigation(a)	N (b)	t/ha	%	I effect	N effect	kg/mm	mm	kg/mm
0	**50**	3,10	100	0,00	0,00	0,0	345	9,0
0	**100**	2,86	100	0,00	-0,24	0,0	329	8,7
0	**150**	2,93	100	0,00	-0,17	0,0	324	9,0
0	**200**	2,11	100	0,00	-0,99	0,0	312	6,8
a$_1$ (b average)		**2,8**	**100**	**0,00**	**-5,62**	**0,0**	**328**	**8,4**
80	**50**	6,81	220	3,71	0,00	46,4	404	16,8
80	**100**	7,81	273	4,95	1,00	61,9	409	19,1
80	**150**	8,25	281	5,32	1,44	66,5	418	19,7
80	**200**	8,21	388	6,09	1,40	76,2	412	19,9
a$_2$ (average)		**7,8**	**282**	**5,02**	**0,96**	**62,7**	**411**	**18,9**
160	**50**	7,46	241	4,36	0,00	27,2	460	16,2
160	**100**	8,75	306	5,89	1,29	36,8	485	18,0
160	**150**	11,13	380	8,20	3,67	51,2	487	22,8
160	**200**	11,43	540	9,31	3,97	58,2	513	22,3
a$_3$ (b.average)		**9,7**	**352**	**6,94**	**2,23**	**43,4**	**465**	**19,8**
235	**50**	5,83	188	2,73	0,00	11,6	504	11,6
235	**100**	9,75	341	6,89	3,92	29,3	543	18,0
235	**150**	11,02	376	8,09	5,19	34,4	534	20,6
235	**200**	11,63	550	9,51	5,80	40,5	548	21,2
a$_4$ (b.average)		**9,6**	**364**	**6,81**	**3,73**	**20,9**	**532**	**17,9**
SZD 5%**: (a)**		*0,86*	*15*	*0,86*	*0,76*	*2,23*	*20,20*	*2,4*
b$_1$ (a.átl.)	**50**	**5,80**	100	2,70	0,00	21,31	428	13,4
b$_2$ (a.átl.)	**100**	**7,30**	88	4,43	1,50	32,00	442	16,0
b$_3$ (a.átl.)	**150**	**8,33**	101	5,40	2,53	38,04	441	18,1
b$_4$ (a.átl.)	**200**	**8,3**	101	6,23	2,54	43,71	446	17,6
a*b. (átl.)		7,4	90	4,69	1,64	33,76	439	16,2
SzD 5 %: **(b)**		*0,71*	*8,11*	*0,71*	*0,71*	*2,10*	*14,00*	*0,89*
SzD 5 %: **(a*b)**		*1,25*	*11,23*	*1,25*		*2,52*	*29,60*	*2,63*
	0	80	160	235	t/ha	%		
50	3,10	6,81	7,46	5,83	**5,80**	100		
100	2,86	7,81	8,75	9,75	**7,30**	88		
150	2,93	8,25	11,13	11,02	**8,33**	101		
200	2,11	8,21	11,43	11,63	**8,34**	101		
	0	80	160	235				
50	3,57	7,93	8,05	8,78				
100	3,10	8,90	9,49	10,06				
150	2,98	9,68	11,75	11,89				
200	2,77	9,68	11,89	12,44				

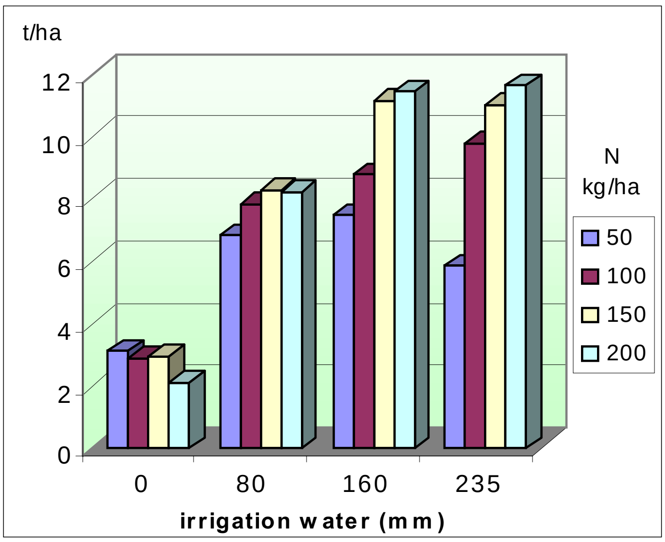

Figure 3: **Dry grain yield of maize in lysimeters, 2002**

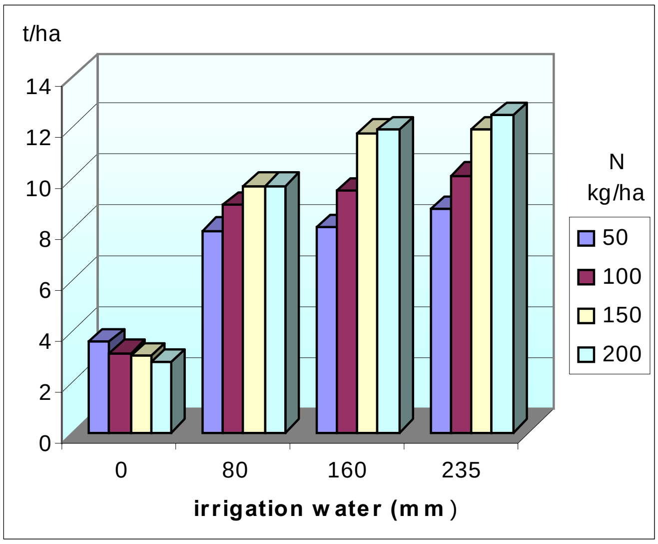

Figure 4: **Dry grain yield of maize on plots, 2002**

Table 3: **The amount - and concentration of infiltration water**

treatment	infiltration l/m²	NO_3-N mg/l	P_2O_5 mg/l	K mg/l	Ca mg/l	Mg mg/l	Na mg/l	salt mg/l	pH
2001. May - July (in average of 3 blocks)									
11	**33**	45	4,87	93	82	32	17	780	8,35
12	**27**	72	4,21	97	97	38	19	792	8,28
13	**22**	84	3,68	132	122	44	21	1050	8,27
14	**21**	100	2,83	144	162	58	21	1525	8,54
21	**37**	34	8,16	91	76	26	30	897	8,28
22	**32**	60	3,52	72	104	31	42	918	7,12
23	**28**	60	4,64	105	121	36	39	1142	7,73
24	**25**	72	3,56	138	108	50	35	1257	8,18
31	**43**	23	4,24	64	86	35	34	705	7,90
32	**35**	45	4,12	68	116	35	44	932	8,37
33	**33**	60	4,01	73	131	38	38	1097	7,75
34	**29**	76	3,15	79	144	43	35	1228	7,70
41	**56**	12	2,91	82	91	32	34	755	8,14
42	**51**	23	4,89	106	101	32	38	787	7,85
43	**47**	30	3,11	104	101	44	39	938	8,15
44	**40**	45	4,78	120	105	44	45	1028	7,96
2002. March (in average of 3 blocks)									
11	**44**	22	1,86	81	86	38	14	575	6,87
12	**40**	64	1,52	94	130	50	18	1255	6,80
13	**36**	121	1,08	72	121	62	13	1636	6,82
14	**35**	160	1,10	70	146	77	17	1822	6,29
21	**52**	18	2,59	126	87	30	27	778	6,60
22	**46**	82	1,79	116	143	40	27	1062	6,61
23	**44**	105	1,93	112	134	45	30	1130	7,13
24	**42**	143	0,93	99	156	76	38	1700	6,68
31	**63**	5	1,97	76	155	35	44	935	6,94
32	**58**	33	1,02	66	120	48	34	743	6,73
33	**55**	72	1,60	61	113	57	21	875	6,94
34	**52**	96	1,31	60	171	64	31	1312	7,12
41	**77**	9	1,13	60	114	40	33	750	7,68
42	**74**	14	1,39	67	121	45	36	725	7,33
43	**69**	27	1,16	83	122	56	63	820	7,22
44	**65**	41	1,69	105	132	60	44	955	7,43

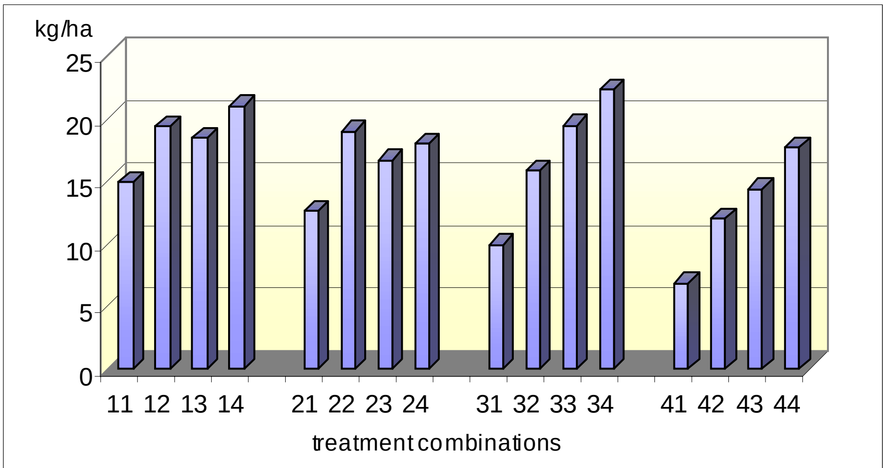

Figure 5: **The washed out NO_3-N in 2001 (May-July)**

the next equation: $y = 2070\ x^{-0,6477}$; $R^2 = 0,90$; where x = dry grain yield(t/ha), y = evapotranspiration coefficient, l/kg.

At unfavourable nutrient supply treatments the connection between the water and yield is not too strong. The dry grain yield of maize was influenced by the water and nutrient supply yearly in varying extent. The maize has hardly any yield in the driest years without irrigation. In such years the fertilizer was not effective without irrigation, even it had depressive effect. The favourable water supply had big effect also in that case, when the nutrient supply was favourable too. In many years average the yield was increased at optimum water supply at good nutrient supply by 6.7 t/ha and at low nutrient supply level by 3.2 t/ha.

The difference in yield at the doses of 100 and 400 kg/ha NPK substance is 0.5 t/ha without irrigation and 3.8 t/ha at optimum water supply.

In 2001, which year more precipitous was than the average, the ET was around 417 mm in the non irrigated (a1) treatment (*Table 1*). The ET was increased by 50 mm supplementary water with 40 mm, by 100 mm 83-, and by 150 mm with 116 mm. The ET was raised only slightly in average with 22 mm - by raising nutrient supply.

The dry grain yield was around 8,2 t/ha in the non-irrigated treatment. The fertiliser had a depressive effect above 150 kg/ha N. The yield increased by 35 % at 225 kg N supply and 50 mm supplementary water, by 41 % at 100 mm-, and 55 % at 150 mm irrigation water.

The more yield per 1 mm irrigation water were 56, 33 and 29 kg/ha/mm in the above-mentioned treatments, while in the non irrigated treatments 19,7 kg/ha/mm.

In the 2002 droughty year the ET of maize was 328 mm in the non-irrigated treatment (*Table 2*), and the dry grain yield only 2.87 t/ha (*Figure 3-4*). In this year the ET was increased by the fertiliser doses significantly, by 40-50 mm at the higher irrigation treatments.

The dry grain yield was increased in average by 5-7 t/ha by irrigation and together with the highest nitrogen dose by 6-9 t/ha.

The productivity of ET at the non-irrigated treatments was 18.9; 19.8 and 17,9 kg/ha/mm in average of nutrient supply. The highest value (22,8 kg/ha/mm) was found at the 33 treatment.

The productivity of irrigation water was 63 kg/ha/mm at 80 mm irrigation water, and 43 kg/ha/mm at 160 mm.

In *Table 3* the amount of infiltrated water from lysimeters in growing season of 2001 and in early spring of 2002 can be seen, furthermore the more important elements, the total salt and pH. The data announced in the table shows a tendency, which is similar to the many years' average.

The quantity of infiltration water was increased considerably by the amount of irrigation water, and decreased by the enhancing fertiliser dose in a lower extent. However the salt concentration was raised with the growing nutrient dose in a large extent, and decreased with the enhancing irrigation water to a similar degree.

The change was the biggest in the nitrogen concentration. The amount of leached out nutrients was the highest at the non-irrigated treatment at the highest dose of fertiliser, and the lowest at the biggest irrigation and lowest nutrient supply. The quantity of leached out nitrogen was not much higher at optimal water- and nutrient supply (a4b4) than at the non-irrigated and getting the lowest nutrient supply treatment (a1b1).

By the effect of fertiliser not only the amount of given nutrients (NPK) raised in the infiltration water but also the Ca^{2+} and Mg^{2+}. This change occurred by the effect of fertilisation. The amount of Ca and Mg showed a close relation with the amount of nitrate in the infiltration water ($y = 1,5465\,x + 96,424$; $R^2 = 0,8352$, where $x = NO^{3-}$, mg/l; $y = Ca^{2+} + Mg^{2+}$, mg/l).

The infiltration water and nutrients leached deeper than 1 m was used by plants on plots, and from nutrients even more was used. The nutrient shortage is more than 80 kg/ha in many years average in the 31 and 41 treatments. It was not found nowhere nitrate accumulation until 3 m depth of the soil at favourable water and nutrient supply treatments (33, 34, 43, 44).