IONIC INTERACTIONS IN MAIZE GROWN UNDER WATER STRESS CONDITIONS

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ABSTRACT

The purpose of the study was to estimate the influence of water stress on the content of macro- and microelements within various ionic interactions in several maize hybrids (Fundulea 322, Fundulea 340, Fundulea 365 and Fundulea 376), grown on a chernozemic soil at Fundulea. Plant samples were collected at 3-4 leaf stage, flowering and maturity and the content of N, P,K, Cu, Zn, Fe and Mg were determined using the standard methods applied in agrochemical laboratories. Ionic interactions with synergetic or antagonistic effects between phosphorus and Zn, Mn and Fe, as well as Fe/Zn interaction were calculated as microelement atoms /100 P atoms. Optimal water supply determined the production of a great amount of plant assimilates during grain filling period. Consequently, nitrogen uptake was greater than under water stress conditions. Fundulea 322 and Fundulea 365 show the highest capacity of nitrogen translocation. The existence of phosphorus-zinc antagonism was revealed in all hybrids studied, but it was more evident under optimal irrigation conditions and for Fundulea 340 and Fundulea 365 hybrids. Phosphorus-zinc antagonism is determined by both the direct effect of phosphorus on reduction of plant zinc concentration and by an indirect effect due to phosphorus-manganese and phosphorus-iron synergism, which allow the preferential uptake of Mn and Fe to the detriment of zinc. Low zinc uptake might be caused, on one hand by the relative low zinc content of the soil and, on the other hand, by increased phosphorus uptake as result of irrigation, which determines the zinc retention as acetates at the roots level.

Key words: ionic interactions, macro- and microelement, uptake, water stress, *Zea mays* L.

INTRODUCTION

Irrigation represents the most efficient crop management measure to increase and stabilize yield in areas with insufficient rainfall.

Water supplied by irrigation may induce modifications of physical, chemical and biological characteristics of the soil such as: soil structure, microbial metabolism, mobilization or immobilization of certain nutritive elements, ionic relationships, leaching, volatilization etc. (Eliade and Chiriþã, 1982; Chiriþã and Eliade, 1984).

Uptaking of nutritive elements, their transport and metabolization depend, also, to a great extent on the level of water supply which determines the development of a series of processes, essential for plant productivity such as: leaf water potential, stomate opening and closure, net photosynthesis, plant temperature etc. (Wanyura et al., 1990).

Special nutrition requirements of the new crop varieties and hybrids, grown under irrigation conditions, impose applications of large amounts of fertilizers. Under these conditions ionic interactions (antagonism or synergism) with major effects on soil fertility and plant nutrition could occur with high probability (Hera and Borlan, 1984).

Ionic interactions are based on competition for active groups of organic substances that function as molecules carrying the energy necessary for plant metabolic activity. These interactions occur in the cells and influence the physiological and biochemical activity of the whole plant. As plant mineral nutrition is conditioned by the whole absorption complex, the uptake of a certain ion is determined by the presence and concentration of other ions. Excess of an ion could be damaging and could lead to a more difficult absorption of another ion by plants, even if the latter is in sufficient quantities (Hera et al., 1986).

Plant growth and development depend on both biological characteristics and ionic nutrition balance.

Limitation of water resources and high pumping costs require an efficient utilization of irrigation water, even in crop with low tolerance to water stress, as maize (Crãciun et al., 1987; Crãciun and Crãciun, 1994).

The purpose of this study was to determine the influence exerted by water deficit on plant content of macro- and microelements and on the interaction of various ions in several maize hybrids grown on the chernozemic soil of Fundulea.

MATERIALS AND METHODS

Plant samples were collected from a split-plot design experiment with four replicates and two factors. The main plots consisted of four irrigation levels (50% from a. w., considered optimal irrigation; 60% from optimum; 30% from optimum; non-irrigated) and sub-lots were represented by four Romanian hybrids from FAO maturity groups 400 and 500 (Fundulea 322, Fundulea 340, Fundulea 365 and Fundulea 376).

One-line pipe technique was used to create a continuous moisture gradient that was conventionally divided into four levels as described above.

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Plant samples were collected at 3-4 leaf stage, flowering and maturity, processed and analysed for their content of macro- and microelements.

Nitrogen was determined by Kjeldhal method. Phosphorus and potassium mineralization was done in a mixture of H_2S0_4 and $HClO_4$. Phosphorus was colormetrically analysed by the method with ammonium vanadat-molibdat, and potassium by flame photometry. Microelements (Cu, Zn, Fe and Mn) were determined by atomic absorption spectrometry, in vegetal extract obtained by dry mineralization.

Analyses of variances and linear regression were computed and used to interpret the experimental data.

RESULTS AND DISCUSSIONS

Nitrogen content (%) decreased along the vegetation period due to a normal dilution process. Water stress did not manifest in early vegetation stages, so that water supply levels did not influence nitrogen at 3-4 leaf stage of maize. Hybrids did not differ significantly in their capacity of nitrogen uptaking at this stage. N content increased in all water stress levels, as compared to optimal irrigation (50% from a.w.) at flowering but significant differences were registered only in non-irrigated entry. Beginning with this stage till maturity, Fundulea 322 and Fundulea 365 manifested a higher capacity of nitrogen uptaking as compared to Fundulea 340 and Fundulea 376 (Table 1).

N content from grains varied between 1.36-1.89%. It was 0.21% greater in 30% irrigated entry and 0.28% greater in non-irrigated entry.

Grain content of crude protein had a similar variation to that of grain N content, registering 0.60-1.59% increases in water stress entries (Table 2). There were no significant differences among hybrids for their crude protein content.

Yield of grain crude protein decreased with 101 kg /ha^{-1} in 60% irrigated, 244 kg/ ha^{-1} in 30% irrigated and with 331 kg/ ha^{-1} in non-irrigated entry.

The largest crude protein yield was recorded in Fundulea 365 (950 kg/ha^{-1}), followed by Fundulea 322 (914 kg /ha^{-1}), Fundulea 340 (798 kg /ha^{-1}) and Fundulea 376 (754 kg/ ha^{-1}).

As photosynthesis was hindered by water stress in all maize hybrids, N quantities accumulated in grains decreased, according to water stress level, with 10.0-67.6%.

N quantities translocated into grains were calculated by subtracting from N quantities accumulated in stalks and leaves at grain filling period the quantities found at final harvest. N translocation (kg /ha^{-1}) was influenced significantly by water supply levels (Figure 1).

Table 1. Influence of water stress on evolution of N, P, K content in several maize hybrids (g%)

Water stress level (A)	Hybrid (B)	Vegetation stage								
		3-4 leaves			Flowering			Maturity		
		N	P	K	N	P	K	N	P	K
Optimum irrigation	F 322	3.95	0.47	3.72	2.36	0.20	1.21	1.40	0.57	1.51
	F 340	4.08	0.50	3.67	2.59	0.19	1.48	1.43	0.48	1.33
	F 365	3.94	0.48	3.17	2.30	0.18	1.40	1.60	0.52	1.60
	F 376	3.91	0.45	3.24	2.61	0.20	1.50	1.36	0.57	1.36
Irrigation 60% of optimum	F 322	3.91	0.45	3.68	2.45	0.28	1.20	1.50	0.42	1.45
	F 340	4.00	0.48	3.57	2.46	0.31	1.33	1.48	0.47	1.34
	F 365	4.10	0.46	3.76	2.44	0.27	1.20	1.64	0.47	1.50
	F 376	3.88	0.40	3.81	2.53	0.30	1.18	1.50	0.46	1.58
Irrigation 30% of optimum	F 322	4.00	0.40	3.86	2.48	0.32	1.29	1.65	0.39	1.36
	F 340	4.10	0.42	3.57	2.61	0.32	1.74	1.64	0.50	1.41
	F 365	3.95	0.40	3.77	2.77	0.32	1.29	1.75	0.49	1.52
	F 376	3.90	0.41	3.76	2.63	0.32	1.70	1.58	0.45	1.49
Non-irrigation	F 322	4.14	0.37	4.19	2.50	0.32	1.38	1.72	0.37	1.62
	F 340	4.08	0.40	4.14	2.90	0.33	1.60	1.72	0.42	1.52
	F 365	3.93	0.45	4.19	2.90	0.33	1.50	1.89	0.40	1.69
	F 376	4.08	0.47	4.19	2.80	0.37	1.43	1.70	0.41	1.60
LSD for P<0.05	A	0.20	0.03	0.15	0.15	0.02	0.09	0.10	0.03	0.11
	B	0.15	0.08	0.30	0.20	0.03	0.13	0.15	0.04	0.14
	AB	0.35	0.10	0.45	0.21	0.06	0.18	0.20	0.06	0.18

Table 2. Influence of water stress on protein content in several maize hybrids

Water stress level (A)	F 322		F 340		F 365		F 376	
	Protein content	Protein yield kg/ha $^{-1}$	Protein content	Protein yield kg/ha $^{-1}$	Protein content	Protein yield kg/ha $^{-1}$	Protein content	Protein yield kg/ha $^{-1}$
Optimum irrigation	8.75	1131	8.94	986	9.38	1078	8.50	899
Irrigation 60% of optimum	9.38	1003	10.25	879	9.25	1038	9.38	766
Irrigation 30% of optimum	10.31	802	9.62	719	10.31	893	9.87	701
Non-irrigation	10.62	719	10.13	607	10.56	791	10.62	650
LSD for P<0.05	1.25	51	1.2	46	1.30	63	1.35	40

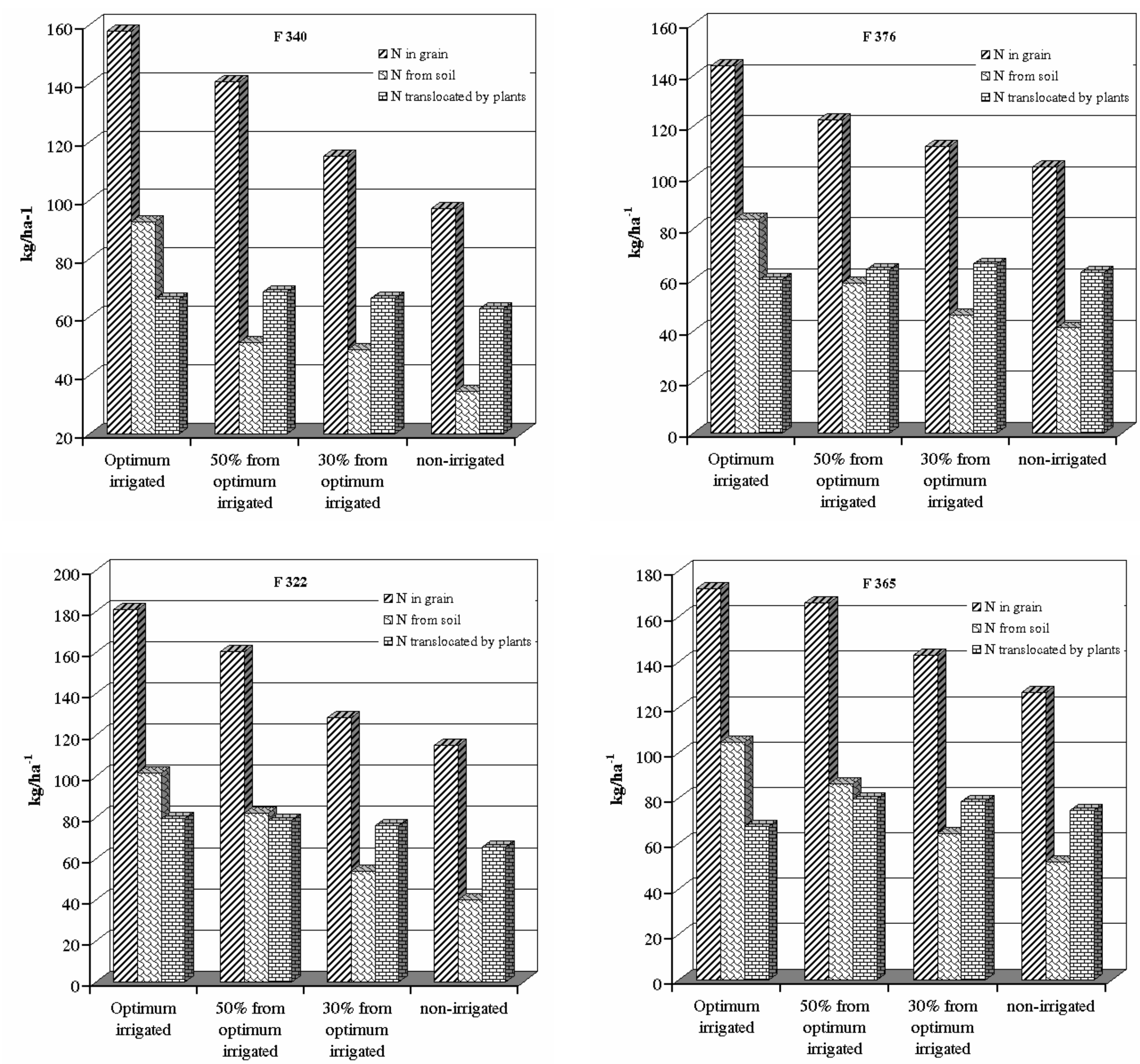

Figure 1. Influence of water stress on nitrogen translocated in grains of different maize hybrids

Table 3. Effect of water stress on microelement content (ppm) in several maize

Water stress level (A)	Hybrid (B)	Vegetation stage											
		3-4 leaves				Flowering				Maturity			
		Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu
Optimum irrigation	F 322	20.1	88.3	281.3	8.7	26.3	75.0	187.5	6.3	22.5	17.5	128.3	2.5
	F 340	18.8	77.5	355.0	8.8	33.0	52.5	200.0	6.3	23.8	17.5	127.5	2.5
	F 365	18.5	86.3	372.5	8.7	21.3	67.5	227.5	7.5	24.3	17.5	131.3	2.5
	F 376	18.8	86.3	337.5	8.8	28.5	67.5	212.5	7.5	18.8	16.3	131.3	2.5
Irrigation 60% of optimum	F 322	21.8	68.8	281.3	8.8	29.5	85.0	212.5	6.3	28.8	16.3	131.2	2.5
	F 340	20.3	77.5	237.5	8.8	35.0	75.0	200.0	6.3	30.0	17.5	127.5	2.5
	F 365	19.8	86.3	317.5	8.8	25.5	75.0	200.0	7.5	24.3	17.5	135.0	2.5
	F 376	20.1	86.3	262.5	8.8	30.0	75.0	212.5	6.3	22.5	16.3	121.3	2.5
Irrigation 30% of optimum	F 322	28.0	77.5	260.0	8.6	33.0	81.3	162.5	6.3	30.0	16.3	131.3	2.5
	F 340	26.3	77.6	262.5	8.7	37.0	60.0	200.0	6.3	31.3	17.5	125.0	2.5
	F 365	22.5	86.3	262.9	8.8	27.3	60.0	162.5	7.5	26.3	17.5	125.0	2.5
	F 376	22.5	77.5	257.0	8.7	33.0	52.5	162.5	6.3	30.0	17.5	127.5	2.5
Non-irrigation	F 322	33.8	68.8	237.0	8.8	36.3	67.5	137.5	6.7	32.5	22.5	121.3	2.5
	F 340	28.8	77.5	262.5	8.5	39.5	77.5	162.5	6.4	30.0	22.5	121.0	2.5
	F 365	23.7	86.9	225.0	8.8	28.8	67.5	200.0	7.5	33.8	17.5	121.5	2.5
	F 376	28.8	77.5	257.5	8.8	36.3	81.3	187.5	6.3	30.0	17.5	121.3	2.5
LSD for <0.05	A	1.7	3.7	15.0	0.01	3.0	3.0	8.0	0.03	1.7	0.5	1.0	0.0
	B	4.0	7.2	21.0	0.03	6.2	8.0	12.0	0.04	2.1	0.7	1.6	0.0
	A x B	6.0	9.7	25.3	0.03	9.1	9.4	15.3	0.05	2.6	0.8	2.2	0.0

Optimal water supply stimulated the process of N mineralization from the soil and permitted the absorption and translocation of larger quantities of N during grain filling period. N amount absorbed by plants from soil decreased with 21.8-53.9 kg /ha^{-1} in water stress entries. Fundulea 322 and Fundulea 365 had the highest capacity of translocation.

P content (%) decreased along the vegetation period as shown in table 1. In contrast to N, water stress caused significant decreasing of P content in all vegetative stages, as compared to optimal irrigation conditions.

Potassium had similar evolution to that of nitrogen; in the first vegetation stages a direct relationship of K content to water stress levels resulted in significant increasing of contents in low water supply entries. The highest capacity of K uptaking was registered in Fundulea 340 and Fundulea 376, known to be more tolerant to drought.

Optimal mineral nutrition could not be achieved without taking into consideration several microelements, considered essential for plant nutrition, such as: Fe, Mn, Zn and Cu. These microelements have specific actions and are indispensable for a normal development of important physiological function, their deficiency or insufficiency causing the occurrence of cytological, histologic or anatomo-morphologic disturbances, and ultimately to qualitative and quantitative decreasing of the crop yield.

Microelement contents from maize plants varied in relation to plant age and water supply levels, as shown in table 3.

Zn concentration registered larger values in water stress entries in all vegetation stages, as compared to optimal irrigation. The greatest differences (18.2 ppm), recorded in early vegetative stages (3-4 leaves) in all maize hybrids, grown on the chernozemic soil of Fundulea, were very close to the deficiency level. During the entire vegetation period, for all maize hybrids, significant inverse relationship of Zn uptake to that of phosphorus was found (Table 4).

Table 4. Relationship between zinc (ppm) and phosphorus (g%) absorption in several maize hybrids grown on chernozemic soil of Fundulea

Vegetation stage	Equation of quadratic regression	Correlation coefficients
Fundulea 322		
1. 3-4 leaves	$y=212.78-757.85x+740.22x^2$	-0.992***
2. Flowering	$y=401.00+306.25x-723.96x^2$	-0.914**
3. Maturity	$y=86.55-210.94x+172.97x^2$	-0.985***
Fundulea 340		
1. 3-4 leaves	$y=268.75+1408.33x-1666.67x^2$	-0.827*
2. Flowering	$y=31.55+616.11x-1274.65x^2$	-0.876**
3. Maturity	$y=496.06-2041.94x+2220.80x^2$	-0.909**
Fundulea 365		
1. 3-4 leaves	$y=65.61+467.90x-610.79x^2$	-0.958***
2. Flowering	$y=6.48+213.96x-498.00x^2$	-0.828*
3. Maturity	$y=172.81-548.05x+500.18x^2$	-0.941**
Fundulea 376		
1. 3-4 leaves	$y=907.44-4642.42x+6581.21x^2$	-0.803*
2. Flowering	$y=34.86+40.33x-164.14x^2$	-0.968***
3. Maturity	$y=113.90-855.14x+226.73x^2$	-0.868*

*, **, *** - significant for $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively

Mn concentration decreased slightly along vegetation period. Grain content of Mn was lower than leaf content, varying between 16.3-22.5 ppm. A slight non-significant increasing of Mn content was registered in water stress entries, as compared to optimal irrigation.

Fe concentration was very closed to the maximum level admitted for maize, in all vegetation stages. Irrigation stimulated Fe uptake, particularly in 3-4 leaf stage, Fundulea 365 and Fundulea 376 manifested a high capacity of Fe uptake, as compared to Fundulea 340 and Fundulea 322.

Low Cu content, close to the deficiency levels, was recorded in leaves at 3-4 leaf stage, but at maturity Cu content reached normal values for maize nutrition with this microelement. Neither water stress nor hybrids influenced Cu content of the leaves and grains.

Interactions and ratios between micro- and macroelements with synergetic or antagonistic effects, represent other important factors affecting the essential physiological and biochemical processes such as morphology and activity of root system, stimulation or inhibition of nutritive element transfer through xymplast or xylem, metabolic control of absorption, translocation and metabolization.

The main ionic ratios presented in table 5, points out the P-Zn antagonism for all maize hybrids, particularly in optimum irrigation entry, where Zn atoms /100 atoms of P ratios decreased almost twofold as compared to non-irrigated entry.

Similarly, Mn / P interaction was evident mainly under optimal irrigation conditions, where active P uptaking induced a lower Mn mobility.

Fe-Zn antagonism could hamper Zn nutrition of maize when soil physicochemical conditions are favourable to Fe mobilization.

Phosphorus had a stimulating effect on Fe uptake in all vegetation stages so that, Fe/ P synergetic interaction may be associated with low uptake of Zn and its translocation into leaves.

P-Zn antagonism could be explained by both direct effect of phosphorus in decreasing plant Zn content and indirect effect of P-Mn and P-Fe synergism, which may promote preferential absorption of these microelements in detriment of Zn.

P-Zn antagonism manifested to a greater extend in Fundulea 340 and Fundulea 365, grown under optimal irrigation conditions.

CONCLUSIONS

Yield of crude protein from grains decreased in water stress entries from 101 up to 331 kg ha^{-1}. The highest yield of crude protein was registered at Fundulea 365.

Optimal water supply determined the uptake and translocation into grain of larger quantities of nitrogen. Water stress induced a decrease of 21.8-53.9 kg/ha^{-1} of nitrogen uptake from soil. Fundulea 322 and Fundulea 365 manifested the highest capacity of nitrogen translocation.

Table 5. Influence of water stress ionic relationship of macro- and microelements absorbed by several maize hybrids

Water stress level (A)	Hybrid (B)	Vegetation stage											
		3-4 leaves				Flowering				Maturity			
		Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu
Optimum irrigation	F322	2.0	10.0	33.2	16.4	3.9	13.2	32.5	8.4	1.9	7.4	12.4	4.9
	F340	1.8	8.7	39.4	22.2	4.7	11.0	33.6	7.1	2.4	8.8	14.6	4.6
	F365	1.8	10.1	43.1	23.6	3.1	11.5	38.3	9.5	2.2	8.1	14.0	4.6
	F376	1.9	10.8	41.6	21.1	3.7	10.3	31.9	8.7	1.6	6.2	12.8	6.0
Irrigation 60% of optimum	F322	2.3	8.6	34.7	15.1	4.4	15.0	36.9	8.4	3.2	8.4	13.6	3.9
	F340	2.0	9.1	27.5	13.7	5.2	13.2	34.7	6.7	3.0	9.0	14.9	3.6
	F365	2.0	10.6	38.3	18.8	3.8	13.2	34.7	9.2	2.5	9.0	14.3	3.8
	F376	2.4	12.2	36.4	15.3	4.4	13.3	38.9	8.3	2.3	7.7	14.7	3.6
Irrigation 30% of optimum	F322	3.3	10.9	36.1	10.9	5.6	16.4	32.2	5.8	3.7	9.0	14.2	3.7
	F340	3.0	10.7	35.5	11.7	5.7	10.9	35.8	6.3	3.0	8.5	14.8	3.5
	F365	2.4	10.1	33.1	13.7	4.8	12.5	33.4	7.0	2.5	8.6	14.8	3.6
	F376	2.7	10.9	35.7	13.4	5.2	12.9	34.7	5.8	3.2	9.4	15.3	3.4
Non-irrigation	F322	3.5	10.5	35.6	8.2	8.6	19.0	38.2	4.7	4.2	10.9	18.2	3.2
	F340	3.2	10.4	34.7	10.7	9.9	23.0	47.5	4.8	3.4	10.7	16.0	3.5
	F365	3.8	12.2	31.2	10.1	7.6	21.2	61.7	5.1	4.0	10.5	16.8	3.1
	F376	3.3	10.7	34.9	10.5	8.6	23.0	52.0	6.1	3.5	10.3	16.4	3.5

Irrigation improved plant nutrition with phosphorus but disturbed Zn nutrition, due to a indirect relationship between P and Zn uptake. Although P-Zn antagonism was detected in all hybrids, it appeared more intensively in Fundulea 340 and Fundulea 365 fully irrigated.

P-Zn antagonism is determined by both the direct effect of phosphorus on Zn concentration from maize plants and an indirect effect caused by P-Mn and P-Fe synergism, which favourized a preferential uptake of Mn and Fe.

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Table 1. Influence of water stress on evolution of N, P, K content in several maize hybrids (g%).

Water stress level (A)	Hybrid (B)	Vegetation stage								
		3-4 leaves			Flowering			Maturity		
		N	P	K	N	P	K	N	P	K
Optimum Irrigation	F 322	3.95	0.47	3.72	2.36	0.20	1.21	1.40	0.57	1.51
	F 340	4.08	0.50	3.67	2.59	0.19	1.48	1.43	0.48	1.33
	F 365	3.94	0.48	3.17	2.30	0.18	1.40	1.60	0.52	1.60
	F 376	3.91	0.45	3.24	2.61	0.20	1.50	1.36	0.57	1.36
Irrigation 60% of optimum	F 322	3.91	0.45	3.68	2.45	0.28	1.20	1.50	0.42	1.45
	F 340	4.00	0.48	3.57	2.46	0.31	1.33	1.48	0.47	1.34
	F 365	4.10	0.46	3.76	2.44	0.27	1.20	1.64	0.47	1.50
	F 376	3.88	0.40	3.81	2.53	0.30	1.18	1.50	0.46	1.58
Irrigation 30% of optimum	F 322	4.00	0.40	3.86	2.48	0.32	1.29	1.65	0.39	1.36
	F 340	4.10	0.42	3.57	2.61	0.32	1.74	1.64	0.50	1.41
	F 365	3.95	0.40	3.77	2.77	0.32	1.29	1.75	0.49	1.52
	F 376	3.90	0.41	3.76	2.63	0.32	1.70	1.58	0.45	1.49
Non-Irrigation	F 322	4.14	0.37	4.19	2.50	0.32	1.38	1.72	0.37	1.62
	F 340	4.08	0.40	4.14	2.90	0.33	1.60	1.72	0.42	1.52
	F 365	3.93	0.45	4.19	2.90	0.33	1.50	1.89	0.40	1.69
	F 376	4.08	0.47	4.19	2.80	0.37	1.43	1.70	0.41	1.60
LSD for $P<0.05$	A	0.20	0.03	0.15	0.15	0.02	0.09	0.10	0.03	0.11
	B	0.15	0.08	0.30	0.20	0.03	0.13	0.15	0.04	0.14
	AB	0.35	0.10	0.45	0.21	0.06	0.18	0.20	0.06	0.18

Table 2. Influence of water stress on protein content in several maize hybrids.

Water stress level (A)	F 322		F340		F 365		F 376	
	Protein content	Protein yield ka ha $^{-1}$	Protein content	Protein yield ka ha $^{-1}$	Protein content	Protein yield ka ha $^{-1}$	Protein content	Protein yield ka ha $^{-1}$
Optimum irrigation	8.75	1131	8.94	986	9.38	1078	8.50	899
Irrigation 60% of optimum	9.38	1003	10.25	879	9.25	1038	9.38	766
Irrigation 30% of optimum	10.31	802	9.62	719	10.31	893	9.87	701
Non-Irrigation	10.62	719	10.13	607	10.56	791	10.62	650
LSDfor P<0.05	1.25	51	1.2	46	1.30	63	1.35	40

Table 3. Effect of water stress 0icrn several maize

Water stress level (A)	Hybrid (B)	Vegetation stage											
		3-4 leaves				Floweing				Maturity			
		Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu
Optimum jrrigation	F 322	20.1	88.3	281.3	8.7	26.3	75.0	187.5	6.3	22.5	17.5	128.3	2.5
	F 340	18.8	77.5	355.0	8.8	33.0	52.5	200.0	6.3	23.8	17.5	127.5	2.5
	F 365	18.5	86.3	372.5	8.7	21.3	67.5	227.5	7.5	24.3	17.5	131.3	2.5
	F 376	18.8	86.3	337.5	8.8	28.5	67.5	212.5	7.5	18.8	16.3	131.3	2.5
Irrigation60% of optimum	F 322	21.8	68.8	281.3	8.8	29.5	85.0	212.5	6.3	28.8	16.3	131.2	2.5
	F 340	20.3	77.5	237.5	8.8	35.0	75.0	200.0	6.3	30.0	17.5	127.5	2.5
	F 365	19.8	86.3	317.5	8.8	25.5	75.0	200.0	7.5	24.3	17.5	135.0	2.5
	F 376	20.1	86.3	262.5	8.8	30.0	75.0	212.5	6.3	22.5	16.3	121.3	2.5
Irrigation 30% of optimum	F 322	28.0	77.5	260.0	8.6	33.0	81.3	162.5	6.3	30.0	16.3	131.3	2.5
	F 340	26.3	77.6	262.5	8.7	37.0	60.0	200.0	6.3	31.3	17.5	125.0	2.5
	F 365	22.5	86.3	262.9	8.8	27.3	60.0	162.5	7.5	26.3	17.5	125.0	2.5
	F 376	22.5	77.5	257.0	8.7	33.0	52.5	162.5	6.3	30.0	17.5	127.5	2.5
Non-irrigation	F 322	33.8	68.8	237.0	8.8	36.3	67.5	137.5	6.7	32.5	22.5	121.3	2.5
	F 340	28.8	77.5	262.5	8.5	39.5	77.5	162.5	6.4	30.0	22.5	121.0	2.5
	F 365	23.7	86.9	225.0	8.8	28.8	67.5	200.0	7.5	33.8	17.5	121.5	2.5
	F 376	28.8	77.5	257.5	8.8	36.3	81.3	187.5	6.3	30.0	17.5	121.3	2.5
LSD for <0.05	A	1.7	3.7	15.0	0.01	3.0	3.0	8.0	0.03	1.7	0.5	1.0	0.0
	B	4.0	7.2	21.0	0.03	6.2	8.0	12.0	0.04	2.1	0.7	1.6	0.0
	A x B	6.0	9.7	25.3	0.03	9.1	9.4	15.3	0.05	2.6	0.8	2.2	0.0

Table 4. Relationship between zinc (ppm) and phosphorus(g%) absorption in several maize hybrids grown on chernozemic soilfmm Fundulea.

Vegetation stage	Equation of quadratic regression	Correlation coefficients
	Fundulea 322	
1. 3-4 leaves	$y=212.78-757.85x+740.22x^2$	-0.992
2. Flowering	$y=401.00+306.25x-723.96x^2$	-0.914 ++
3. Maturity	$y=86.55-210.94x+172.97x^2$	-0.985
	Fundulea 340	
1. 3-4 leaves	$y=268.75+1408.33x-1666.67x^2$	-0.827 +
2. Flowering	$y=31.55+616.11x-1274.65x^2$	-0.876 ++
3. Maturity	$y=496.06-2041.94x+2220.80x^2$	-0.909 ++
	Fundulea 365	
1. 3-4 leaves	$y=65.61+467.90x-610.79x^2$	-0.958
2. Flowering	$y=6.48+213.96x-498.00x^2$	-0.828 +
3. Maturi ty	$y=172.81-548.05x+500.18x^2$	-0.941 ++
	Fundulea 376	
1. 3-4 leaves	$y=907.44-4642.42x+6581.21x^2$	-0.803 +
2. Flowering	$y=34.86+40.33x-164.14x^2$	-0.968
3. Maturity	$y=113.90-855.14x+226.73x^2$	-0.868 +

+, + +, + + + - significantfor $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 5. Influence of water stress ionic relationship of macro- and microelements absorbed by several maize hybrids

Water stress level (A)	Hybrid (B)	Vegetation stage											
		3-4 leaves				Floweing				Maturity			
		Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu	Zn	Mn	Fe	Cu
Optimum jrrigation	F322	2.0	10.0	33.2	16.4	3.9	13.2	32.5	8.4	1.9	7.4	12.4	4.9
	F340	1.8	8.7	39.4	22.2	4.7	11.0	33.6	7.1	2.4	8.8	14.6	4.6
	F365	1.8	10.1	43.1	23.6	3.1	11.5	38.3	9.5	2.2	8.1	14.0	4.6
	F376	1.9	10.8	41.6	21.1	3.7	10.3	31.9	8.7	1.6	6.2	12.8	6.0
Irrigation 60% of optimum	F322	2.3	8.6	34.7	15.1	4.4	15.0	36.9	8.4	3.2	8.4	13.6	3.9
	F340	2.0	9.1	27.5	13.7	5.2	13.2	34.7	6.7	3.0	9.0	14.9	3.6
	F365	2.0	10.6	38.3	18.8	3.8	13.2	34.7	9.2	2.5	9.0	14.3	3.8
	F376	2.4	12.2	36.4	15.3	4.4	13.3	38.9	8.3	2.3	7.7	14.7	3.6
Irrigation 30% of optimum	F322	3.3	10.9	36.1	10.9	5.6	16.4	32.2	5.8	3.7	9.0	14.2	3.7
	F340	3.0	10.7	35.5	11.7	5.7	10.9	35.8	6.3	3.0	8.5	14.8	3.5
	F365	2.4	10.1	33.1	13.7	4.8	12.5	33.4	7.0	2.5	8.6	14.8	3.6
	F376	2.7	10.9	35.7	13.4	5.2	12.9	34.7	5.8	3.2	9.4	15.3	3.4
Non-irrigation	F322	3.5	10.5	35.6	8.2	8.6	19.0	38.2	4.7	4.2	10.9	18.2	3.2
	F340	3.2	10.4	34.7	10.7	9.9	23.0	47.5	4.8	3.4	10.7	16.0	3.5
	F365	3.8	12.2	31.2	10.1	7.6	21.2	61.7	5.1	4.0	10.5	16.8	3.1
	F376	3.3	10.7	34.9	10.5	8.6	23.0	52.0	6.1	3.5	10.3	16.4	3.5

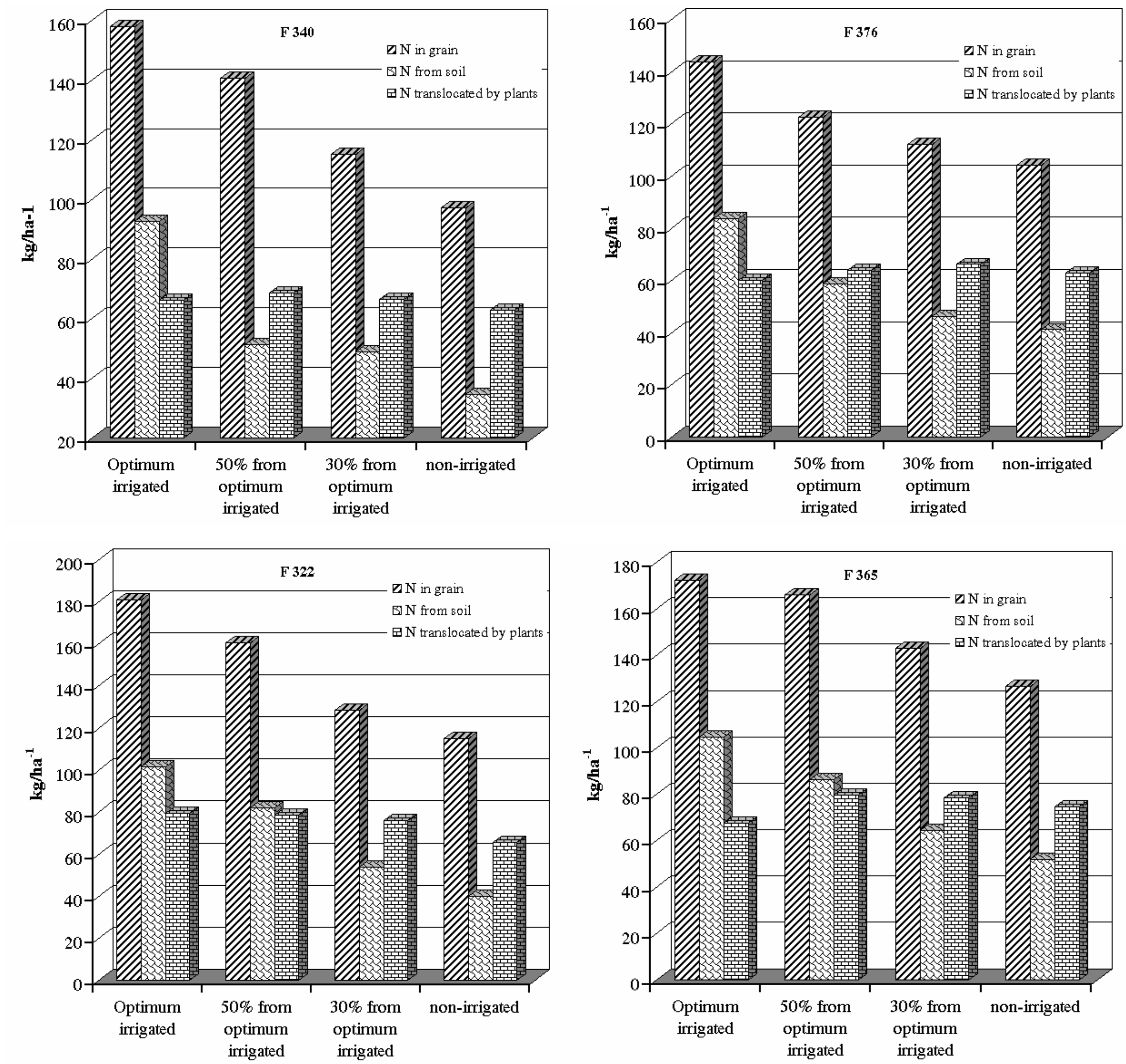

Figure 1. Influence of water stress on nitrogen translocated in grains of different maize hybrids