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ACTIVITY OF SOME PHYSIOLOGICAL PROCESSES AND YIELD OF SPRING WHEAT AND TRITICALE AS EFFECT OF SUPPLEMENTAL IRRIGATION AND FERTILIZATION

AKTYWNOŚĆ NIEKTÓRYCH PROCESÓW FIZJOLOGICZNYCH ORAZ PLONOWANIE PSZENICY I PSZENŻYTA JAREGO POD WPŁYWEM DESZCZOWANIA I NAWOŻENIA MINERALNEGO

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The aim of field - and laboratory studies was the assay of the influence of irrigation and mineral fertilization on the activity of some physiological processes and yield of spring wheat and spring triticale cultivated on a sandy soil.

The results show that, supplemental irrigation and high NPK doses caused a marked increase of chlorophyll and carotenoides content and prolonged their activity. The activity of red-ox enzymes in the flag-leaves, photo-synthesis, transpiration and diffusive conductivity of leaves was also enhanced whereas the concentration of carbon dioxide in the substomatal cells was decreased.

As effect of both applied measures, the yield of spring wheat grain was by 106% higher, that of triticale by 120%.

INTRODUCTION

The choice of plants to be cultivated on sandy soils is limited, and intensification of agriculture on such soils is hard to achieve and costly. Application of high mineral fertilizer doses combined with supplemental irrigation makes the selection of plant species easier.

Studies performed a.o. by Dzieżyc (1989), Karczmarczyk (1979), Żarski (1993), Podsiadło (1993), have shown that, there exists the possibility of obtaining high yields of spring and winter wheat on poor soils, providing intense agrotechnics. Recently the cultivation of triticale gains momentum, and it could be grown on poor soils, such which are hardly proper for wheat. Studies pertaining to the cultivation of triticale are not many. Results presented by Bieszczad and Piotrowski (1992), Koziar et al. (1994) proved a good response of triticale to irrigation. Since a good growth and development of plants is strongly connected with the activity of physiological processes, this study aimed also at the assessment of the impact of irrigation and mineral fertilizers on the content of photosynthetic pigments, photosynthesis and enzyme activity of the tested plants.

MATERIALS AND METHODS

The study was performed in 1996 and 1997 on a sandy soil. The soil containes 1.5% humus, 11-13% floatable parts, low levels of available potassium and phosphorus, pH KCl 5.2-5.6.

Meteorological conditions were average, and though these were not dry years, in 1996 dry periods occured in May and June, thus coinciding with the plants' critical stages. Hence the irrigation doses were 60 mm in 1996 and 80 mm in 1997. The experiments were trifactorial; irrigation (0 - not irrigated, W - irrigated), two plant species (spring wheat cv.Bant, spring triticale cv.Migo), 3 levels of mineral fertilization (0, 300, 450 kg NPK/ha). Irrigation needs were assessed by 10-day water requirement (Dzieżyc et al. 1987). Cultivation measures were applied accordingly to common practice.

Pigment content was assayed in samples taken from flag leaves, shank and spike, at heading, flowering and milk maturity. At the same time the dry matter content in these organs was assessed, to calculate the pigment content in the whole organ.

Chlorophyll content was assessed by the method of Arnon et al. (1956), carotene by Schnarrenberger and Mohr (1970). The leaves were extracted by N,N-dimethylformamide for 24 h. Extinction of the extracts was measured at 645, 663, 440 mm. Nitrate content and nitrate reductase activity was measured in the flag leaf at the flowering stage. Nitrate nitrogen content was measured by ionselective electrode. Nitrate reductase activity was measured by colorymetry, reduced NADH was used as hydrogen source, acid and alkaline phosphatase and peroxydase activities were also measured by colorymetry. The gas analyser LCA-4 was used for the assay of CO_2 assimilation intensity, transpiration, CO_2 concentration in the substomatal cells, leaf conductivity and temperature. The CO_2 assimilation intensity, and the other parameters mentioned above were assessed in the canopy at noon, and at a temp. of 20-21°C, one day after irrigation, at a photone density of 600 μMol·m^{2}·sec.$^{-1}$ PAR. Grain and straw were harvested from whole plots of 18 m^{2} and calculated for t·ha^{-1}. All results were subjected to statistical analysis by the analysis of variance.

RESULTS

The content of pigments in plants depends on their genetic properties, but it can be influenced also by the environment, nutrition, particularly nitrogen fertilization, water availability and insolation. All the factors caused variations of the pigments' content (Table 1, 2). Irrigation increased the leaf chlorophyll content measured at heading by 13%, whereas at milk maturity by 187%. Similarly, in the spike at heading the differences were minor but towards the end of vegetation the amount of chlorophyll in plants well supplied with water was almost doubled. This was caused by a prolonged photosynthetic activity of the organs, which led to enhanced biomass production. The positive effect of irrigation was more pronounced in wheat, which may be connected with a better developed rootsystem of triticale and its greater resistance to drought and low water content in the soil.

There was a distinct influence of high doses of mineral fertilizer on the pigment content. At heading the content of chlorophyll in wheat flag leaf was three times higher in plants fertilized with triple NPK, and in triticale it was doubled. From the results shown in table 1 can be seen, that the chlorophyll content decreases with vegetation, but this process was much slower in plants which had been well fertilized and irrigated.

Of the pigments involved in photosynthesis, carotenoides play a great role. According to Devlin and Barker (1971), and Lawlor (1981) these compounds absorb the sun energy of the medium- and shortwave spectrum range, thus protect chlorophyll from photooxydation. Results presented in table 2 prove that both irrigation and fertilization caused an increase of carotene content, though to a lesser extent than that of chlorophyll, but also protected the last from destruction when the plants grew to maturity. Similarly to the chlorophyll content, the highest level of carotenoides was found in the flag leaf, which, according to Nalborczyk et al. (1981) is the main organ of assimilation, later on, when the leaf begins to fade, its role is taken over by the shank and spike.

Table 1. Chlorophyll content in some parts of spring wheat and spring triticale depending on growth stage, sprinkling and NPK doses (mg/g d.m.)

Plant	Sprinkling irrigation	Fertilization (kg/ha)	Heading			Flowering			Milk ripenes		
			flag leaf	shank	spike	flag leaf	shank	spike	flag leaf	shank	spike
Spring wheat	O	0	2.50	0.58	0.20	3.14	0.33	0.36	0.66	0.36	0.08
		150	3.88	0.58	0.34	3.26	0.72	0.35	1.05	0.75	0.09
		450	7.80	0.86	0.49	6.25	1.01	0.48	1.71	1.10	0.13
		$\bar{x}$	4.72	0.67	0.34	4.21	0.68	0.39	1.14	0.75	0.10
	W	0	2.70	0.60	0.10	4.08	0.63	0.35	1.29	0.66	0.12
		150	3.90	0.62	0.36	5.58	0.99	0.36	3.66	0.87	0.28
		450	9.40	1.00	0.82	6.66	2.97	0.37	4.87	3.00	0.30
		$\bar{x}$	5.33	0.74	0.42	5.44	1.46	0.36	3.27	0.72	0.23
Effect of NPK		0	2.60	0.59	0.15	3.61	0.38	0.35	0.97	0.25	0.10
		150	3.89	0.60	0.35	4.42	0.85	0.36	2.35	0.60	0.20
		450	8.60	0.93	0.65	6.45	1.99	0.42	3.29	0.78	0.19
Mean			5.02	0.70	0.38	4.82	1.07	0.37	2.20	0.54	0.16
Spring triticale	O	0	4.17	1.17	0.40	4.97	1.20	0.33	0.80	1.37	0.18
		150	8.52	1.26	0.47	8.30	0.81	0.32	1.80	0.93	0.25
		450	9.16	1.33	0.50	8.83	0.84	0.25	4.08	1.05	0.29
		$\bar{x}$	7.28	1.25	0.45	7.36	0.70	0.30	2.23	0.61	0.24
	W	0	6.34	1.21	0.46	4.11	1.24	0.17	1.56	1.31	0.23
		150	6.90	1.30	0.56	6.30	1.34	0.51	1.84	1.59	0.31
		450	11.32	1.86	0.76	9.62	1.34	0.57	5.50	1.80	0.34
		$\bar{x}$	8.18	1.45	0.59	6.67	1.30	0.42	2.96	0.73	0.29
Effect of NPK		0	5.25	1.19	0.43	4.54	0.85	0.25	1.18	0.34	0.20
		150	7.71	1.28	0.51	7.30	1.07	0.41	1.82	0.51	0.28
		450	10.24	1.60	0.63	9.22	1.09	0.41	4.79	1.17	0.31
Mean			7.73	1.35	0.52	7.00	0.95	0.36	2.60	0.67	0.23
$LSD_{0.05}$ for:											
plants (A)			0.034	0.07	0.12	0.025	0.14	0.18	0.035	0.08	0.11
irrigation (B)			0.014	r.n.	0.02	0.023	0.18	0.02	0.006	0.06	0.13
fertilization (C)			0.018	0.06	0.11	0.028	0.21	0.04	0.017	0.09	0.07
A × B			0.019	r.n.	0.028	0.33	0.23	0.03	0.008	0.09	0.17
A × C			0.026	0.09	r.n.	0.40	0.28	r.n.	0.024	0.137	0.11
B × C			0.025	0.09	r.n.	0.40	0.30	r.n.	0.020	0.130	0.11

Table 2. Carotenoid content in some parts of spring wheat and spring triticale depending on growth stage, sprinkling and NPK doses (mg/g d.m.)

Plant	Sprinkling irrigation	Fertilization (kg/ha)	Heading			Flowering			Milk ripenes		
			flag leaf	shank	spike	flag leaf	shank	spike	flag leaf	shank	spike
Spring wheat	O	0	1.13	0.26	0.22	1.04	0.13	0.18	0.44	0.10	0.03
		150	1.40	0.28	0.36	1.01	0.24	0.17	0.55	0.14	0.04
		450	1.65	0.52	0.40	1.80	0.32	0.20	0.82	0.18	0.06
		x̄	1.39	0.35	0.32	1.28	0.23	0.18	0.60	0.14	0.043
	W	0	1.64	0.26	0.28	1.54	0.15	0.12	0.60	0.09	0.04
		150	1.80	0.33	0.39	1.65	0.32	0.18	1.51	0.27	0.06
		450	2.10	0.67	0.47	1.90	0.64	0.24	1.54	0.33	0.09
		x̄	1.84	0.42	0.38	1.70	0.47	0.18	1.21	0.23	0.06
Effect of NPK		0	1.38	0.26	0.25	1.29	0.14	0.15	0.52	0.095	0.05
		1	1.60	0.30	0.37	1.33	0.28	0.17	1.03	0.20	0.04
		3	1.87	0.59	0.43	1.85	0.48	0.22	1.18	0.25	0.06
Mean			1.61	0.38	0.35	1.49	0.35	0.18	0.90	0.18	0.24
Spring triticale	O	0	1.36	0.18	0.13	1.87	0.20	0.13	0.72	0.14	0.06
		150	1.50	0.19	0.18	1.80	0.27	0.13	0.75	0.19	0.06
		450	1.68	0.37	0.25	2.39	0.37	0.14	1.31	0.37	0.12
		x̄	1.51	0.24	0.18	2.02	0.28	0.13	0.92	0.23	0.08
	W	0	1.10	0.20	0.18	1.55	0.17	0.15	0.52	0.18	0.05
		150	1.16	0.30	0.20	2.15	0.28	0.17	0.81	0.17	0.06
		450	1.85	0.39	0.28	2.60	0.40	0.19	1.26	0.32	0.08
		x̄	1.37	0.30	0.22	2.1	0.28	0.17	0.86	0.22	0.06
Effect of NPK		0	1.44	0.27	0.20	2.06	0.28	0.15	0.89	0.22	0.07
		1	1.23	0.19	0.15	1.71	0.18	0.14	0.62	0.16	0.055
		3	1.33	0.24	0.19	1.97	0.27	0.15	0.78	0.18	0.06
Mean			1.76	0.38	0.26	2.49	0.38	0.16	1.28	0.34	0.10
$LSD_{0.05}$ for:											
plants (A)			0.078	0.009	0.005	0.011	0.026	r.n.	0.0092	0.014	0.029
irrigation (B)			0.087	0.037	0.053	0.020	0.031	0.017	0.0047	0.019	0.067
fertilization (C)			0.011	0.030	0.031	0.038	0.030	0.020	0.0041	0.028	0.034
A × B			0.011	r.n.	r.n.	r.n.	0.040	r.n.	0.006	0.024	0.073
A × C			0.014	r.n.	0.036	r.n.	0.042	r.n.	0.005	0.035	0.049
B × C			r.n.	0.042	r.n.	r.n.	0.042	0.029	0.005	0.038	0.049

Wojcieska et al. (1983) has shown that, the plants' content of chlorophyll and carotenoides is not directly related to the production of photosyntheates, but the total assimilation surface of the plant has an impact on the amount of biomass production, of course at a certain level of pigments and intensity of photosynthesis. For that reason the dry matter of some organs was assessed (Table 3), and the content of pigments in the whole organs calculated, at three stages of plant growth, the results are given in Table 4 and 5. The results show the efficiency of biomass production in various plant organs, taking into account the pigment content, surface and weight of the whole organ. These data show that the weight of particular plant parts increased as effect of irrigation and fertilization by up to 160% (spike in bloom), and the amount of pigments exceeded, by 300% that of the control plants.

Table 3. Dry matter of tested plant parts (mg)

Plant	Irrigation	Fertilization (kg/ha)	Heading			Flowering			Milk ripenes		
			flag leaf	shank	spike	flag leaf	shank	spike	flag leaf	shank	spike
Spring wheat	O	0	25	36	59	28	49	98	32	55	342
		150	27	42	86	33	68	112	41	72	565
		450	32	54	122	48	78	176	56	84	686
		$\bar{x}$	28	44	89	36	65	129	43	70	531
	W	0	25	58	74	38	62	214	48	76	521
		150	30	84	118	45	92	340	69	97	648
		450	33	99	162	65	114	452	88	132	836
		$\bar{x}$	29	80	118	49	89	335	68	102	668
Mean			29	62	104	43	77	232	56	86	600
Spring triticale	O	0	28	42	62	39	56	115	44	68	368
		150	32	56	99	54	82	130	62	92	672
		450	38	64	140	62	96	198	70	108	790
		$\bar{x}$	33	54	100	52	78	148	59	89	610
	W	0	32	66	86	42	78	236	62	86	582
		150	38	98	132	58	112	382	74	116	726
		450	42	115	198	69	134	516	86	142	912
		$\bar{x}$	31	93	139	56	108	378	74	115	740
Mean			35	74	120	54	93	263	67	102	675

As effect of supplemental irrigation the chlorophyll content of the flag leaf dry matter was at heading by 18% higher, at flowering by 69% and at milk maturity by 360% (Table 4). The triticale contained at heading 27%, milk maturity 90% more chlorophyll. At milk maturity the wheat shank contained 227% more chlorophyll, that of triticale 90%. The dry spike contained at that stage 193% and 46% more, respectively.

The influence of fertilization was much more pronounced, for example at milk maturity the chlorophyll content of flag leaf dry matter was in both plants by 300% higher if the plants had been fertilized with a triple NPK dose.

The content of carotenoides in the chosen plant organs (Table 5) increased similary to that of chlorophyll, which was due to a prolonged photosynthetic activity of the irrigated plants and a larger production of biomass, and consequently resulting in higher yield. These findings are confirmed by studies of Wojcieska (1971), and Karczmarczyk et al. (1990, 1993).

The intensity of plant biological processes depends on their nutrition and water supply, and the engine of all biochemical reactions are enzymes. Nitrate reductase, which controls the conversion of nitrogen plays a major role, peroxydase protects the phytohormones, phosphatases which regulate phosphorus management in plants, all of them are vital in the process of plant growth.

Table 4. Chlorophyll content in some organs of spring wheat and spring triticale at different stages, dependent on irrigation and mineral fertilization (mg/d.m. of organ)

Plant	Irrigation	Fertilization (kg/ha)	Heading			Flowering			Milk ripenes		
			flag leaf	shank	spike	flag leaf	shank	spike	flag leaf	shank	spike
Spring wheat	O	0	63	20	12	88	21	35	21	20	27
		150	105	24	29	108	49	39	43	54	51
		450	250	46	60	300	79	84	96	92	89
		$\bar{x}$	139	30	34	165	50	53	53	55	56
	W	0	67	35	7	155	39	75	62	50	62
		150	117	52	42	251	91	122	248	84	181
		450	310	99	133	432	338	167	428	408	250
		$\bar{x}$	165	62	61	279	156	121	246	180	164
Effect of NPK		0	65	27	9,5	121	30	55	42	35	44.5
		150	111	38	35	179	70	80	145	69	116
		450	280	72	96	366	208	125	262	250	169
Spring triticale	O	0	116	49	25	193	67	38	35	93	66
		150	273	70	46	448	66	41	111	85	168
		450	348	85	70	547	80	49	285	113	229
		$\bar{x}$	246	68	47	396	71	43	144	97	154
	W	0	202	79	39	172	96	40	96	112	133
		150	262	127	74	365	150	194	136	184	225
		450	475	214	150	663	246	294	473	257	310
		$\bar{x}$	313	140	88	400	164	176	235	184	225
Effect of NPK		0	159	64	32	182	81	39	65	102	99
		150	267	98	60	406	108	117	123	134	196
		450	411	149	110	605	122	171	253	185	270

Table 5. Carotenoid content in some organs of spring wheat and spring triticale at different stages dependent on applied treatments (μg/d.m. of organ)

Plant	Irriga-tion	Fertili-zation (kg/ha)	Heading			Flowering			Milk ripenes		
			flag leaf	shank	spike	flag leaf	shank	spike	flag leaf	shank	spike
Spring wheat	O	0	28	9	13	29	6	18	14	5	10
		150	38	12	31	33	16	19	22	10	22
		450	53	28	49	86	25	35	46	15	41
		x̄	40	16	31	49	16	24	27	10	24
	W	0	41	15	20	58	9	26	28	7	20
		150	54	27	46	74	29	61	104	26	39
		450	69	66	76	123	73	108	135	43	75
		x̄	55	36	47	85	37	65	89	25	45
Effect of NPK		0	34	12	16	43	7	22	21	6	15
		150	46	19	38	53	22	40	63	18	30
		450	61	47	62	104	49	71	90	29	58
Spring triticale	O	0	38	7	8	73	11	15	32	9	22
		150	48	11	18	97	22	17	46	17	40
		450	64	24	35	148	35	28	92	40	95
		x̄	50	14	20	106	23	20	57	22	52
	W	0	35	13	15	65	13	35	32	15	29
		150	44	30	26	124	31	65	60	20	43
		450	78	45	55	180	54	98	108	45	73
		x̄	52	29	32	123	33	66	67	27	48
Effect of NPK		0	36	10	11	69	12	25	32	12	25
		150	46	20	22	110	26	41	53	18	41
		450	71	34	45	164	44	63	100	42	84

As can be seen in Table 6, the content of nitrogen in flag leaves increased with high fertilizer doses, yet plants which had been irrigated contained less nitrate - by 20% in case of wheat and by 12% - triticale. It seems possible that part of the nitrates could have been transported with water into deeper soil layers, however since the irrigated plants showed an increased nitrate reductase activity, the nitrates could be easier reduced and incorporated into aminoacids by better developed plants which produced more carbohydrates. Nitrate reductase playes in these processes a key role (Beovers and Hageman 1969; Erich and Hageman 1973).

Our study showed a close relation of the increased nitrate content and nitrate reductase activity. On the other hand it is hard to explain the increased biomass production and high yield from irrigated plots, which plants contained less nitrates and showed a lower nitrate reductase activity. It seems most likely that, not only the enzyme activity, but its whole mass contained in the larger organs (flag leaf, shank, spike), affected the total amount of nitrogen reduced and incorporated into protein during the whole, prolonged vegetation. This is supported by the larger grain and straw yield (Table 9) gathered from irrigated plots, and also a greater surface of leaves, shanks and spikes (Table 3), moreover the vegetation on irrigated plots lasted longer, and carbon dioxide assimilation was more intense (Table 7, 8). This caused an enhanced production of assimilation products, including carbon structures necessary for the production of high-molecule compounds, and also, according to Joy and Hageman (1966), the increased photosynthesis delivered more electrons used by the nitrate and nitrite reductases for the reduction of them to NH_4^+.

Table 6. Nitrate nitrogen content and activity of some enzymes in spring wheat and spring triticale flag leaf at flowering stage (means of two years)

Obiects		$N-NO_3$	Nitrate reductase	Peroxydase	Phosphatase (mmol/kg)	
irrigation	NPK (kg/ha)	(mg/kg)	(μmol·g·h)	(ΔE/s·100 g)	alkaline	acid
Spring wheat						
O	0	220	234	167	17.4	35.2
	150	316	440	180	16.0	66.6
	450	350	748	210	15.7	96.2
Mean		295	474	186	16,4	66.0
W	0	180	212	208	17.2	84.0
	150	245	386	216	15.8	108.4
	450	308	642	230	15.5	131.0
Mean		244	413	218	16,2	107.8
Effect of NPK	0	200	223	188	17.3	59.6
	150	281	413	198	15.9	87.5
	450	329	695	220	15.6	113.6
Mean		270	444	202	16.3	86.9
Spring triticale						
O	0	235	296	180	31.2	82.2
	150	280	520	232	31.8	83.1
	450	300	780	256	25.2	108.4
Mean		272	532	223	29,4	91.2
W	0	170	260	212	31.9	91.0
	150	220	425	240	32.2	115.4
	450	256	668	286	26.6	116.6
Mean		215	451	246	30,2	107.7
Effect of NPK	0	203	278	196	31.6	86.6
	150	250	473	236	32.0	99.3
	450	275	724	271	25.9	112.5
Mean		243	492	234	29.8	99.5

Nitrate reductase reacts distinctly to the nitrates content in plants (Hagemann and Feeshes, in Wojcieska, and Wojcieska et al. 1981). In our study a close corelation between the level of mineral fertilization and nitrate concentration in the flag leaf, and the nitrate reductase activity was also found. These results are fully confirmed by the findings of Wojcieska et al. (1991, 1992), Karczmarczyk et al. (1993), Zbieć et al. (1989).

An increased activity of peroxydase, as effect of both aplied measures, has also been found (Table 6). In irrigated wheat this activity increased by 17%, in triticale - by 10%, high fertilizer doses enhanced this activity by 17 and 38%, respectively. According to Machackova (1975) peroxydase protects the endogenous growth regulators in plant cells.

The activity of phosphatases which are responsible for phosphorus management in plants, was also modified by the applied measures. Plants which were irrigated showed an increased acid phosphatase activity - wheat by 63%, triticale by 18%, high doses of fertilizer enhanced the activity of this enzyme by 91 and 30%, respectively. The activity of alkaline phosphatase was not affected. Similar results were reported by Karczmarczyk et al. (1990, 1993), pertaining to winter wheat and winter triticale, and oats, and by Zbieć et al. (1988, 1989) for maize and sugar beet, and also by Wojcieska et al. (1981, 1991, 1992).

Table 7. Photosynthetic activity of spring wheat flag leaf

Obiects		Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Transpiration ($mol \cdot m^{-2} \cdot s^{-1}$)	Sub-stomatal CO_2 concentration C_i ($\mu mol \cdot mol^{-1}$)	Leaf temperature T_{leaf} (°C)	Stomatal conductance g_c ($mol \cdot m^{-2} \cdot s^{-1}$)
Not irrigated	0 NPK	7.15	1.30	287	23.9	0.06
	3 NPK	12.1	3.39	175	22.6	0.30
Irrigated	0 NPK	14.0	3.25	283	21.9	0.52
	3 NPK	18.6	3.90	278	22.0	0.95
Effect of irrigation	O	9.62	2.35	231	23.2	0.18
	W	16.30	3.58	281	21.9	0.73
Effect of fertilization	0 NPK	10.60	2.28	285	22.9	0.29
	3 NPK	15.30	3.65	227	22.3	0.62
$LSD_{0.05}$ for:						
irrigation		2.43	1.14	33	0.40	0.31
fertilization		2.32	1.11	28	r.n.	0.18
interaction		3.28	1.28	51	r.n.	0.62

Table 8. Photosynthetic activity of spring triticale flag leaf

Obiects		Photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Transpiration ($mol \cdot m^{-2} \cdot s^{-1}$)	Sub-stomatal CO_2 concentration C_i ($\mu mol \cdot mol^{-1}$)	Leaf temperature T_{leaf} (°C)	Stomatal conductance g_c ($mol \cdot m^{-2} \cdot s^{-1}$)
Not irrigated	0 NPK	8.11	1.85	255	23.6	0.09
	450 NPK	11.80	2.55	182	23.6	0.17
Irrigated	0 NPK	13.30	3.58	275	22.7	0.36
	450 NPK	14.40	3.85	254	23.1	0.62
Effect of irrigation	O	9.95	2.20	218	23.6	0.13
	W	13.80	3.71	264	22.9	0.49
Effect of fertilization	0 NPK	10.70	2.71	265	23.1	0.22
	450 NPK	13.10	3.20	218	23.3	0.39
$LSD_{0.05}$ for:						
irrigation		2.13	1.24	39.6	0.50	0.19
fertilization		2.01	1.19	33.6	r.n.	0.13
interaction		3.05	1.44	52.0	r.n.	0.44

An increased pigment content and enzyme activity caused by irrigation and fertilization is also connected with the intensity of CO_2 assimilation by plants, and, consequently with the yield. Data reported in table 7 and 8 confirm this statement. Assimilation of the flag leaf from irrigated plots increased by 69% in case of wheat, and by 39% - triticale, high level of mineral fertilizer caused increases by 44 and 22%, respectively. Similarly increased the transpiration: on the average by 50-60%, These processes are closely related, since an enhanced production of organic compounds requires a good supply in minerals, taken up by the roots and transported to the plant upper parts, and the amount of them, particularly nitrogen and magnesium stimulates the CO_2 assimilation and creation of photosynthetic compounds.

The concentration of CO_2 in substomatal cells (C_i) was adverse to its assimilation, that is in well fertilized plants more intense assimilation caused the decrease of the amount of carbon dioxide, since it has been used up in photosynthesis. There was also found a decrease of leaf temperature and almost fourfold increase of leaf conductivity as effect of irrigation, and double - - as effect of high fertilizer doses. Enhanced leaf conductivity allows the carbon dioxide to be better transported, thus the plant is better supplied with carbon. Our studies have shown that, intense agrotechnique - irrigation and fertilization causes an increase of the intensity and effectivity of CO_2 assimilation. When the water status of the protoplasm is poor, the chloroplasts work less efficienlty, furthermore dry cell walls limit the penetration of CO_2, and wilting plants close their stomata, so that the assimilation of CO_2 is disrupted.

Increased yield of the tested plants can be explained by more vigorous physiological processes of plants well supplied with water and nutrients (Table 9).

Table 9. Spring wheat and spring triticale yield

Sprinkling irrigation	Fertilization (kg/ha)	Yield of grain		Yield of straw	
		spring wheat	spring triticale	spring wheat	spring triticale
O	0	3.30	3.72	4.50	5.50
	150	5.00	5.79	6.30	7.33
	450	5.87	6.60	7.25	8.16
Mean		4.72	5.37	6.00	6.99
W	0	3.89	5.00	4.98	6.00
	150	5.72	5.80	7.10	8.25
	450	6.80	8.20	8.00	11.90
Mean		5.47	6.33	6.69	8.71
Effect of fertilization	0	3.59	4.36	4.74	5.75
	150	5.36	5.79	6.70	7.79
	450	6.33	7.40	7.65	10.03
Mean		5.09	5.85	6.36	7.86
$LSD_{0.05}$ for:	plant	r.n.	r.n	-	-
	irrigation	0.31	0.67	-	-
	fertilization	0.48	0.59	-	-
	interaction	r.n.	r.n.	-	-

The yield of wheat which had been irrigated was by 16%, that of triticale by 18% higher, the straw yields were by 12% and 24% higher, respectively. Since the years of the experiment were not very dry, the effect of fertilization was much higher: wheat gave a yield higher by 76%, triticale by 70%, the straw yield of well fertilized plants was by 61% and 74% higher, respectively. The combined effect of fertilization and irrigation was expressed by a 106% increase of wheat grain yield, and triticale - by 120%, if compared to 0 NPK, and if compared to the single dose - by 36% and 42%.

This study has shown the necessity of testing the reaction of plant species and cultivars to agrotechnique, including irrigation and fertilization. Assay of the plant's physiological activity gives a wider, and well documented basis for interpretation of the results obtained in field experiments.

CONCLUSIONS

1. Supplemental irrigation and high doses of mineral fertilizers cause a significant increase of the content of chlorophyll and carotenoides in wheat and triticale, and also prolong their photosynthetic activity.
2. The applied agrotechnical measures modyfied the activity of red-ox enzymes contained in the plant flag leaf. High doses of mineral fertilizer increased the activity of nitrate

reductase, peroxydase and acid phosphatase, whereas irrigation decreased the activity of nitrate reductase but increased that of acid phosphatase and peroxydase.

3. The photosynthetic activity of the flag leaf, transpiration was enhanced as effect of irrigation and fertilization, whereas the concentration of CO_2 in the substomatal cells was decreased.
4. As effect of a good supply of the plants with water and nutrients and the resulting increase of their physiological activity, the yield of spring wheat and spring triticale increased by 16-18%, and as effect of fertilization by 60-74%. The combined effect of irrigation and fertilization was 106% in case of spring wheat and by 120% of spring triticale compared to the control.

REFERENCES

1. Arnon D. J., Allen M. B., Whatley F., 1956, Photosynthesis by isolated chloroplasts. IV General concept and comparison of three photochemical reactions. Acta Bioch. 20: 449-461.
2. Beovers H., Hageman R. H., 1969, Nitrate reduction in higher plants. A. Rev. Plant Physiol. 20: 495-522.
3. Bieszczad S., Piotrowski M., 1992. Spring triticale yield as effect of irrigation and mineral fertilization. Zesz. Nauk. ATR Bydg. 180: 15-21. [In Polish].
4. Devlin R. M., Barker A. K., 1971, Photosynthesis. Van Nostrand Reinhold Company New York.
5. Dzieżyc J. (red.), 1989, Water demand of cultivated plants. PWN Warszawa. [In Polish].
6. Dzieżyc Nowak L., Panek K., 1987, Method of irrigation steering according to plant need for water. Zesz. Probl. Post. Nauk Rol. 314: 137-148. [In Polish].
7. Erich G. L., Hageman R. H., 1973, Nitrate reductase activity and its relationship to accumulation of vegetative and grain nitrogen in wheat (*Triticum aestivum* L.) Crop Sci. 13: 59-66.
8. Joy K., Hageman R. H., 1966, The purification and properties of nitrite reductase from higher plants and its dependence on ferrodoxin. Biochem. J. 100: 263-273.
9. Karczmarczyk S., 1979, Influence of irrigation and mineral fertilization on the yield of small bean, winter wheat and spring barley cultivated in crop rotation and on some properties of a sandy soil. AR Szczec. Rozpr. 60. [In Polish].
10. Karczmarczyk S., Kaczmarek G., Kowalski W., Friedrich S., 1990, Yield, growth and development of some oat cultivars as affected by irrigation and mineral fertilization. Part III. Plant features and pigment content and enzyme activity. Szczec. Rocz. Nauk. 5 (2): 27-43. [In Polish].
11. Karczmarczk S., Koszański Z., Podsiadło C., 1993, Physiological processes and yield of winter wheat and triticale under the influence of irrigation and nitrogen fertilization. Part I. Chlorophyll and carotenoides content in some organs of wheat and triticale. Acta Agrobot. 46 (1): 15-30. [In Polish].
12. Koziar W., Czajka M., Sobiech S., 1994, Effect of irrigation, N-fertilizer and Bercema CCC on the yielf of spring triticale. Zesz. Nauk. AR Szczec. Ser. Rol. 162 (58): 107-110. [In Polish].
13. Lawlor D. W., 1981, Photosynthesis metabolism control and physiology. John Wiley and Sons Inc.New York.
14. Machackowa J., Gauceva K., Zmarkal Z., 1975, The role of peroxidase in the metabolism of indolo-3 acetic acid phenols in wheat. Phytochemistry 4: 1251-1254.
15. Nalborczyk E., Nalborczyk T., Wawrzonowska B., 1981, Models of photosynthetic activity in cereals. Photosynthesis VI. Photosynthesis and Environment. Ed. by George Akoyunoglon: 97-106.
16. Podsiadło C., 1993, Influence of irrigation and mineral fertilization on the yield of spring wheat cultivated on a sandy soil. Praca doktorska, AR Szczecinie (maszynopis). [In Polish].

17. Schnarrenberg C., Mohr H., 1970, Carotenoid synthesis in mustard seedlings as controlled by phytochrome and inhibitors. Planta, 94, 296-307.
18. Sestak Z., Catsky J., 1962. Intensity of photosynthesis and chlorophyll content as related to leaf age in Nicotiana sanderae. Hort.Biol.Plantar, t.4,131.
19. Wojcieska U., Szczypa E., 1971, Growth and photosynthesis productivity of winter wheats. Part II. Changes of photosynthetic activity and its productivity with the plant aging. Pam. Puł. 44: 49-70. [In Polish].
20. Wojcieska U., Wolska E., Krol M., 1981, Yield, yield structure and nitrate reductase activity in several oat cultivars, affected by nitrogen dose. Pam. Puł. 75: 31-43. [In Polish].
21. Wojcieska U., Wolska E., Samiec H., 1983, Comparision of photosynthetic activity of some strains of triticale and rye cv. Dańkowskie Złote. Hod. Rośl. Aklim. 27: 69-84. [In Polish].
22. Wojcieska U., Wolska E., Giza A., 1991, Influence of nitrogen feeding on the yield of spring wheat and on the activity of nitrate reductase as an index of the plant's nitrogen supply. Pam. Puł. 98: 22-38. [In Polish].
23. Wojcieska U., Wolska E., Giza A., 1992, Nitrate reductase activity in fragments of main shoot of rye (*Secale cereale*). Acta Physiol. Plant 14: 85-91.
24. Wojcieska-Wyskupajtys U., 1996, Effect of nitrogen on yield and some physiological parameters in rye plants. Acta Physiol. Plant. 18 (1): 19-24.
25. Zbieć I., Karczmarczyk S., Kaczmarek G., 1988, Growth and yield of corn subjected to water and nutrient stress. Part I. Intensity of photosynthesis and enzyme activity in leaves, and yield. Zesz. Nauk. AR Szczec. Ser. Rol. 135 (46): 257-272. [In Polish].
26. Zbieć I., Karczmarczyk S., Kowalski W., Friedrich S., Gurgul E., 1989, Influence of the supply of corn with water and mineral fertilizer on its growth, features, pigment content and activity of some enzymes in leaves. Zesz. Probl. Post. Nauk Rol. 343: 101-109. [In Polish].
27. Żarski J., 1993, Response of spring cereals to irrigation and nitrogen fertilization when growth on a very poor sandy soil. ATR Bydg. Rozpr. 59. [In Polish].

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Streszczenie

Celem badań polowych i laboratoryjnych było określenie wpływu deszczowania i wysokiego nawożenia mineralnego na aktywność niektórych procesów fizjologicznych oraz plon pszenicy jarej i pszenżyta jarego uprawianych na glebie lekkiej.

Uzyskane wyniki wykazały, że uzupełniające deszczowanie i wysokie dawki NPK spowodowały istotny wzrost zawartości chlorofilu i karotenoidów oraz hamowało proces ich zanikania wraz z upływem wegetacji. Ponadto wzrosła aktywność enzymów redukcyjno-oksydacyjnych w liściu flagowym, fotosynteza i transpiracja oraz przewodność dyfuzyjna liści, a zmniejszyła się koncentracja dwutlenku węgla w komórkach przyszparkowych.

Pod wpływem obu zastosowanych zabiegów agrotechnicznych plon ziarna pszenicy jarej wzrósł o 106, a pszenżyta o 120% w stosunku do obiektu kontrolnego.

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