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The interaction of mineral nutrition and water supply in the process of winter wheat production

J. ŠVIHRA, R. HOJČUŠ, M. ZIMA

Department of Plant Physiology and Microbiology, University of Agriculture, 949 76 Nitra, Czechoslovakia

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Abstract

In pot experiments performed in 1972-1976 with winter wheat variety 'Ilyichovka' grown at three levels of increasing mineral nutrition and at different levels of water supply (70% and 40% of maximal water capacity) an interaction was observed between mineral nutrition and water availability on the yield and some physiological characteristics of the plants. Water stress during heading stage reduced nearly by one half the grain yield per plant, mostly by decreasing the number of completely filled grains. The quicker leaf senescence and grain number reduction as well as the total grain yield due to water stress differed between the nutritional levels. The relations between leaf surface area and grain yields were nearly linear in treatments with optimal water supply, but were markedly changed by water stress.

INTRODUCTION

Total water consumption of plants in determined by the biological characters, growth and developmental changes of the plant organism, the nutritional status of the soil, the weather, cultivation practices atc. (Slukhai et al., 1979). The mineral nutrition level influences growth, development and the basic physiological processes of the plant organism – among them the water balance. Water supply causes changes both of absorption and ion utilization.

Conditions of mineral nutrition together with availability of water are important factors influencing the structure and functions of individual plant organs (Hsiao, 1973; Górecki and Grzesiuk, 1978). Shortage of water (water stress) altering key processes such as uptake of nutrients, glycide and protein metabolism, translocation of ions and metabolites is connected directly with wegetative and reproductive growth, causing a reduction of yield (Švihra et al., 1975, 1977, 1979; Goncharova et al., 1979; Slavík, 1975; Zima, 1976; Biscoe and Gallagher, 1977; Rackham, 1972). Owing to the different influence of water stress during particular stages of plant ontogeny "critical stages" of water shortage have been described (Motkaljuk and Kozhushko, 1973; Gusev and Petinov, 1974).

The influence of interaction of between nutrition and water availability on crop yields has been described in many papers, but the results are controversial. The difficulties are more specifically related to water stress because of the extremely dynamic nature of the plant water status, the dependence of the effects on the severity, duration, and timing of the stress during plant ontogeny ⟨Mantulenko et al., 1974; Nátr, 1975⟩. Other difficulties arise owing to the variability of the biological material, and conditions of evaluation.

The objective of the present study is to describe the influence of water stress imposed during the heading stage of winter wheat on growth and yield, in interaction with the level of mineral nutrition.

MATERIALS AND METHODS

Winter wheat plants ⟨cultivar 'Ilyichovka'⟩ were grown on clay-loam soil in Mitscherlich pots shielded with polyethylene covers against rain during the vegetation periods 1972-1976. Total weight of soil in the pot was 30 kg. Mineral nutrients were added to the soil at three different levels – A, B, C. At level A ⟨basic level⟩ were applied: 1.5 g of nitrogen, 1.08 g of phosphorus and 1.74 g of potassium per pot. The levels B and C represent a five or ten times increase of A dose, respectively. The ratio of basic elements in non-oxide form remains constant ⟨N: P: K = 1 : 0.78 : 1. 16⟩ at all three applied levels. The total amount of phosphorus and potassium in the form of superphosphate and potassium chloride was added before sowing together with two thirds of the nitrogen dose ⟨ammonium sulphate⟩; the rest ⟨one third⟩ of nitrogen was added in the period of tillering as ammonium nitrate fertilizer.

The levels of soil humidity applied during the spring period of vegetation were following:

40% of maximal water capacity ⟨40% MWC⟩,

70% of maximal water capacity ⟨70% MWC⟩.

Changes of soil humidity were introduced in one half of the total number of pots in every humidity treatment in the period before the heading stage ⟨7 th stage of organogenesis according to Kupermanova⟩. The second half of the pots served as control. Four levels of soil humidity were, therefore, applied: 40% MWC ⟨from spring to ripress⟩, 70% MWC ⟨from spring to ripress⟩, 40 to 70% <change before heading from 40% to 70% MWC>, 70 to 40% <change before heading from 70% to 40% MWC>.

Soil water content was maintained at the desired level by irrigation after the weight change due to loss of water caused by evapotranspiration.

A total number of 50 grains were sown per pot in autumn. The number of healthy plants was reduced to 30 of equal size after the winter season.

Leaf surface area was measured photoplanimetrically on detached leaves. The data refresent constant weight at 105°C. In the tables averages for a 5-year period are given.

RESULTS AND DISCUSSION

The importance of optimal water availability for reproductive organs formation is documented by a marked decrease of grain yield of plants submitted to water stress in the period preceeding the heading stage – or exactly in the 7 th stage of organogenesis. In the treatments in which drought was applied by withholding irrigation during the heading stage ⟨decrease from 70% to 40% MWC⟩ the grain yield was as low as 55.6 per cent of that of plants permanently optimally watered ⟨Table 1⟩.

Table 1

Yield characteristics of winter wheat in dependence on different water supply (5-year average for all nutrition levels)

MWC %	Grain			Straw			Total dry weight		
	g per plant	g per pot	in %	g per plant	g per pot	in %	g per plant	g per pot	in %
70	1.35 d	40.5	100	1.99 c	59.7	100	3.34	100.2	100
40	0.92 b	27.6	68.1	1.55 a	46,5	77.9	2.47	74.1	73.9
70 – 40*	0.75 a	22.5	55.6	1.85 bc	55.5	93.0	2.60	78.0	77.8
40 – 70*	1.12 c	33.6	83.0	1.69 ab	50.7	84.9	2.81	84.3	84.1
LSD at 0.05	0.15			0.18			0.23		
at 0.01	0.21			0.25			0.32		

*Change during heading stage.

The other yield characteristics confirm that vegetative growth was already almost completely finished in the mentioned period. The yield of straw decreased under water stress during the heading stage only by 7 per cent.

A similar influence of drought on grain yield was reported earlier ⟨Hsiao et al., 1976⟩. We further examined the most important factor which is influenced by drought during the 7 th stage of organogenesis – the number of grains per ear ⟨Table 2⟩. The sensitivity of the reproductive organ development to water stress was confirmed by the absolute or relative reduction of developed grains in two opposite treatments: in the treatment with decreasing watering from opptimal ⟨70-40% MWC⟩ and in the treatment with increasing soil moisture to the optimal level ⟨from 40 to 70% MWC⟩.

The nutritional level dramatically changes the moisture influence on the basic yield characteristics ⟨Table 2⟩. The most marked reduction of the number of grains – 51.8% and of the grain yield ⟨Table 3⟩ was observed at the highest nutritional level ⟨level C⟩ after submitting the plants to water stress ⟨Table 3⟩. Many of the stress effects merely represent empirical observations and the underlying mechanisms remain obscure.

Table 2

Reduction of the number of grains in the ear of the main stalk, in comparison with plants grown at 70% MWC

MWC %	Level of nutrition						Average of all nutritional levels	
	A		B		C			
	absolute number	% reduction	absolute number	% reduction	absolute number	% reduction	absolute number	% reduction
70	24.1	–	30.6	–	28.0	–	27.6	–
40	17.7	26.2	21.3	30.4	20.1	28.2	19.7	28.6
70 to 40*	15.1	37.3	19.6	36.0	13.5	51.8	16.1	41.7
40 to 70*	19.2	20.3	26.0	15.0	31.0	+10.7	25.4	8.0
LSD at 0.05	2.12		2.83		2.45		2.14	
at 0.01	2.78		3.71		3.21		2.80	

*Change during the heading stage.

Table 3

Relative (percentual) comparison of the grain, straw and total above-ground biomass yields between variants of water supply at different levels of mineral nutrition (A, B, C)

	Level of nutrition	Grain	Straw	Total above-ground biomass
Yield at 70-40% minus yield at 70% MWC	A	–38.84	–19.21	–27.94
	B	–37.41	–6.70	–19.38
	C	–56.20	–0.84	–21.07
Yield at 40-70% minus yield at 40% MWC	A	+9.30	+7.41	+8.25
	B	+11.0	+7.06	+8.52
	C	+50.0	+9.47	+22.30
Yield at 40% minus yield at 70% MWC	A	–28.93	–28.48	–28.68
	B	–31.97	–18.66	–24.16
	C	–35.77	–20.17	–25.87

The decrease of water supply influenced the transport of assimilates to the developing grains by changing the diameter and size of the phloem and xylem parts of the vascular bundles as reported in our previous paper ⟨Š v i h r a et al., 1977⟩. Besides water stress causes increased schlerenchyma formation and slowing down of parenchyma development.

Blocking of the transport routes together with hormonal control of grain filling are the factors influencig the partition of assimilates among competing sinks ⟨H s i a o et al., 1976⟩.

During water stress after the 7 th stage of organogenesis we observed in winter wheat 'Ilyichovka' cv. an increased thickness of leaves, a changed structure and order of granum thylakoids and other plastid components ⟨Švihra et al., 1977⟩.

The production of assimilates is primarily influenced by the rapid senescence of leaves during water stress ⟨Table 4⟩, but the rate of photosynthesis also diminished ⟨Zima, 1976; Hsiao et al., 1976⟩.

Table 4

Linear correlation coefficients between leaf surface area size and yields of grain and total biomass per plant, respectively

Average leaf area per plant during the period	Yield		Level of significance	
	total above-ground biomass	grain	$P_{0.05}$	$P_{0.01}$
Total spring vegetation	+0.79	+0.35	0.40	0.52
Grain filling	+0.74	+0.49	0.40	0.52
From heading to ripeness	+0.80	+0.55	0.40	0.52
Before heading	+0.62	+0.09	0.40	0.52
Grain filling (only in plants grown at 70% MWC)	+0.73	+0.44	0.58	0.71
Grain filling (only in plants grown at 40% MWC)	+0.80	+0.49	0.58	0.71

The relation between leaf surface area and grain yield is not linear, although some linear correlation coeficients suggest this ⟨Table 5⟩. In some cases – especially the leaf surface area before heading or during the early vegetative period has no relation to the grain yield. The relations expressed by the parabolic curve ⟨Figs. 1, 2⟩ and the index of correlation are the most suitable functions for expressing the relationships between leaf surface area and grain yield.

Table 5

Influence of water stress before heading stage on the rate of leaf senescence (in percent) during the 3 weeks period after heading of winter wheat grown at different nutritional levels

Level of nutrition	Variant of soil moisture (%)	
	70 to 40	control
A (basic)	41.75	34.72
B	39.71	33.77
C	34.50	28.58

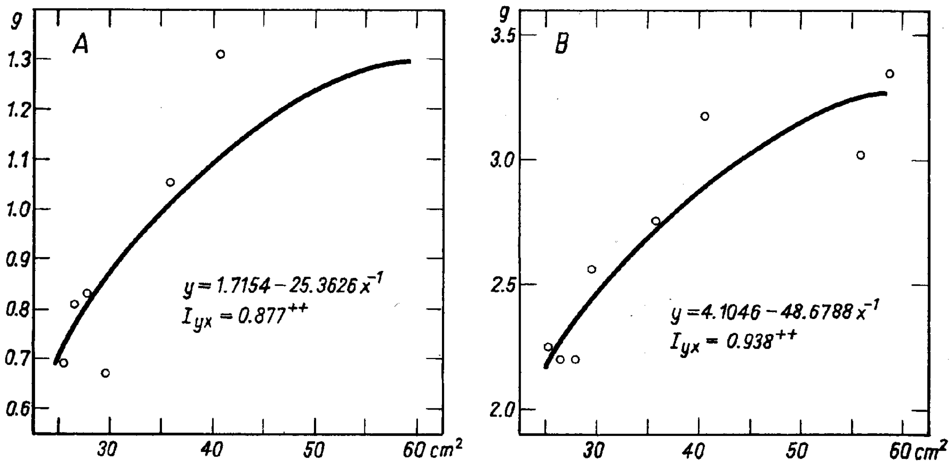

Fig. 1. The parabolic relationship between leaf area per plant ⟨cm²⟩ during grain – filling period and grain yield of winter wheat plant ⟨g⟩ – 1 A, resp. total biomass production per plant – 1 B

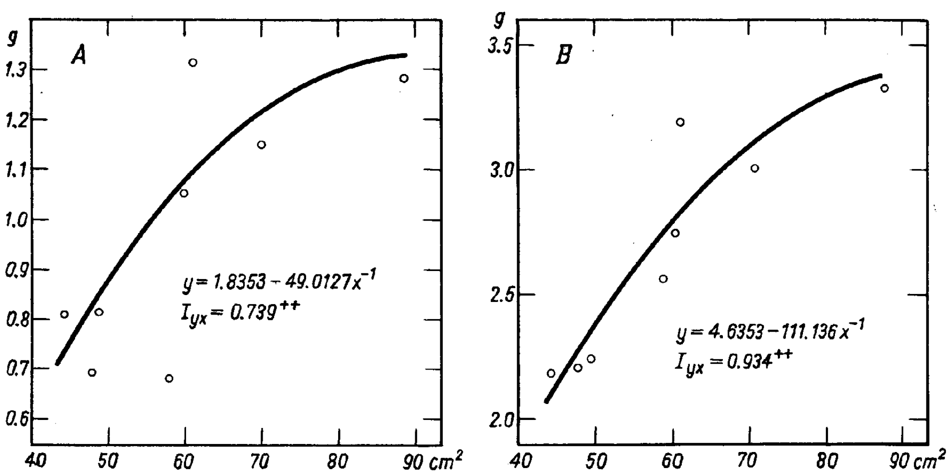

Fig. 2. Parabolic relationship between leaf area per plant ⟨cm²⟩ during the periods from heading to ripeness and grain yield per plant ⟨g⟩ – 2 A, resp. total biomass production per plant – 2 B

The dynamic nature of plant responses to water stress underlines the importance of the timing of water stress. As demonstrated in winter wheat plants, cultivar 'Ilyichovka', the interactions between water stress and productivity are modulated by the ability of the variety to adapt itself to water stress as well as by the mineral nutrition status.

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Współdziałanie żywienia mineralnego i zaopatrzenia w wodę w procesie produkcji pszenicy ozimej

Streszczenie

W doświadczeniu wazonowym przeprowadzonym w latach 1972-1976 uprawiano rośliny pszenicy 'Iliczowka', przy 3 poziomach nawożenia i przy zróżnicowanych poziomach zaopatrzenia w wodę ⟨70% i 40% maksymalnej zawartości wody⟩. Zaobserwowano współdziałanie nawożenia mineralnego i zaopatrzenia w wodę na plony i na niektóre cechy fizjologiczne roślin. Stres wodny w czasie kłoszenia się redukuje prawie o połowę plon ziaren na roślinę, głównie dzięki redukcji liczby, w pełni wypełnionych, ziaren. Szybsze starzenie się liści i spadek liczby ziaren oraz spadek ogólnego plonu występowały w różnym nasileniu, zależnie od poziomu nawożenia. W warunkach optymalnego zaopatrzenia w wodę występowała zależność liniowa pomiędzy powierzchnią liścia a plonem ziaren — w warunkach stresu wodnego obserwowano wyraźne zmiany.