THE EFFECT OF NITROGEN IN NUTRITIVE SOLUTION ON DRY MATTER AMOUNT AND ACCUMULATION OF ENERGY IN WHEAT PLANTS*

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In the laboratory conditions the trial on the effect of different nitrogen concentrations in nutritive solution Hoagland No. 3 as affected an energy accumulation and amount of dry matter of roots and above-ground biomass in young plants of winter wheat, the Samanta variety. The trial included the following variants: control variant – 1 N, variant with marked deficit of nitrogen – 0.1 N, the variant with reduced nitrogen content – 0.5 N, the variant with increased nitrogen in solution – 2 N and 4 N. The weight of dry matter of roots and above-ground biomass (stems and leaves) of young plants of winter wheat was studied in selected stages of ontogeny (14.DC, 19.DC, 21.DC, 22.DC, 23.DC, 25.DC, 26.DC, 28.DC and 30.DC). Amount of accumulated energy per 1 g of dry matter was finding calorimetrically in dry matter of different plant organs. It follows from the results obtained that the growth of amount of dry matter per one plant in all studied variants is apparent during ontogeny. The lowest weight of roots can be found in the variant 2 N when average weight of roots from all samplings was 1.112 g. On the other side, the highest weight of dry matter of above-ground biomass (3.810 g was an average) and thus also total amount of dry matter per one wheat plant. This result led to the broadest ratio of above-ground biomass to roots in the variant 2 N. On the other hand, unbalanced level of nutrients, i.e. above all deep deficit (variant 0.1 N) or abundance of nitrogen (variants 2 N and 4 N), leads to limitation of production of energy-rich substances and their subsequent accumulation into different plant organs and hence there is a possibility of the use of calorimetry as a method to detect tolerance of plants against unfavourable conditions of environment.

wheat; nitrogen concentration; dry matter; net energy

INTRODUCTION

Plants are the organisms that are able to produce energy-rich substances from energy-poor substances in the process of photosynthesis, which can be a source of nutrition for heterotrophic structures. The production of dry matter and energy-rich substances is influenced not only by the type of variety genotype but also by outdoor medium, e.g. by mineral nutrition of plants (Golley, 1961).

One of the limiting factors of formation of both biological and economic yield of field crops is nitrogen, which is an element that most affects the final level of the yield. In terms of this it is necessary to add that nitrogen fertilization belongs to most demanding supplementary additions into production, because the addition of 1 kg of nitrogen is represented by the value 80 MJ, which may subsequently decrease the total energy profit of the stand. For these reasons, too, rational nitrogen fertilization is essential, because deficit of nitrogen reduces the yield and overabundant nitrogen fertilization can be inefficient and non-economic.

The effect of nitrogen on energy accumulation into wheat plants is connected with dry matter production. Hansen and Diepenbrock (1994) report that energy content per 1 kg of applied nitrogen is linearly falling with growing nitrogen rates.

Our study has been concentrated on explanation of nitrogen action on dry matter production and accumulation of energy in young wheat plants.

MATERIAL AND METHOD

In the years 1997 to 1999 in laboratory conditions the authors have been establishing repeatedly the trial on the effect of different nitrogen concentrations in nutritive solution as affected energy accumulation and amount of dry matter of roots and above-ground biomass in young plants of winter wheat, the Samanta variety.

Plants were cultivated hydroponically in controlled light and temperature conditions of climatized box at the light regime 16 hours light with intensity of irradiation 490 $\mu mol.m^{-2}.s^{-1}$ and 8 hours of dark. The temperature was set to 25 ± 1 °C in day and 20 ± 1 °C at night.

In the trial the authors studied the effect of five different nitrogen concentrations in nutritive solution Hoagland No. 3 (Table I): control variant (1 N), variant with a marked deficit of nitrogen (0.1 N), the variant with reduced nitrogen contents (0.5 N), the variant with increased nitrogen contents in solution (2 N and 4 N). The other qualities of nutritive solution remained the same in all variants (pH was 4.57 and osmotic concentration was 1.583).

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I. Variants of the Hoagland nutritive solution No. 3

Substance ($g.l^{-1}$)	N concentration in solution				
	1	0.1	0.5	2	4
	variant 1	variant 2	variant 3	variant 4	variant 5
$Ca(NO_3)_2$	0.821	0.12293	0.61465	0.821	0.821
KNO_3	0.506	0	0	0.506	0.506
KH_2PO_4	0.136	0.136	0.136	0.136	0.136
$MgSO_4$	0.120	0.120	0.120	0.120	0.120
NH_4NO_3	0	0	0	0.6006	1.8018
KCl	0	0.3737	0.3737	0	0
$CaCl_2$	0	0.93079	0.27513	0	0
Citrate Fe	1 ml	1 ml	1 ml	1 ml	1 ml
Microelements by Benson in the rate 1 ml					

In selected phases of ontogeny (14.DC, 19.DC, 21.DC, 22.DC, 23.DC, 25.DC, 26.DC, 28.DC and 30. DC) we were finding the weight of root and above-ground biomass dry matter (stems and leaves) of young plants of winter wheat. In addition, the amount of accumulated energy was set in dry matter of several plant organs.

Net energy (energy content converted per 1 g of dry matter without ash) was set calorimetrically, when a sample is totally burnt in calorimetric pot. Automatic adiabatic combustion calorimeter NS 10 A (LAGET, Germany) was used to measure heat of combustion.

The Czechoslovak Standard ČSN ISO 1928 (1999) was used to measure gross and net energy for their subsequent calculation.

The results obtained were evaluated statistically using the computer program SAS, on the level of significance $\alpha = 0.05$.

RESULTS AND DISCUSSION

As it can be seen from the results obtained, amount of dry matter in roots in experimental variants (Fig. 1) grew gradually from lowest values in the phase 14.DC (from 0.2345 g to 0.2900 g) to highest values in the phase 30.DC (from 1.5625 g to 3.0360 g). The similar trend was also recorded with above-ground biomass (Fig. 2), when dry matter of leaves and stems was the lowest in the phase 4 of visible leaf (fluctuating from 0.409 to 0.501 g) and it was highest at the onset of heading (ranging from 4.626 g to 8.666 g).

Another factor influencing the production of dry matter of different plant organs was also nitrogen concentration in nutritive solution. It can be said that higher amount of dry matter in above-ground biomass than in roots was produced in all variants of nitrogen nutrition. These results are in agreement with the observation made by Greef and Kullmann (1992).

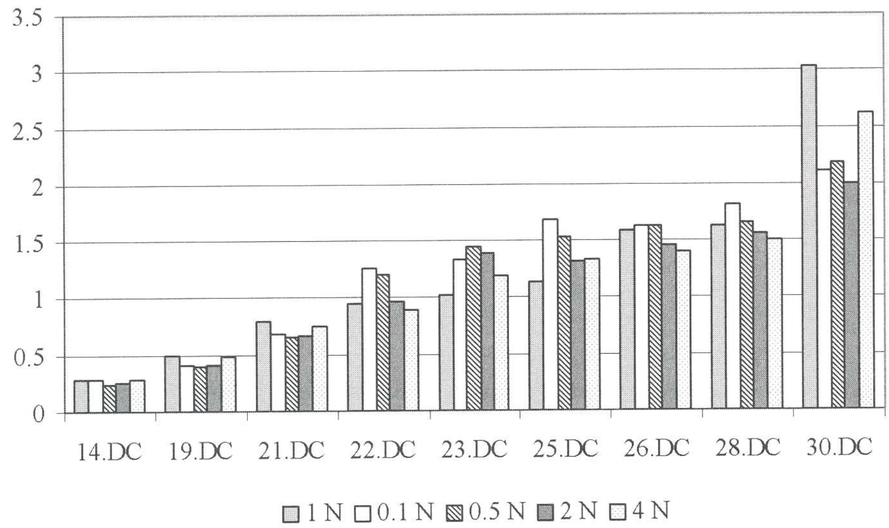
The highest and most dynamic growths of weight of dry matter of above-ground biomass were recorded in the variant 2 N, which was statistically significantly from remaining variants of the trial (Table II). Herzog (1981), who reported that increased nitrogen rate leads in spring wheat to increase of dry matter production, obtained the similar result. Higher nitrogen concentration (2 N) in solution increased more production of above-ground matter, i.e. also weight of its dry matter (on average for all samplings 3.807 g) than the weight of roots. Amount of root dry matter grew more considerably in the variant 0.1 N, when average weight of dry matter for all samplings amounted to 1.247 g. Černý, Ferik (1977) and Novák et al. (1988) came to similar conclusions.

The ratio between biomass of above-ground organs and root mass can be determined from the values obtained of the weight of dry matter. The above ratio was

II. Differences in the weight of dry matter of roots (g) and the weight of dry matter of above-ground biomass – stems and leaves (g)

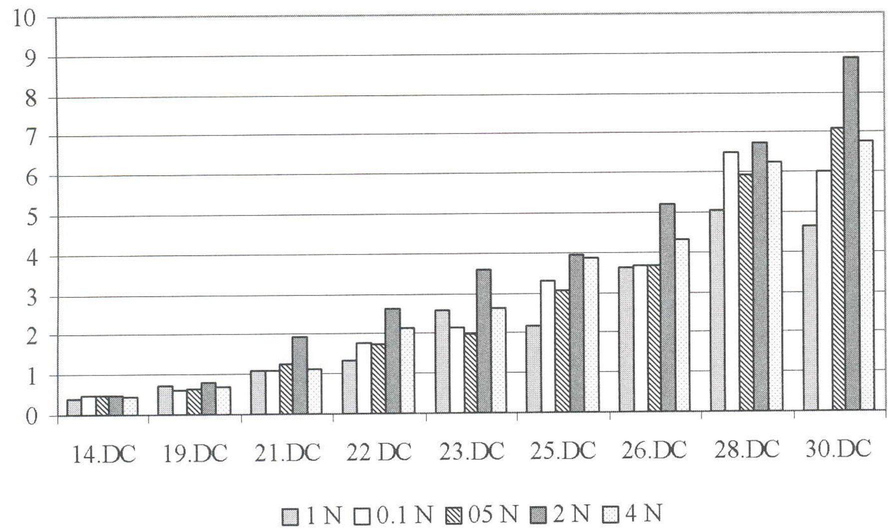
Differences in dry matter of roots (g)			Differences in dry matter of above-ground biomass – stems and leaves (g)		
Variant	average measured values from all measurements	homogeneous groups	variant	average measured values from all measurements	homogeneous groups
2 N	1.112	*	1 N	2.401	*
4 N	1.164	*	0.1 N	2.840	*
1 N	1.214	*	0.5 N	2.880	*
0.5 N	1.214	*	4 N	3.131	* *
0.1 N	1.247	*	2 N	3.807	*

T-method = 0.05



1. The weight of dry matter of roots (g)

x-axis – phase of ontogeny, y-axis – weight of dry matter (g)



2. The weight of dry matter of above-ground biomass (g)

x-axis – phase of ontogeny, y-axis – weight of dry matter (g)

significantly affected by nitrogen concentration because highest average value of ratio from all samplings was in the variant 2 N (3.06). In other variants of the trial the ratio of above-ground biomass and roots was as follows: 1 N (1.89), 0.1 N (2.05), 0.5 N (2.18) and 4 N (2.42). It is clear from the results that lower concentration of nitrogen in nutritive solution (0.1 N, 0.5 N, 1 N) or on the contrary too high concentration of nitrogen in solution lead to narrowing of the ration between above-ground biomass and roots. Similar results were obtained by N o v á k et al. (1988) in the case of spring barley.

Based on the values of ratio of above-ground biomass to roots it can be concluded that the value of this ratio is increasing with increasing nitrogen rates, but only to its double concentration. W o j c i e s k a ' s study (1994) has also confirmed this fact.

Nitrogen concentration in solution led not only to changes in accumulation of dry matter into different organs of the plant but also affected the total amount of dry matter in plant. High concentration of nitrogen led to increase of the total dry matter in plant and increased also the ratio of above-ground biomass to roots.

Except determination of amount of dry matter of different organs, heat of combustion of different plant organs (net energy) was measured under laboratory conditions.

When studying the content of net energy in roots, it is possible to record more stable values in different variants during ontogeny in roots than in above-ground part. The highest values of net energy were found in the variant 1 N (ranging between 14.07 and 16.41 $kJ.g^{-1}$). The other variants reached lower values of net energy compared with the variant 1 N, as presented in Table III, e.g. in the variant 0.5 N the values of net energy were fluctuating in the interval from 10.11 $kJ.g^{-1}$ in the phase 14.DC and to 13.82 $kJ.g^{-1}$ of dry matter in the phase 3.DC and in the variant 2 N the values of heat of combustion were ranging between 13.02 $kJ.g^{-1}$ (14.DC) and 15.86 $kJ.g^{-1}$ (30.DC).

The content of energy-rich substances in organic matter of above-ground biomass similar to that in roots had an evident growing trend during vegetation (Table III). The highest values of heat of combustion were recorded in the phase 30.DC, when the values are ranging between

III. The values of accumulated net energy into dry matter of roots and above-ground biomass (kJ.g^{-1})

Phase	Root					Stems, leaves				
	1 N	0.1 N	0.5 A	2 N	4 N	1 N	0.1 N	0.5 N	2 N	4 N
14.DC	14.07	11.34	10.11	13.02	13.04	14.62	11.69	12.89	12.86	12.67
19.DC	15.47	12.16	13.43	13.22	13.85	15.00	11.86	14.16	13.16	12.94
21.DC	15.58	12.64	13.56	13.39	14.04	16.18	12.29	14.13	13.34	13.05
22.DC	15.65	13.57	13.65	13.71	14.37	16.26	12.95	15.27	13.67	13.10
23.DC	15.66	13.65	13.77	13.83	14.54	16.47	13.41	15.41	13.93	13.19
25.DC	15.74	13.83	13.82	13.87	14.58	16.67	13.59	15.84	13.95	13.22
26.DC	15.95	13.91	13.90	14.64	15.62	16.89	13.91	16.29	14.23	13.45
28.DC	16.30	14.13	14.17	14.78	16.21	17.09	14.22	16.29	14.27	13.57
30.DC	16.41	14.22	17.29	15.86	17.29	17.39	14.51	16.56	14.56	14.01
Average	**15.65**	**13.27**	**13.74**	**14.04**	**14.84**	**16.29**	**13.16**	**15.20**	**13.77**	**13.24**

14.01 and 17.39 kJ.g^{-1}. On the contrary, the lowest content of energy was in the phase 14.DC (from 11.69 to 14.62 kJ.g^{-1}).

The measured value of heat of combustion corresponds to the values found by Hnilička and Novák (1998). The found value of heat of combustion was lower than that reported by Strašil (1995). These differences were probably given by the fact that the trial comprised only plants at juvenile stages of development when protein character of metabolism prevails in young plants owing to dynamic prolonged growth in plants, which is changing with proceeding development, and saccharide metabolism in the plants prevails in plants to the end of vegetation and lignin and other incrusting substances are producing. The value of heat of combustion is also affected by the correlation between proteins and saccharides (mono- and polysaccharides).

Hoffmann (1988) reports in wild wheat species the value of net energy in roots in interval 17.30 to 18.40 kJ.g^{-1} and in leaves and stems the range of values from 17.90 to 24.10 kJ.g^{-1}. We suppose that it consists in different course of photosynthesis in wild and cultural wheat species together with differences in morphological and anatomic structure not only of photosynthesising organs, which are thicker and smaller. In addition, the ratio of roots and above-ground biomass is changing in modern varieties compared with older varieties and wild species, because an emphasis was laid upon maximum formation of the yield.

An amount of accumulated energy in above-ground organs of wheat plants was affected significantly by nitrogen concentration in nutritive solution when the variant 1 N reached the highest value of heat of combustion compared with the other varieties. This variant had the value of heat of combustion 16.29 kJ.g^{-1}. In the variants with a markedly low as well as with high concentration of nitrogen the measured values of heat of combustion fell compared with the control variant (1 N) as presented in Table III. It is apparent from this table that in the variant 0.1 N the average values of heat of combustion were 13.16 kJ.g^{-1} of dry matter and average content of energy was 13.25 kJ.g^{-1} in the variant 4 N, and this content was 13.77 kJ.g^{-1} in the variant 2 N. It can be said that amount of energy per 1 g of dry matter of stems and leaves with abundant and insufficient concentration of nitrogen in solution was decreasing compared with the control variant (1 N) by approximately 20%.

It is apparent that high as well as low concentrations of nitrogen in nutritive solution reduce the value of energy per 1 g of dry matter (Table IV). The present results confirmed the conclusion from the previous study (Hnilička, 1998), in which he reports that extremely insufficient or on the contrary, excessive rates of nitrogen have been manifested significantly in accumulation of energy-rich substances by reduction of heat of combustion.

Compared with the content of energy in organs of the plant body within different variants, we found that higher values of net energy in above-ground biomass against roots were recorded only in the variant 1 N (increase by 0.67 kJ.g^{-1} of dry matter) and 0.5 N (increase by 1.49 kJ.g^{-1} of dry matter). In the case of the other variants the content of net energy fell in above-ground biomass against roots. The most marked decrease can be found in the variant 4 N (decrease by 1.58 kJ.g^{-1} of dry matter) and further, in the variant 2 N (decrease by 0.29 kJ.g^{-1}).

It can be said in conclusion that the growth of amount of dry matter per plant is apparent during ontogeny in all studied variants. The lowest weight of root dry matter can be found in the variant 2 N when average weight of roots from all samplings was 1.112 g. On the contrary, highest weight of dry matter of above-ground biomass (3.807 g was an average) was recorded for this variant and hence also the total amount of dry matter per wheat plant. This result led to the broadest ratio of above-ground biomass to roots in the variant 2 N. In addition, unbalanced level of nutrients, i.e. above all the deep deficit (variant 0.1 N) or surplus of nitrogen (variants 2 N and 4 N) lead to reduction of production of energy-rich substances and their subsequent accumulation in different plant organs, and hence there is a possibility of utilisation of calorimetry as a method used to detect tolerance of plants to unfavourable conditions of the environment.

IV. The differences in the values of net energy of roots and above-ground biomass (kJ.g^{-1} of dry matter)

Differences in the values of net energy of roots (kJ.g^{-1} of dry matter)			Differences in the values of net energy of above-ground biomass (kJ.g^{-1} of dry matter)		
Variant	average measured values from all measurements	homogeneous groups	variant	average measured values from all measurements	homogeneous groups
0.1 N	13.16	*	0.1 N	13.17	*
0.5 N	13.24	*	2 N	14.03	*
4 N	13.74	*	0.5 N	14.56	*
2 N	13.77	*	4 N	15.20	*
1 N	15.65	*	1 N	16.29	*

T-method = 0.05

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Vliv koncentrace dusíku v živném roztoku na množství sušiny a akumulaci energie v rostlinách pšenice.

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V laboratorních podmínkách byl opakovaně zakládán pokus za účelem zjištění vlivu pěti různých koncentrací dusíku v živném roztoku Hoagland č. 3 na akumulaci energie a na množství sušiny kořenů a nadzemní biomasy u mladých rostlin pšenice ozimé odrůdy Samanta. Pokus zahrnoval tyto varianty: varianta kontrolní – 1 N, varianta s výrazným deficitem dusíku – 0,1 N, varianta se sníženým obsahem dusíku – 0,5 N, varianty se zvýšeným obsahem dusíku v roztoku – 2 N a 4 N. Ve vybraných fázích ontogeneze (14.DC, 19.DC, 21.DC, 22.DC, 23.DC, 25.DC, 26.DC, 28.DC a 30.DC) byla zjišťována hmotnost sušiny kořenů a nadzemní biomasy (stonků a listů) mladých rostlin pšenice ozimé. V sušině jednotlivých rostlinných orgánů se kalorimetricky zjišťovalo množství naakumulované energie na 1 g sušiny.

Ze získaných výsledků vyplývá, že během ontogeneze je patrný nárůst množství sušiny v jedné rostlině u všech sledovaných variant. Nejnižší hmotnost sušiny kořenů je možné nalézt u varianty 2 N, kdy průměrná hmotnost kořenů ze všech odběrů byla 1,112 g. Na straně druhé byla však u této varianty zaznamenána nejvyšší hmotnost sušiny nadzemní biomasy (průměr byl 3,810 g) a tím i celkové množství sušiny u jedné rostliny pšenice. Tento výsledek vedl k nejširšímu poměru nadzemní biomasy ke kořenům u varianty 2 N.

Nevyrovnaná hladina živin, tedy především hluboký nedostatek (varianta 0,1 N) či nadbytek dusíku (varianta 2 N a 4 N), vede k omezení tvorby energeticky bohatých látek a jejich následné akumulace do jednotlivých rostlinných orgánů, a tím zde vyvstává možnost využití kalorimetrie jako metody k detekování tolerance rostlin vůči nepříznivým podmínkám životního prostředí.

pšenice; koncentrace dusíku; sušina; netto energie

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