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Accumulation and Dynamic of Dry Mass in Durum Wheat Cultivars in dependence of Nitrogen fertilization

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Abstract

Dry mass accumulation and dynamic until anthesis and during a grain filling period of seven Bulgarian durum wheat cultivars (Progress, Vazhod, Victoria, Predel, Deana, Zvezdica and Elbrus) were studied in 2010-2011. A field experiment with four rates of nitrogen fertilization – 0, 60, 120 and 180 kg N.ha^{-1} was conducted. The climatic conditions (temperature and precipitations) during the vegetation of durum wheat were close to the mean long-term values for the region of South Bulgaria. It was found that dry mass at anthesis and maturity (without grain) and grain yield significantly increased with increasing of the nitrogen fertilizing up to rate N_{120}. The high nitrogen rate of 180 kg N.ha^{-1} decreased the post anthesis net dry mass accumulation of studied cultivars with the exception of variety Predel. The model of dry mass dynamic depended of the cultivar and nitrogen fertilizing. The nitrogen fertilization increased average values of dry mass translocation and dry mass translocation efficiency, the contribution of pre-anthesis assimilates to the grain, and enhanced the average ratio of pre- to post anthesis accumulated dry mass of wheat cultivars. Bulgarian standard cultivar Vazhod was characterized with positive dry mass translocation and dry mass translocation efficiency, independently of nitrogen levels. At fertilization rates N_{60} and N_{180} new cultivar Elbrus demonstrated the highest dry mass translocation - 2590 and 2750 kg DM.ha^{-1}, respectively, and high dry mass translocation efficiency (25 %) and contribution of pre-anthesis assimilates to the grain (50 %). At moderate nitrogen rate 120 kg N.ha^{-1} the reutilization efficiency of biomass and contribution of pre anthesis assimilates to the grain were the highest in cultivar Predel – 25.2 and 49.1 %, respectively.

Keywords: dry mass reutilization, translocation efficiency, durum wheat

Introduction

Durum wheat is typically cultivated in the region of South Bulgaria which characterized with the suitable growing conditions to obtain a good grain quality (Panayotova and Kostadinova, 2010; Kostadinova and Panayotova, 2010). Cereals grains accumulate carbohydrates from two sources during grain filling. The first source are current assimilates transferred directly to the grain. The second source are assimilates redistributed from reserve pools stored in vegetative plant parts, or matter assimilated before anthesis and stored temporarily in leaves, culms, chaff, and other vegetative parts of plant (Austin et al., 1980; Van Sanford and MacKown, 1987, Cox et al., 1985ab). The remobilization of assimilates originates from plant senescence, an active and ordered process that involves translocation of stored reserves from stems and leaves to the grain (Zhang et al., 1998). Temporary storage and mobilization of assimilates are of high importance in source-sink relationships (Wardlaw, 1990). Many factors can affect the source–sink relations during the different growth phases including genotype, temperature, rainfall and fertilization (Borrás et al., 2004; Miralles and Slafer, 2007). Nitrogen is the most important nutrient thus it affects the assimilate production and distribution and influences directly or indirectly the source–sink relation (Arduini et al., 2006; Muchow, 1988). Nitrogen can influence the leaf area development and maintenance as well as photosynthetic efficiency (Arduini et al., 2006; Muchow, 1988) and dry matter partitioning to reproductive organs (Prystupa et al., 2004; Vouillot and Devienne-Barret, 1999; Guitman et al., 1991).

Under optimal growing conditions, assimilation and storage of assimilate is high (Blum, 1998). The contribution of pre-anthesis assimilates to the grain filling and kernel weight depends on the amount of matter that is mobilized between anthesis and maturity and the efficiency of conversion of the mobilized matter in the kernels (Asseng et al., 2003). Dry mass partitioning depends on sink number and sink activity and seed number is strongly associated with assimilate availability at anthesis (Guitman et al., 1991; Wardlaw, 1990). In Bulgaria and in most areas of growing durum wheat, anthesis period usually coincides with high levels of evapotranspiration and periods of water deficit start. During this time diseases also spread, leading to diminishing photosynthesis and crop uptake of nitrogen. Thus, it is important to accumulate assimilates in vegetative tissues before anthesis and translocation to grains, in order to obtain higher grain yields, especially under stress conditions (Wardlaw, 1990; Blum et al., 1997).

Many authors calculated sink-sourse relationship in cereals from the net loss of dry matter of the vegetative parts from anthesis to maturity. (Cox et al., 1984ab; Papakosta and Gagianas, 1991; Dordas, 2009). This approach assumes that decreases in aboveground vegetative biomass between anthesis and maturity are exclusively due to the mobilization of reserves. The role of the roots as a source of pre-anthesis nitrogen is ignored in the majority of studies. Pre-anthesis reserves contributed up to 57% to the grain yield of wheat (Hermans et al., 2012) when crops suffered from severe post-anthesis drought. An understanding of source and sink relationships of cereals could be used to identify physiological traits suitable for genetic selection and modification of grain yield (Borrás et al., 2004). Dry mass translocation and reutilization is important for durum wheat which is mainly grown without irrigation. Many studies were focused on studying soft wheat and there is not enough information about durum wheat, especially about Bulgarian durum wheat cultivars concerning the contribution of pre- and post-anthesis assimilation for grain production.

The objective of the present research is to examine accumulation and remobilization of dry mass during grain filling in standard and new durum wheat cultivars in dependence of nitrogen fertilization.

Materials and Methods

The investigation was carried out on the experimental field of the Institute of Field Crops, Chirpan, Bulgaria in a fertilizing trial at cotton-durum wheat crop rotation under non-irrigated conditions in 2010-2011. Bulgarian durum wheat cultivars Progress, Vazhod, Victoria, Predel, Deana, Zvezdica and Elbrus were studied. A field experiment with four rates of nitrogen fertilization 0, 60, 120 and 180 kg $N.ha^{-1}$ was conducted. The experimental design was a randomized block design with four replications and plots area of 10 m^2. Nitrogen as NH_4NO_3 was applied two times - 1/3 pre-sowing and 2/3 as an early spring dressing.

The soil type of experimental field was Pelic vertisols, (FAO, 2006) and generally refers to the so called Mediterranean chernozems. The soil type is one of the most generous and widely spread and significant in Bulgaria. It is suitable for growing most of the field crops and has a potential for high yield. The main parent materials are pliozen clay deposits. It has a high-powered humus horizon (70–80 cm). By humus content it belongs to the mean humus soils. It characterizes with high humidity capacity, caused by the high percentage of clay minerals, with heavy mechanical composition, small water-permeability, bulk weight of the arable soil layer 1.1-1.3 $g.cm^{-3}$, with specific gravity 2.4-2.6 and low total porosity, neutral soil reaction and high cation exchange capacity (CEC) - 35-46 meq per 100 g soil, with high degree of bases saturation (93.4-100.0 %), with total N in the arable layer 0.095-0.14 % and low content of total phosphorus (0.05-0.11 %), poor to medium supplied with hydrolyzed nitrogen, poorly supplied with available phosphorus and well-supplied with available potassium.

Table 1. Meteorological conditions during durum wheat vegetation period.

Year	Temperature sum (^oC)			Precipitation ($L.m^{-1}$)		
	X-II	III-VI	X-VI	X-II	III-VI	X-VI
2010-2011	839	1734	2413	311	206	517
1928-2008	705	1670	2375	238	203	442

Meteorological conditions during durum wheat vegetation period were recorded daily in the experimental area and are given in Table 1, together with the 80-year average of temperature and precipitations. The values of temperature and precipitations during the vegetation of durum wheat were close to the mean long-term values for the region of Chirpan in South Bulgaria.

At about mid-anthesis and at maturity the aboveground dry mass of durum wheat plants of each plot/cultivar were analyzed by representative sampled areas of 1 m^2. Whole plants (leaf+culm + chaff-flowered spikes) were analyzed at anthesis. At maturity the plant samples were separated in two components grain and vegetative plant parts (leaf+culm+chaff). After cutting and separation at anthesis and maturity, the samples were weighed, oven-dried at 70 °C for 48 h and then weighed again. After drying, all divided samples were ground to pass a 1-mm screen.

Accumulation and translocation of dry mass within the durum wheat plant and cultivars were studied on the base of parameters referring to dry matter movement. The parameters were calculated as follows according to different authors (Papakosta and Gagianas (1991); Cox et al., 1985ab; Papakosta (1994):

1. Pre-anthesis and post-anthesis dry mass accumulation (DM, $kg.ha^{-1}$);
2. Dry mass translocation (DMT, $kg.ha^{-1}$) = dry mass at anthesis - dry mass of straw at maturity;
3. Dry mass translocation efficiency (DMTE, %) = (dry mass translocation / dry mass at anthesis) × 100
4. Contribution of pre-anthesis assimilates to the grain (CAVG, %) = (dry mass translocation / grain yield) × 100 (Papakosta and Gagianas, 1991).
5. Post anthesis net dry mass accumulation, or the increased biomass during the period of grain filling, were estimated as the difference between total DM at maturity and the total DM at anthesis (Przulj and Momcilovic, 2001).

An overall analysis of variance (ANOVA) was performed to evaluate the effect of the experimental treatments on the referred variables. In order to establish the difference among the means Duncan’s multiple range test at level of significance α=0.05 was used. Analyses were performed with a personal computer using the SPSS™ (SPSS Inc., IL, USA) statistical program.

Results

The obtained results showed significant effect of the N fertilization on the above-ground dry mass at anthesis (Table 1). Average dry mass significantly increased with increasing of nitrogen rate up to N_{120}. Growing of wheat plants at higher level of nitrogen fertilizing N_{180} slightly increased accumulated dry mass at anthesis, but the difference was not proved compare to the rate N_{120}. At anthesis cultivars Victoria, Predel and Elbrus accumulated similar amounts of dry matter when grown at nitrogen rates 120 and 180 kg $N.ha^{-1}$.

Similar results were obtained for total accumulated dry mass (without grain) of wheat cultivars in maturity. Average dry weight of vegetative plant parts (leaves+stems+chaff) increased in parallel with nitrogen fertilizing up to N_{120}. Cultivars Vazhod and Predel demonstrated significant higher dry mass of straw at nitrogen rate 180 kg $N.ha^{-1}$. This effect of high nitrogen fertilization was not observed in the rest of cultivars, where the dry mass of vegetative plant parts at maturity were close at applying of rates N_{120} and N_{180}. Wheat cultivars realized the highest grain yields in nitrogen fertilizing N_{120} - 5630 $kg.ha^{-1}$ in average. This moderate nitrogen rate significantly exceeded the other levels of fertilization. The nitrogen fertilization rates 60, 120 и 180 kg $N.ha^{-1}$ let to higher grain productivity by 14, 37 и 26 %, in respect to control plants without nitrogen fertilization.

Table 2. Dry mass at anthesis and maturity (without grain) and post anthesis net dry mass in dependence of nitrogen fertilization.

Cultivars	N_0	N_{60}	N_{120}	N_{180}
Dry mass at anthesis, $kg.ha^{-1}$				
Progress	5850	6950	10160	11190
Vazhod	5940	7350	7900	11010
Victoria	6740	8800	12320	11220
Predel	5240	8490	10870	11110
Deana	5040	6120	7300	10220
Zvezdica	4920	7270	8700	10620
Elbrus	6320	9820	11010	11410
Average	5721 c	7829 b	9751 a	10969 a
Dry mass at maturity (without grain), $kg.ha^{-1}$				
Progress	6260	7590	8850	9170
Vazhod	5590	7110	7610	9480
Victoria	6300	8930	9990	8590
Predel	5460	6860	8130	11800
Deana	5000	6890	7750	8500
Zvezdica	5650	6200	9050	8480
Elbrus	6580	7230	9870	8660
Average	5834 c	7259 b	8750 a	9240 a
Grain dry mass, $kg.ha^{-1}$				
Progress	4100	4620	5420	4890
Vazhod	4030	4960	5650	5450
Victoria	4100	4830	5910	5520
Predel	4080	4570	5580	5380
Deana	4010	4580	5360	4990
Zvezdica	4030	4250	5620	4670
Elbrus	4520	5150	5850	5490
Average	4124 d	4709 c	5627 a	5199 b

The difference between total dry mass at maturity and the total dry mass at anthesis was positive value in all cultivars and treatments (Table 3).

Table 3. Post anthesis net dry mass accumulation, $kg.ha^{-1}$ and ratio of pre- to post anthesis accumulated dry mass of durum wheat cultivars in dependence of nitrogen fertilization.

Cultivars	N_0	N_{60}	N_{120}	N_{180}
Post anthesis net dry mass, $kg.ha^{-1}$				
Progress	4510	5260	4110	2870
Vazhod	3680	4720	5360	3920
Victoria	3660	4960	3580	2890
Predel	4300	2940	2840	6070
Deana	3970	5350	5810	3270
Zvezdica	4760	3180	5970	2530
Elbrus	4780	2560	4710	2740
Average	4237 ns	4139	4626	3470
Ratio of pre- to post anthesis accumulated dry mass				
Progress	1.30	1.32	2.47	3.90
Vazhod	1.61	1.56	1.47	2.81
Victoria	1.84	1.77	3.44	3.88
Predel	1.22	2.89	3.83	1.83
Deana	1.27	1.14	1.26	3.13
Zvezdica	1,03	2.29	1.46	4.20
Elbrus	1.32	3.84	2.34	4.16
Average	1.35	1.89	2.11	3.16

Consequently, the plants increased biomass during the period of grain filling. Post anthesis net dry mass accumulation of wheat cultivars varied between 2530 $kg.ha^{-1}$ (Zvezdica at N_{180}) and 6070 $kg.ha^{-1}$ (Predel at N_{180}). The effect of nitrogen fertilizing levels on the post anthesis net dry mass accumulation of wheat plants strongly depended of genotype. Higher nitrogen fertilizing rate N_{180} reduced the amount of dry matter accumulated after anthesis close to amount of control unfertilized plants (cultivar Vazhod) or below values of control plant in cultivars Progress, Victoria, Deana, Zvezdica and Elbrus. Only Predel variety was distinguished from studied cultivars by greater amount of post anthesis dry mass accumulation. The relative amount of DM accumulated at pre- and post-anthesis was presented as the ratio of pre- to post anthesis accumulated dry mass (Table 3), which was higher than one of all studied cultivars. This indicated that plants accumulated more dry mass in the pre-anthesis period than after anthesis. The highest values of of pre- to post anthesis ratio of wheat cultivars were obtained at high nitrogen fertilization N_{180}, excepted variety Predel. There was a tendency showed that nitrogen fertilization enhanced pre-anthesis dry mass accumulation of durum wheat. At rates 60, 120 and 180 kg $N.ha^{-1}$ the average ratio of pre- to post anthesis accumulated dry mass of wheat cultivars were 1.89, 2.11 and 3.16, respectively.

The nitrogen fertilization increased average values of dry mass translocation and dry mass translocation efficiency, and the contribution of pre-anthesis assimilates to the grain (Table 4). The model of dry mass translocation of cultivars was changed depending on the genotype. At unfertilized treatment four cultivars Progress, Predel, Zvezdica and Elbrus had a negative dry mass translocation. Bulgarian standard cultivar Vazhod was characterized with positive dry mass translocation and dry mass translocation efficiency, independently of nitrogen levels. At fertilization rates N_{60} and N_{180} new cultivar Elbrus demonstrated the highest dry mass translocation - 2590 and 2750 kg $DM.ha^{-1}$, respectively, high dry mass translocation efficiency (25 %) and contribution of pre-anthesis assimilates to the grain (50 %). At moderate nitrogen rate 120 kg $N.ha^{-1}$ the reutilization efficiency of biomass and contribution of pre anthesis assimilates to the grain were the highest in cultivar Predel – 25.2 and 49.1 %, respectively.

Table 4. Dry mass translocation (DMT), dry mass translocation efficiency (DMTE) and contribution of pre-anthesis assimilates to the grain (CAVG) in dependence of nitrogen fertilization.

Cultivars	N_0	N_{60}	N_{120}	N_{180}
Dry mass translocation, $kg.ha^{-1}$				
Progress	-410	-640	1310	2020
Vazhod	350	240	290	1530
Victoria	440	-130	2330	2630
Predel	-220	1630	2740	-690
Deana	40	-770	-450	1720
Zvezdica	-730	1070	-350	2140
Elbrus	-260	2590	1140	2750
Average	-113	570	1001	1729
Dry mass translocation efficiency, $kg.ha^{-1}$				
Progress	-7.0	-9.2	12.9	18.1
Vazhod	5.9	3.3	3.7	13.9
Victoria	6.5	-1.5	18.9	23.4
Predel	-4.2	19.2	25.2	-6.2
Deana	0.8	-12.6	-6.2	16.8
Zvezdica	-14.8	14.7	-4.0	20.2
Elbrus	-4.1	26.4	10.4	24.1
Average	-2.0	7.3	10.3	15.8
Contribution of pre-anthesis assimilates to the grain, $kg.ha^{-1}$				
Progress	-10.0	-13.9	24.2	41.3
Vazhod	8.7	4.8	5.1	28.1
Victoria	10.7	-2.7	39.4	47.6
Predel	-5.4	35.7	49.1	-12.8
Deana	1.0	-16.8	-8.4	34.5
Zvezdica	-18.1	25.2	-6.2	45.8
Elbrus	-5.8	50.3	19.5	50.1
Average	-2.7	12.1	17.8	33.3

Discussion

Papakosta and Gagianas (1991) was reported a decrease in dry matter between anthesis and maturity for winter wheat. In other cases it varied greatly with environmental factors (Dordas, 2009; Przulj and Momcilovic, 2001; Daiger et al., 1976), can also be affected by cultivar (Cox et al., 1985a), and carbon reserves in stem and leaves can contribute to grain filling in wheat (Blum, 1998). Total aboveground biomass increased after anthesis and the difference between total dry mass at maturity and the total dry mass at anthesis was positive value in all cultivars and fertilization treatments. A similar effect of increased biomass during the period of grain filling was found for durum wheat (Dordas, 2009), and for other plant species such as barley (Kostadinova and Ganusheva, 2013) and sunflower (Koutroubas et al., 1998). Grain dry mass in wheat and barley can be affected by cultivar and fertilization (Kostadinova, 2003; Przulj and Momcilovic, 2001). In present study wheat cultivars realized the highest grain yield in nitrogen fertilizing rate N_{120}. This corresponds with other publications for durum wheat in Bulgaria, whereby under favorable hydrothermal conditions the moderate rate of 120 kg $N.ha^{-1}$ can result in a higher grain yield of wheat (Kostadinova and Panayotova, 2010).

The reserves in stems or other vegetative tissues can be used for grain filling under any stress that depresses the photosynthetic source during seed filling (Dordas, 2009). The translocation of pre-anthesis reserves varies in different species and genotypes and a large movement of assimilates can occur under low soil fertility conditions (Demotes-Mainard and Jeuffroy, 2001). Our data demonstrated that the model of dry mass translocation of cultivars was changed depending on the genotype. At unfertilized treatment four cultivars Progress, Predel, Zvezdica and Elbrus had a negative dry mass translocation and Bulgarian standard cultivar Vazhod was a positive dry mass translocation and dry mass translocation efficiency, independently of nitrogen levels..

The contribution of pre-anthesis assimilates to the grain may be crucial for maintaining grain yield when adverse climatic conditions reduce photosynthesis, water and mineral uptake (Arduini et al., 2006). During grain filling of barley and wheat, the stem can lose up to 50 % of its dry weight, primarily water soluble carbohydrates, which accounts for 90-100 % of weight losses (Austin et al., 1980; Palta et al., 1994). Winter wheat transfers from 6 to 73% of its pre-anthesis storage of assimilates to the grain (Papakosta and Gagianas, 1991). In present study we found that the contribution of pre-anthesis assimilates to the grain were lower and ranged from 7.3 % (N_{60}) to 15.8% at rate N_{180}, in average.

Conclusion

Dry mass at anthesis and maturity (without grain) and grain yield significantly increased with increasing of the nitrogen fertilizing up to rate N_{120}. The high nitrogen rate of 180 kg $N.ha^{-1}$ decreased the post anthesis net dry mass accumulation of studied cultivars with the exception of variety Predel. The model of dry mass dynamic depended of the cultivar and nitrogen fertilizing. The nitrogen fertilization increased average values of dry mass translocation and dry mass translocation efficiency, the contribution of pre-anthesis assimilates to the grain, and enhanced the average ratio of pre- to post anthesis accumulated dry mass of wheat cultivars.

Bulgarian standard cultivar Vazhod was characterized with positive dry mass translocation and dry mass translocation efficiency, independently of nitrogen levels. At fertilization rates N_{60} and N_{180} new cultivar Elbrus demonstrated the highest dry mass translocation - 2590 and 2750 kg $DM.ha^{-1}$, respectively, and high dry mass translocation efficiency (25 %) and contribution of pre-anthesis assimilates to the grain (50 %). At moderate nitrogen rate 120 kg $N.ha^{-1}$ the reutilization efficiency of biomass and contribution of pre anthesis assimilates to the grain were the highest in cultivar Predel – 25.2 and 49.1 %, respectively.

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