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Agronomic Response of Durum Wheat (*Triticum durum* Desf.) to Nitrogen Rates in a Long–Term Fertilizing Experiment

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Abstract

The aim of the study was to analyze the agronomic response of durum wheat during 1990-2014 to nitrogen rates 0, 40, 80, 120 and 160 kg.ha^{-1}. It was found that without N durum wheat realized grain yield of 2.34 t.ha^{-1}. The highest yield was obtained at 120 kg N.ha^{-1}. The partial factor of productivity decreased with the increase of N from 74.7 kg.kg^{-1} (N_{40}) to 24.1 kg.kg^{-1} (N_{160}). No proven differences were found in the agronomic efficiency for rates of N_{40} to N_{120}, as the values were 17.0 - 14.9 kg grain.kg^{-1}. The use of 160 kg N.ha^{-1} reduced the N agronomic efficiency by 40% compared to N_{40}. A strong positive correlation was obtained between N rates and yield (r = 0.930*). The strong negative relationship was proven by N and by partial factor productivity and agronomic efficiency.

Key words: nitrogen rates, durum wheat, efficiency

Introduction

Nitrogen is often regarded as the single most important nutrient and it is one of the most limiting nutrients for wheat production in Bulgaria. The relationship between grain yields and fertilizing rates are usually discussed as yield efficiency or agronomic efficiency. This relationship represents the yield increased per unit of applied nitrogen or other nutrients (Pervaoz, 2004).

There are many factors that can affect the grain yield and nitrogen efficiency of durum wheat including genotype, temperature, rainfall and fertilization (Miralles and Slafer, 2007). Among all of them, the nitrogen rate, year conditions and fertilizing levels are usually the most important for determining the agronomic efficiency (Delogua et al., 1998). Economic and environmental challenges have led to an increased interest in nitrogen use efficiency. Higher prices for both crops and fertilizers have shifted interest to efficiency-improving technologies and practices that also improve productivity (Ladha et al, 2005).

Risks of increased environmental N losses via leaching, runoff, volatilization and denitrification, which may be associated with increased global N use and harm air and water quality can be reduced by improving the efficiency of nitrogen use (Voicu and Soare, 2012). On-farm N use efficiency and effectiveness can be improved through better management of N sources, rates, timing, and placement (Koteva and Marcheva, 2012). According to Dobermann and Cassman (2005), 66% of N fertilizer was used to fertilize cereal crops, mainly corn and wheat. The aim of this study was to analyze the agronomic response of durum wheat to nitrogen rates grown under conditions of a long-term fertilizing experiment.

Material and Methods

A long-term fertilizing experiment was conducted at the Institute of Field Crops – Chirpan, Bulgaria. Durum wheat (*Triticum durum* Desf.) was grown in two field crop rotations (cotton – durum wheat) under non-irrigation conditions for a period of twenty-five growing seasons from 1990 to 2014. The experimental design consisted of randomized block design with four replications. The harvested size of the plots was 10 m^2. The treatments were as follows: 0, 40, 80, 120 and 160 kg $N.ha^{-1}$. Nitrogen fertilization in the form of NH_4NO_3 was applied before sowing (1/3 of the rate) and in the early spring (2/3 of the rate). The precursor crop cotton was fertilized with N_{80}. The soil type of the experimental field was *Pellic vertisols* (FAO) 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), with a compact zone of the profile (united horizon). Based on the humus content, it belongs to the mean humus soils.

It is characterized by high humidity capacity, caused by the high percentage of clay minerals, with clay soil texture, low water-permeability, bulk density of the arable soil layer – 1.2-1.3 g.cm^{-3}, 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. The hydro-thermal conditions during the wheat vegetation period were different: four of the harvested years were very unfavorable, eight of the years were unfavorable, and the temperature and precipitations of the other thirteen years were close to the long-term average for the region. The agronomic response of durum wheat to nitrogen rate was determined by the obtained grain yields and the main nitrogen use efficiency indicators, namely partial factor productivity and agronomic efficiency.

Partial factor productivity (PFP) and agronomic efficiency (AE) were calculated according to Dobermann (2007) using the following formulas: PFP = Y/F (kg.kg^{-1}), and AE = (Y-Y_0)/F (kg.kg^{-1}); where Y and Y_0 were grain yields from fertilized treatments and unfertilized control, respectively, and F - amount of N fertilizer applied (kg.ha^{-1}). The data were statistically analyzed with the one way ANOVA procedure within the SPSS statistical program and the Duncan's multiple range test (P = 0.05) to find significant differences among means. The Pearson correlation coefficient was determined.

Results and Discussion

The average grain yields over the 25-year period ranged from 1724 kg.ha^{-1} in 2007 to 4502 kg.ha^{-1} in 2001 (Figure 1). Depending on the hydro-thermal conditions during the vegetation of durum wheat in four of the years, the yields reached up to 2500 kg.ha^{-1}, in eight of the years they ranged from 2500 to 3500 kg.ha^{-1}, and in the other thirteen years of harvest the average yields of grain exceeded 3500 kg.ha^{-1}.

The average results obtained in this study for the 1990-2014 period showed that durum wheat positively responded to nitrogen fertilization (Table 1). The grain yield was highest when fertilized with N_{120} – 4017 kg.ha^{-1}, which exceeded the unfertilized control with 71.9%. No proven differences were established for the obtained yields after application of N_{80} and N_{160} rates. These results correspond to reference data by Panayotova and Dechev (2003), who established the highest productivity of Bulgarian durum wheat cultivars fertilized with N_{120}.

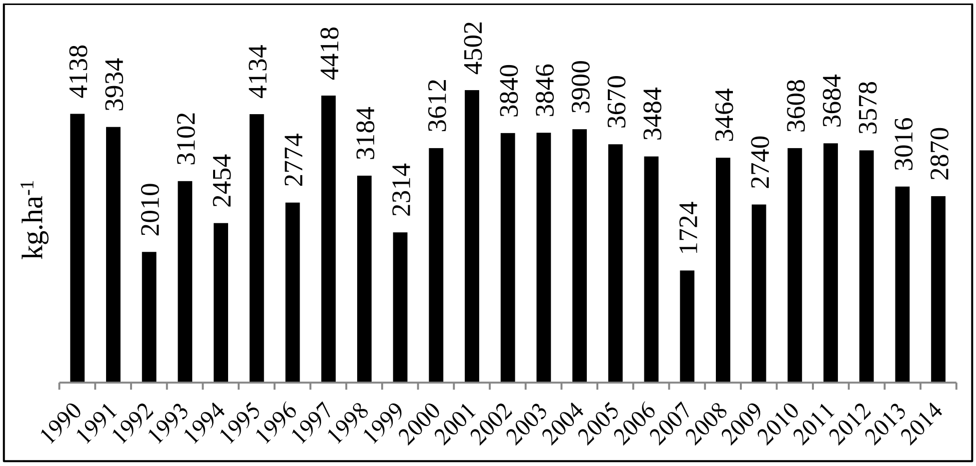

Fig. 1. Average grain yield of durum wheat for the 1990-2014 period
Просјечан принос зрна дурум пшенице у периоду 1990-2014

As a result of the natural soil fertility (unfertilized), the average grain yield was 2336 kg.ha^{-1}. The average grain yield increased by 27.8% when fertilized with N_{40} rate and by 65.3% with N_{160} rate.

Table 1. Grain yield of durum wheat for the 1990-2014 period dependent on nitrogen fertilization, kg.ha^{-1}
Принос зрна дурум пшенице у периоду 1990-2014 у зависности од ђубрења азотом, у kg/ha

Grain yield	Nitrogen fertilization				
	N_0	N_{40}	N_{80}	N_{120}	N_{160}
Average	$2336^c \pm 659$	$2987^b \pm 546$	$3595^a \pm 814$	$4017^a \pm 991$	$3863^a \pm 1058$
Min	1080	1860	2050	1840	1640
Max	4010	4350	5300	5330	5020
% to N_0	100.0	127.8	153.9	171.9	165.3

Mean values for nitrogen rate followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test

Partial factor productivity is the most important indicator for grain farmers because it integrates the use efficiency of soil elements and the efficiency of applied fertilizers (Hawkesford, 2012; Snyder and Bruulsema, 2007). According to Dobermann (2007), typical levels of PFP for cereal crops are 40-80 kg.kg^{-1}. Throughout the 25-year period the average PFP changed ranging from 25 to 59 kg.kg^{-1} as dependent on the yield level, respectively the climate conditions (Figure 2).

In seven of the years of study, PFP of nitrogen had lower than the typical average values of under 40 $kg.kg^{-1}$. In the remaining years, the average PFP values ranged from 41 to 59 $kg.kg^{-1}$.

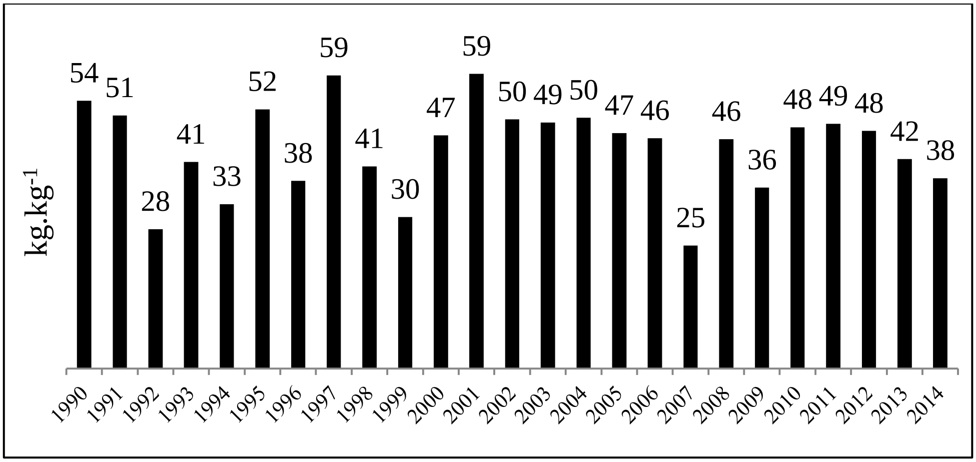

Fig. 2. Average partial factor productivity of N for durum wheat in the 1990-2014 period

Просјечни парцијални фактор продуктивности ђубрења азотом за дурум пшеницу у периоду 1990-2014

The values obtained for PFP significantly decreased with the increase of the applied nitrogen rates (Table 2). Average for the 25-year period, PFP had the highest value of 74.7 $kg.kg^{-1}$ which was close to the upper limit for typical values for wheat after use of the low rate N_{40}.

Table 2. Partial factor productivity (PFP) of nitrogen rates for durum wheat in the 1990-2014 period as dependent on nitrogen fertilization, $kg.kg^{-1}$

Парцијални фактор продуктивности (PFP) за дурум пшеницу у периоду 1990-2014 у зависности од ђубрења азотом, у kg/kg

PFP	Nitrogen fertilization			
	N_{40}	N_{80}	N_{120}	N_{160}
Average	$74.7^{a} \pm 13.7$	$44.9^{b} \pm 10.2$	$33.5^{c} \pm 8.3$	$24.1^{d} \pm 6.6$
Min	46.5	25.6	15.3	10.3
Max	108.8	66.3	44.4	31.4
% to N_{40}	100	60.4	45.0	32.5

Mean values for nitrogen rate followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test

The highest value of 108.8 kg.kg^{-1} for PFP was also established with this fertilization rate in the 1990-2014 period. Nitrogen fertilization with N_{120} and N_{160} led to low nitrogen efficiency and PFP values under the typical lower limit of 40 kg.kg^{-1} for wheat. The minimum estimated value of PFP was 10.3 kg.kg^{-1} and it was obtained after the application of N_{160}.

Agronomic efficiency (AE) characterizes the ability of plants to increase production in response to nitrogen or other fertilizers (Craswell and Gowdin, 1984) and for wheat to depend to a large extent on nitrogen fertilization and the climatic conditions (Delogua et al., 1998). AE is used as a short-term indicator of the nutrient impact on productivity (Moll et al., 1982). The average values of nitrogen AE for wheat was approximately 10-30 kg of grain yield increase per kg of N applied (Moll et. al., 1982). Lower levels suggest that changes in management can increase productivity. Values higher than 25 kg of grain per kg N are obtained in systems with best practices, low levels of nitrogen or low supply of soil nitrogen.

AE is the result of the return of applied fertilizer and the efficiency with which the plant uses each additional unit of the nutrient (Hawkesford, 2012, Snyder & Bruulsema, 2007). AE is often used for economic assessment of fertilization and generally decreases with the increase of fertilizer rates (Panayotova and Kostadinova, 2004). The average AE values for the 1990-2014 period ranged from 3 to 25 kg.kg^{-1} (Figure 3). During the six harvest years, AE of nitrogen was under 10 kg.kg^{-1}, and in the remaining years ranged within the values typical for wheat - 11 to 25 kg.kg^{-1}.

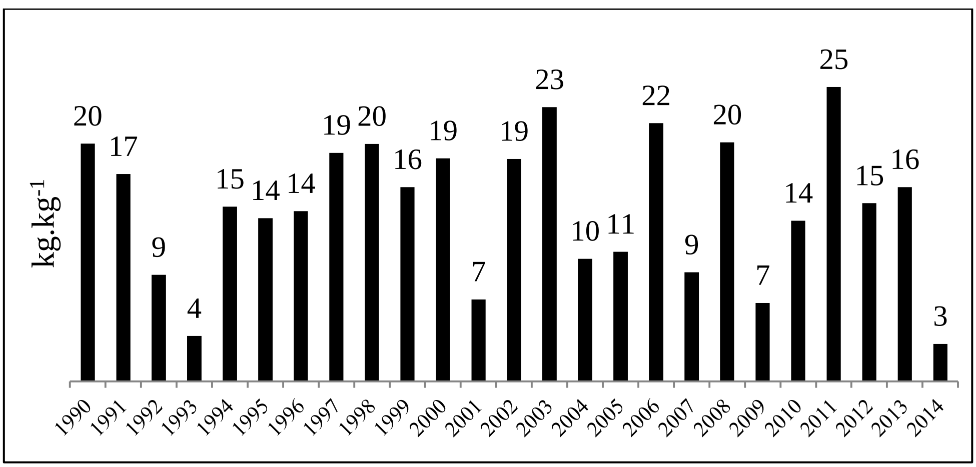

Fig. 3. Average agronomic efficiency of nitrogen for durum wheat in the 1990-2014 period

Просјечна агрономска ефикасност ђубрења азотом за дурум пшеницу у периоду 1990-2014

The results for agronomic efficiency of nitrogen for durum wheat in the 1990-2014 period showed decrease of this efficiency indicator with the increase of applied nitrogen (Table 3). No proven differences were found in agronomic efficiency of nitrogen for applied N_{40} and N_{120} rates. These rates resulted in average agronomic efficiency of 17.0 - 14.9 kg.kg^{-1} over the period. The use of 160 kg N.ha^{-1} reduced the agronomic efficiency of nitrogen by 40% compared to its N_{40} values. The following minimum and maximum values – 1.3 kg.kg^{-1} (for N_{160}) and 31.8 kg.kg^{-1} (for N_{40}), respectively, were established for the 25-year period for the durum wheat.

Table 3. Agronomic efficiency of nitrogen for durum wheat in the 1990–2014 period as dependent on nitrogen fertilization, kg.kg^{-1}
Агрономска ефикасност за дурум пшеницу у периоду 1990–2014 у зависности од ђубрења азотом, у kg/kg

Nitrogen fertilization	N_{40}	N_{80}	N_{120}	N_{160}
AE	$17.0^a \pm 7.5$	$16.6^a \pm 7.1$	$14.9^a \pm 6.7$	$10.2^b \pm 5.8$
Min	2.8	3.3	1.9	1.3
Max	31.8	28.3	26.7	18.8
% to N_{40}	100	97.6	87.6	60.1

Mean values followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test

A strong positive correlation (r = 0.930*) was established between nitrogen rates and grain yield (Table 4). The strong negative relationship was proven for nitrogen fertilization and partial factor productivity (r = -0.951 **) and agronomic efficiency (r = -0.917 *).

Table 4. Correspondence between nitrogen fertilization and grain yield of durum wheat, partial factor productivity and agronomic efficiency
Корелациони односи ђубрења азотом, приноса дурум пшенице, парцијалног фактора продуктивности и агрономске ефеикасности

Parameters	Coefficient of correlation, r	Coefficient of determination, R^2	Equation
Grain yield	0.930*	0.984	$y = - 0.08x^2 + 23.03x + 2286$
Partial factor productivity	- 0.951**	0.991	$y = - 0.003x^2 + 1.05x + 110$
Agronomic efficiency	- 0.917*	0.994	$y = - 0.0007x^2 + 0.77x + 14.9$

*, ** - *Correlation is significant at the 0.05 and 0.01 level of probability, respectively*

Conclusion

It was found that for the long-term 25-year period of nitrogen fertilization of durum wheat the average grain yield ranged from 1.72 $t.ha^{-1}$ to 4.50 $t.ha^{-1}$ depending on weather conditions. The highest grain yield of durum wheat over the 1990-2014 period was obtained at rate of 120 kg $N.ha^{-1}$, but without significant difference compared to N_{80} and N_{160} rates.

Both Agronomic efficiency of nitrogen and Partial factor productivity as main indicators for assessing the efficiency of fertilization in terms of yield showed negative correspondence with the increase in N rate. The use of high nitrogen rates such as 160 kg $N.ha^{-1}$ reduced the agronomic efficiency of N by 40% compared to its N_{40} values. In conclusion, the findings suggest that nitrogen fertilization with 80-120 kg ha^{-1} was the most effective for the conditions of Central Southern Bulgaria.

A strong positive correlation was established between nitrogen rates and grain yield (r = 0.930*), and a strong negative correlation was proven for N fertilization and partial factor productivity and agronomic efficiency.

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Утицај различитих нивоа ђубрења азотом у дугогодишњем огледу на карактеристике тврде пшенице (*Triticum durum* Desf.)

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Сажетак

Циљ истраживања је анализа карактеристика тврде пшенице у периоду 1990-2014 у зависности од нивоа ђубрења азотом (0, 40, 80, 120 и 160 kg/ha). Принос зрна у третману без додатог азота (0 kg/ha N) био је 2,34 t/ha. Највиши принос је постигнут у третману ђубрења азотом са 120 kg/ha. Парцијални фактор продуктивности је имао пад при повећању количине додатог азота од 74,7 kg/kg (N_{40}) ка 24,1 kg/kg (N_{160}). Није било значајних разлика између нивоа ђубрења азотом од N_{40} до N_{120}, јер су вриједности приноса биле од 17,0 до 14,9 kg зрна/kg. Примјена нивоа азота од 160 kg/ha смањило је ефекат азота за 40 % у поређењу са нивоом N_{40}. Висока и позитивна корелација постојала је између нивоа ђубрења и приноса пшенице (r = 0,930*). Висока и негативна корелација постојала је између нивоа ђубрења азотом, као и парцијалног фактора продуктивности и практичне ефикасности с друге стране.

*Кључне ријечи***:** ниво ђубрења азотом, дурум пшеница, ефикасност

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