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Influence of long-term fertilization and environments on test weight of durum wheat (*Triticum durum* Desf.) grain

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Abstract. *The aim of this study was to investigate the influence of long-term nitrogen-phosphorus fertilization and meteorological conditions during the period 1990-2019 on test weight of durum wheat grain in Central South Bulgaria. The influence of nitrogen and phosphorus rates - 0, 40, 80, 120 and 160 kg.ha^{-1}, as well as combined NP fertilization in the same rates on durum wheat grain under conditions of stationary long-term fertilizing experiment in cotton-durum wheat crop rotation was studied. The analysis of the results showed that the test weight was below the standard requirements in eight of the studied years, and in 22 years the average test weight exceeded the requirements. The values in 17 years were over 80.0 kg. The test weight decreased by increasing the N rates above 80 kg and the lowest average value was seen at N_{160} - 79.4 kg. The P application in rates from 40 to 160 kg.ha^{-1} indicated a tendency to increase the test weight. Good values were realized by combining a moderate to high phosphorus rates P_{80-160} with low N levels N_{40-80}. Weather conditions during the 30-year period have a strong significant impact on the test weight of the grain.*

Keywords: durum wheat, test weight, nitrogen, phosphorus, meteorological conditions.

Introduction

Durum wheat (*Triticum durum* Desf.) is an economically important crop cultivated worldwide for producing quality pasta products. This crop takes up approximately 8% of the world's wheat production. Within the EU durum wheat represents 13.2% of the total area and 9.2% of the wheat production. In 2017, it was grown on 2.7 million hectares only in the European Union (EU), providing an output of about 9 million tons. The cultivation area of durum wheat in Europe is mostly concentrated in the Mediterranean region: Italy, Spain and France together account for 80% of the total EU production (Europoean Commission, 2018). Italy is the top EU producer country and a traditional durum wheat growing region as it dedicates half of the total EU durum wheat area to this crop, thus accounting for 45% of the entire EU production, with a yield of about 3.2 t.ha^{-1}. In recent years Bulgaria has increased the grain production of this crop and increased the consumption of products made from durum wheat.

Most research on wheat fertilization refers mainly to common wheat and only a limited number of it is on durum wheat, though not to the present-day most widespread intensive varieties. Grain quality has become one of the most important goals for breeders and growers (Camerlengo et al., 2017; Ceoloni et al., 2017), because it is essential in obtaining premium prices and meeting market needs for high-quality end products of durum wheat such as pasta, couscous and bulghur. The quality of crops, including durum wheat, varies to a wide range in dependence of agroecological conditions, cultivar, crop rotation, fertilization, etc. (Rharrabti et al., 2003; Petrova, 2009; Dechev and Panayotova, 2010; Dechev et al., 2010; Stoyanova and Petkova, 2010; Rossini et al., 2018).

Optimizing mineral nutrition is one of the most important conventions for a favorable growth and production of the plants, for ensuring their need of nutrient elements, for increasing the soil richness. The N use is normally considered a key factor in cereal crops and numerous studies on the best nitrogen fertilization rates and timing have been conducted. In fact, if on the one hand it has been proved that nitrogen positively affects grain yield and quality, on the other hand nitrogen fertilizer management is pivotal to avoiding N losses caused by leaching, runoff, denitrification or volatilization (Garrido-Lestache et al., 2005).

Many studies have been conducted to examine the effects of N fertilizers on cereal grain yield and quality (Panayotova et al., 2015, 2017; Rossini et al., 2018). Some authors (Gagliardi et

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al., 2020) reported that the increasing N rate and rich soil fertility enhanced the grain protein content. Often the high fertilization rates lead to decrease of yield and quality, obtaining negative results, and increase of the economic losses in production. A prerequisite for obtaining high yield semolina and its processing into pasta products with good culinary quality is using quality durum wheat grain with healthy vitreousness grain, with high protein content, with good test weight (Makowska et al., 2008).

The Bulgarian varieties have given comparatively stable yield and good quality parameters in the various agroecological regions of Bulgaria. The fertilization of durum wheat grown after cotton should be complied with the fact that a significant part of the nitrogen for cotton, is not utilized by it, but remains in the soil. The two crops are successfully developed in crop rotation and when fertilized actively participate in the nutrient utilization (Plescuta, 2018).

Test weight is a measure of grain quality, it is a measure of density (mass/volume). Good quality seed of low moisture content can be expected to have a good test weight. Lower test weights are more common when crops have experienced stress during seed fill or when a frost hits before physiological maturity (Davidson, 2018; Deivasigamani and Swaminathan, 2018). Stress can be brought on by disease, insects, soil or weather conditions that impact the uptake, production or flow of nutrients and carbohydrates to the seed during grain fill. High test weights are not always associated with high yields (Nielsen, 2014).

The aim of this study was to investigate the influence of long-term nitrogen and phosphorus fertilization and meteorological conditions during the period 1990-2019 on the test weight of durum wheat grain in cotton-durum wheat crop rotation in Central South Bulgaria.

Material and methods

The present study analyses data from long-term fertilizer stationary experiment based in the field of the Institute of Field Crops, Chirpan, Bulgaria (42°11‘58“N, 25°19‘27“E) with cotton-durum wheat (*Triticum durum* Desf.) crop rotation under rainfed conditions for a period of thirty growing seasons from 1990 to 2019. Treatments were arranged in a randomized complete block design with four replications. The size of the yield plot was 10 m^2 (2.40 x 4.20 m). Durum wheat Progress cultivar was grown during the thirty growing seasons. The levels of nitrogen (N) and phosphorus (P) for durum wheat were 0; 40; 80; 120 and 160. Alone and combined influence of fertilizer levels and the interaction between them were studied. The control was unfertilized. The used fertilizers were ammonium nitrate and triple superphosphate. Nitrogen was applied two times on durum wheat plots: one third - at sowing, and the rest nitrogen as a top dressing at the end of wheat tillering stage, and phosphorus was applied before sowing.

The seeds were sown in October 10-20, and the sowing rate was 400 germinated seeds per m^2. Weeds were controlled with herbicides between tillering and shoot elongation stages. Site-specific agronomic practices for durum wheat were applied throughout the growing season as necessary to ensure high quality collected data. The harvest occurred in July 10-15 by self-propelled plot Wintersteiger combine.

Seed samples during the period 1990-2019 were analysed. The test weight ($kg.hl^{-1}$) of dried grain was determined by scales. The presented data are of 3 parallel determinations. Analysis of variance (ANOVA) was performed and the means were compared to the LSD procedure.

The soil type was Pellic Vertisols, defined by the sandy-clay composition, with high humidity capacity and small water-permeability (FAO, 1974). The soil was with a slightly acidic to neutral reaction, poor to middle provided with nitrogen, poorly supplied with mobile phosphates and well - with mobile phosphates.

Comparison of the meteorological conditions in the studied years (1990-2019) with the long-term 90-year period shows that there are significant deviations, especially in terms of humidity, and the deficit is primarily from vegetative rainfall in the most important development stages of durum wheat. In terms of temperature during the durum wheat growing season (Figure 1), five of the harvested years – 2016, 2009, 2019, 2007 and 2013 were very warm, with temperature sum exceeding the average amount over the long term period (2359°C) by 432-578°C. Four years were characterized as warm with 325-368°C higher temperature sum, eight of the years were moderately warm, seven years were normal, three years were moderately cool and three years - 1993, 2006 and 1996 were cold with temperature sum 99-209°C lower than the long-term values. Temperatures were significantly higher during the April-June period, when grain was formed and grown.

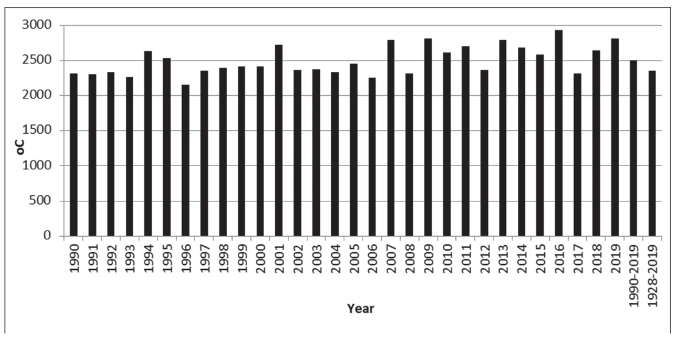

Figure 1. Temperature sum (°C) during the vegetation period (X-VI) of durum wheat, 1990-2019

According to rainfall during the growing season (Figure 2), 2004 and 2015 were very wet (578-587.3 mm); 2014, 2018 and 2008 were wet with 90.3-107.1 mm more precipitation compared to the average long-term value (440.4 mm); 1995,1998 and 2019 were moderately wet; 1991, 1999, 2010, 2012, 2017, and 2013 were with average rainfall; 2016, 2002, 2000, 2006, 1997 and 2005 were moderately dry; 2003, 1993, 2001, 1992, 1994 and 1996 were dry; and 2011, 1990, 2007 and 2009 were very dry, with a total sum of 231.8-329.7 mm.

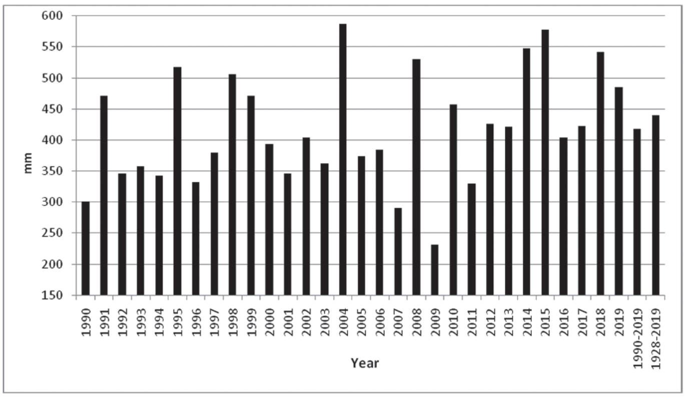

Figure 2. Precipitation (mm) during the vegetation period (X-VI) of durum wheat, 1990-2019

Results and discussion

The test weight is an indirect classification parameter, normally in direct correlation with flour output, criterion for the health state of durum wheat. It is desirable for the test weight to be over 78 kg/hl. In western Canada, grain samples of top grade Canada Western Amber Durum wheat must contain at least 80% hard vitreous kernels and have a test weight of 80 $kg.hl^{-1}$ or higher (May et al., 2008). Typically, higher test weight wheat grain contains more extractable flour and less bran, making it more valuable to the end user (Ransom, 2017).

The influence of the tested factors – meteorological conditions and applied nitrogen and phosphorus fertilization, was very well demonstrated. However, examining the influence of the various factors (year, N and P rates) some significant differences were observed. The results of analysis of variance (Table 1) showed highly significant differences among the nitrogen rates (N), phosphorus rates (P) and environment - in this case years. The mean squares due to years were significant at the 0.001 level of probability and the year conditioned the greatest influence on the test weight - 92.05% of the total variation. The influence of nitrogen and phosphorus rates was low but significant - 0.57% and 0.19%, respectively. The N x P interaction did not have significant effect, indicating that durum wheat plants reacted in the same way to the applied combined fertilization. On average for the long-term study, the coefficient of variation of the values was low (CV=0.95%).

Table 1. Analysis of variance for test weight of durum wheat at nitrogen and phosphorus fertilization, 1990-2019

Source of variation	Degrees of freedom	Sum of squares	Sum of squares, %	Mean squares	F
Total	749	5670.5	100.00	-	-
Years	29	5219.5	92.05	179.98 ***	310.07
Variants	24	47.0	0.83	1.96 ***	3.37
N - N rate	4	32.5	0.57	8.12 ***	14.00
P - P rate	4	11.0	0.20	2.75 **	4.74
N x P	16	3.5	0,06	0.22 n.s.	0.38
Error	696	404	7.12	0.58	-

, * - significant at $p \leq 0.01$ and $p \leq 0.001$ level of probability, respectively

The analysis of the results showed that under the agroecological conditions of the Institute of Field Crops – Chirpan on soil type Pellic Vertisols the test weight of cultivar Progress during the 30-year period was good - an average of 79.9 kg, ranging from 71.0 kg ($N_{160}P_{120}$ in 2018) to 85.5 kg (P_{120} and $N_{80}P_{120}$ in 1996).

Weather conditions affected more strongly compared to fertilization (Figure 3). The test weight was below the standard requirements in eight of the studied years, and in 22 years the average test weight exceeded the requirements. The values in 17 years were over 80.0 kg.

The test weight values were very low in 1994, 2005, 2014, 2018 (73.5-75.7 kg), characterized with high moisture supply, while in 1996, 1997, 2001, 2007 and 2008 under the influence of favourable combination of temperature and precipitation the average values were significantly higher – 82.6-84.9 kg. Heavy rainfall and very high temperatures at the end of durum wheat vegetation, especially at the end of May and June, significantly reduced the test weight. The influence of precipitation was considerably better expressed than the temperature sum.

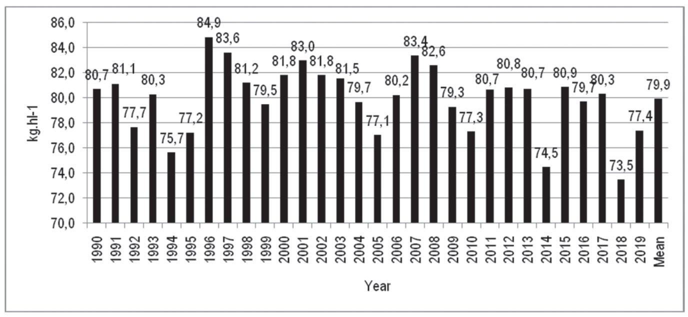

Figure 3. Differences in test weight of durum wheat grain (kg) depending on the year conditions, average for fertilization levels (LSD 0.05; 0.01; 0.001 = 0.39; 0.51; 0.65)

According to Davidson (2018), moisture or temperature stress conditions that impact the uptake, production or transport of nutrients during grain fill are often associated with lower test weights. Peña (2003) reported that the lowest values of test weight could be due to the shortest period available for grain filling, so it is important to identify varieties to achieve short cycle crops with good grain quality, since a sucked grain is not acceptable for milling due to its low yield of flour.

Grain formed without fertiiization has good hectolitre weight - 79.8 kg average for a period. Under the influence of nitrogen fertilization only, the test weight increased significantly to 80.13 kg when fertilized with N_{40}. The increase of the nitrogen rate showed a reduction of this parameter, proven at p≤0.001, despite their very close values. The test weight decreased by increasing the N rates above 80 kg and the lowest average value was seen at N_{160} - 79.4 kg (Figure 4). The highest value at nitrogen fertilization only - 84.2 kg was formed at N_{120} in favorable 1996. A high negative correlation (r= -0.944) between N rate and grain test weight was observed. Saint et al. (2008) also found that reductions in test weight and grain weight and diameter were observed under high N fertilization. Valdés et al. (2020) reported that nitrogen availability modified significantly some quality parameters, including test weight, obtaining the highest values at a rate of 100 kg N ha^{-1}.

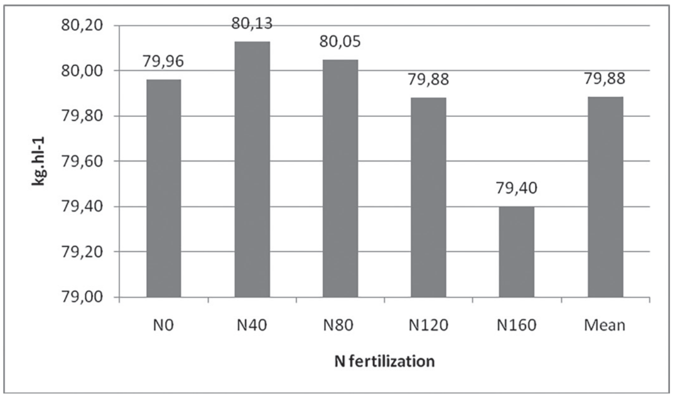

Figure 4. Test weight of durum wheat grain (kg) at nitrogen fertilization, 1990-2019 (LSD 0.05; 0.01; 0.001 = 0.17; 0.23; 0.29)

The phosphorus application only in rates from 40 to 160 kg.ha^{-1} indicated a tendency to increase the test weight of grain compared to unfertilized, and the dilferences were essential at p≤0.01 (Figure 5). Average for the 30-year period, the test weight at P_0 was 79.71 kg and at P_{160} it reached 80.02 kg, by 0.39 % above the phosphorus control.

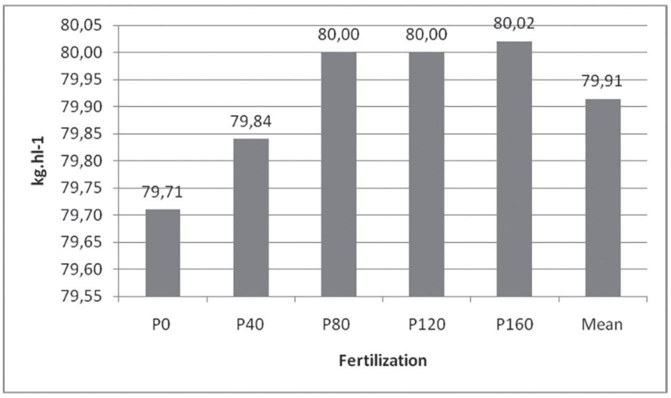

Figure 5. Average test weight (kg) at phosphorus fertilization, 1990-2019 (LSD 0.05; 0.01; 0.001 = 0.17; 0.23; 0.29)

Different NP combination influenced the test weight, but the differences were not proven during the years, despite their very close values. Average for the period, higher proven values for test weight were reported when phosphorus was combined with low and moderate N (80.04-80.24 kg). Average for the period, the highest proven test weight was reported as a result of combining phosphorus fertilization with low nitrogen level N_{40}. Values decreased to 79.48-80.18 kg at combined fertilization with N_{120} and N_{160} (Table 2). Unlike our results, to ensure crop quality Mulè et al. (2020) reported that lower values for test weight in correspondence of BFAs (Animal ByProducts Fertilization) fertilization were not found when compared to no fertilization.

Table 2. Test weight of durum wheat grain (kg) at NP fertilization, average for 1990-2019

N - P fertilization	P_{40}	P_{80}	P_{120}	P_{160}	Average for N	
					kg.hl^{-1}	%
N_{40}	80.04	80.21*	80.22*	80.24*	80.18	100.0
N_{80}	80.00	80.16	80.11	80.04	80.08	99.9
N_{120}	79.75	80.18	79.98	79.83	79.94	99.3
N_{160}	79.48	79.60	79.56	79.74	79.60	99.3
Average for P, kg.hl^{-1}	79.82	80.04	79.97	79.96	9.95	-
%	100.0	100.3	100.2	100.2	-	-

Conclusion

The 30-year (1990-2019) data related to the evaluation of test weight of durum wheat grain under the influence of nitrogen-phosphorus fertilization at increasing rates under soil and climatic conditions of Central Southern Bulgaria were summarized. It was found that on soil type Pellic Vertisols the test weight of cultivar Progress was an average of 79.9 kg, ranging from 71.0 to 85.5 kg. The test weight was below the standard requirements in eight of the studied years, and in 22 years the average test weight exceeded the requirements. The values in 17 years were over 80.0 kg. Heavy rainfall and very high temperatures at the end of durum wheat vegetation significantly reduced the test weight. In years with insufficient precipitation during the vegetation, in late sowing and late germination it is recommended to fertilize with moderate N rates. The test weight decreased by increasing the N rates above 80 kg and the lowest average value was seen at N_{160} - 79.4 kg. The phosphorus application in rates from 40 to 160 kg.ha^{-1} indicated a tendency to increase the test weight. The high phosphorus rates and rich soil supply formed higher test weight regardless of variety or year conditions. In conclusion, we can emphasize that the evaluation conducted on test weight of durum wheat grain provides an objective characteristic of the studied genotype and influence of N-P rates in different years can be successfully used depending on the breeding and production purposes.

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