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Efficiency and risk of long-term fertilization of durum wheat

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Abstract

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The objective of this study was to assess the effectiveness and risk of long-term (1990-2014) nitrogen-phosphorus fertilization on the productivity of durum wheat at a stationary fertilizer trial on soil type *Pellic vertisols* in the Institute of Field Crops – Chirpan, Bulgaria. The rates of N and P were 0, 40, 80,120 and 160 $kg.ha^{-1}$. The N was applied two times: one third at sowing, and the rest – as a top dressing at the tillering stage, and P – before sowing. The block design with four replicates was used. The agronomic efficiency (AE) was calculated using the formula: $AE = (Y-Y_0)/F$ ($kg.kg^{-1}$), where Y and Y_0 were grain yields with fertilization and unfertilized control, respectively, and F – amount of N fertilizer ($kg.ha^{-1}$). The data and the regression dependencies between grain yield and N fertilization were analyzed by the SPSS program and the Duncan's multiple range test to find significant differences among means. The Pearson's correlation coefficient was determined. Comparison of the meteorological conditions in the studied years with the long-term 86-year period shows that there were significant deviations, especially in terms of humidity, and the deficit was primarily from vegetative rainfall. It was found that average for 25 years, the cultivar Progress realized a grain yield of 3.53 $t.ha^{-1}$. The yield was 2.34 $t.ha^{-1}$ without fertilization. At N fertilization the yield increased to N_{120} – 4.02 $t.ha^{-1}$, exceeded the unfertilized by 17.2%. The yield reached up to 2.61 $t.ha^{-1}$ at P_{120}, with 11.8% above unfertilized. With the increase of P rate there was a tendency for yield decrease due to the established good supply of phosphates. The grain yield increased at $N_{120-160}P_{80-120}$ – 4.06-4.33 $t.ha^{-1}$. The highest value was at $N_{120}P_{120}$. The grain yield without fertilization was lowest in 1999 – 1.03 $t.ha^{-1}$, and highest – 3.96 $t.ha^{-1}$ in 2001. The AE increased to N_{80} reaching 173 kg grain/kg N fertilizer. At low applied P_{40} AE was the best – 35 kg grain/kg fertilizer. The regression model showed that without N can be expected grain yields of up to 1.50 $t.ha^{-1}$ in 4 of the years; 1.50-2.00 $t.ha^{-1}$ in 5 of the years; 2.00-2.50 $t.ha^{-1}$ in 6 of them; 2.50-3.00 $t.ha^{-1}$ in 8 of the experimental years and over 3.00 $t.ha^{-1}$ in 2 of the years.

Keywords: durum wheat; fertilization; yield; temperature; precipitation; regression
Abbreviations: N – nitrogen, P – phosphorus, AE – agronomic efficiency

Introduction

Durum wheat (*Tr. durum* Desf.) is an economically important crop for producing quality pasta products. The European Union has about 20% of the areas in the world sown and produces approximately 30% of the total production of this crop. In recent years Bulgaria has increased the durum wheat grain production and consumption of products made from durum wheat. To achieve high and stable grain yields, the issues of farming practices, including the level of mineral nutrition, are particularly relevant.

Weather conditions in the years and applied fertilizers exert great influence on the grain yield of durum wheat. Optimizing the 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. Nitrogen fertilization will continue to be the main factor for high productivity. The main requirement for high yield, combined with good grain quality is the plants to receive an optimal N amount during vegetation (Schillingb, 2003). N use efficiency and effectiveness can be improved through better management of N sources, rates, timing, and placement (Koteva & Marcheva, 2012).

Long-time stationary field experiments are one of the important means for establishing sustainable management of crop potential under the influence of a number of factors, some of which are mineral fertilization and environmental conditions (Liu et al., 1998; Edmeades, 2003; Merbach & Deubel, 2008). World-known are the fertilization trials in Rothamsted, England set in 1842 (Rothamsted Research, 2006), in Askov, Denmark since 1894, in Laustadt, Germany since 1903, in Halle (Saale), Germany (Schmidt et al., 2000), at the Timiryazev Academy, Russia since 1912, the network of stationary trials in Russia, which are regularly summarized by the D Pryanishnikov Institute of Fertilization and Soil Science, long-term field trials in Hungary (Debreczeni & Sisak, 1996), in Czech Republic (Kunzova & Hejcman, 2009), etc. There are also long-term trials in Bulgaria, set on various soil types which are a rich source of information for scientists and producers (Filipov, 1976; Koteva, 2002, 2009; Dimitrova & Borisova, 2003; Hristeva, 2004; Panayotova, 2005; Tomov et al., 2005; Rachovski et al., 2010; Nankov et al., 2014). Takahashi (2007) referring to a continuous fertilizer experiment set up in 1981 on Andosols, found that NP fertilization for 23 years contributed to the highest yield of wheat

Most research on wheat fertilization refers mainly to common wheat and only a limited number of them regard durum wheat, though not to the present-day most widespread intensive varieties. The objective of this study was to assess the effectiveness and risk of long-term (1990-2014) nitrogen-phosphorus fertilization in increasing rates and quantitative proportions on the productivity of durum wheat at a stationary fertilizer trial, carried out at the field of Institute of Field Crops, Chirpan, Bulgaria on soil type *Pellic vertisols* under differing weather conditions.

Material and Methods

The present study analyzes data from long-term fertilizer experiment based in the field of the Institute of Field Crops, Chirpan, with cotton-durum wheat (*Triticum durum* Desf.) crop rotation under non-irrigation conditions for a period of twenty-five growing seasons from 1990 to 2014. The N and P rates for durum wheat Progress were: 0, 40, 80, 120 and 160 $kg.ha^{-1}$. 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 as a top dressing at the end of wheat tillering stage, and phosphorus – before sowing. Block design with four replicates was used. The size of the yield plot was 10 m^2 (2.40 x 4.20 m). The seeds were sown in October 25-30, and the sowing rate was 400 germinated seeds per m^2. Weeds were controlled with herbicides between tillering and shoot elongation. Harvest with plot combine occurred in July10-15. Site-specific agronomic practices for durum wheat were applied.

Data and the regression dependencies between the resultant parameter grain yield and N fertilization were statistically analyzed with the SPSS statistical program and the Duncan's multiple range test ($P \leq 0.05$) to find significant differences among means. The Pearson correlation coefficient was determined.

Most adequate (F test) were regression models of the type: $y = a + bx + cx^2$ where: y – theoretical levels of the resulting indicator and x – factual levels of the factor. All regression coefficients were tested for statistical significance (t-test) at $\alpha = 0.05$.

The soil type of the experimental field was *Pellic vertisols* (FAO) and generally refers to the so-called Mediterranean Chernozems. Based on the humus content, it belongs to the mean humus soils. It is characterized by 0.095-0.14% total N in the arable layer, low content of total phosphorus (0.05-0.11%), poorly to medium supplied with mineral nitrogen, poorly supplied with available phosphorus and well-supplied with available potassium.

Results and Discussions

Comparison of the meteorological conditions in the studied years with the long-term 86-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 the culture. For example, the average rainfall in June of all studied years was 47.3 mm, and it is lower by 20.6 mm compared to the long-term period. The hydro-thermal conditions during the durum 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.

It was found that cultivar Progress realized a grain yield of 3.53 $t.ha^{-1}$ average for 25 years. The grain yields in 2007, 1992 and 1999 were significantly lower compared to the average and the yield was highest in 2001, 1997, 1990 and 1995 (Figure 1). Schulthess et al. (1993) also reported that

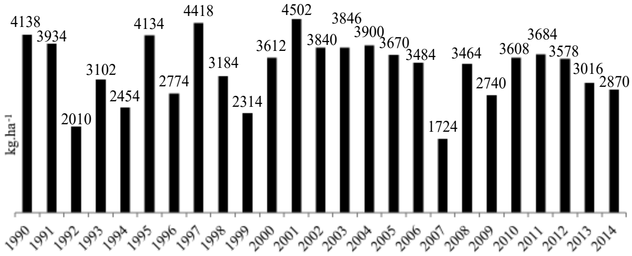

Figure 1. Average grain yield of durum wheat for the 1990-2014 period, kg.ha^{-1}

the N content in grain correlated significantly with the environment conditions. The grain yield without fertilization was lowest in 1999 – 1.03 t.ha^{-1}, and highest – 3.96 t.ha^{-1} in 2001.

As a result of natural soil fertility (without fertilization) the yield was 2.34 t.ha^{-1}. After nitrogen fertilization the yield increased to N_{120} – 4.02 t.ha^{-1}, which exceeded the unfertilized by 17.2%. Annual fertilizing rates of 40 kg/ha were insufficient to realize the durum wheat potential (Table 1). After independent phosphorous fertilization the yield reached up to 2.61 t.ha^{-1} at P_{120}, 11.8% above the unfertilized. The results showed that phosphorus fertilization was a less effective agricultural activity (Table 2). With the increase of the phosphorus rate there was a tendency for yield decrease due to the established good supply of phosphates. At combined fertilization $N_{120-160}P_{80-120}$ the yield increased up to 4.06-4.33 t.ha^{-1} of grain. The highest value was at fertilization with $N_{120}P_{120.}$

Table 1. Grain yield of durum wheat depending on nitrogen fertilization

Nitrogen fertilization	Grain yield, kg.ha^{-1}	Min	Max
0	2337 ± 658.9^{c}	1080	4010
40	2987 ± 546.3^{b}	1860	4350
80	3595 ± 814.2^{a}	2050	5300
120	4018 ± 990.7^{a}	1840	5330
160	3863 ± 1058.3^{a}	1640	5020

Table 2. Grain yield of durum wheat depending on phosphorus fertilization

Phosphorus fertilization	Grain yield, kg.ha^{-1}	Min	Max
0	2337 ± 658.9 b	1080	4010
40	2422 ± 663.2 b	1140	4120
80	2503 ± 727.0 ab	1120	4380
120	2612 ± 748.0 a	1050	4510
160	2522 ± 779.5 a	960	4220

The agronomic efficiency of the applied fertilizer increased to fertilization with N_{80} reaching 173 kg grain per kg N fertilizer. AE decreased to 96 kg grain at high fertilization N_{160} and this fertilization was not economically effective. Fertilization with N rates above 120 kg.ha^{-1} was not effective in years with drought during the spring-summer period. The combination of rich soil fertility with drought and high temperatures during critical development stages depressed plants and reduced grain yield. The variation in yields over the years at the same fertilizing levels was significant. The effect of higher N rates in favourable years was strongly manifested. The rainfall influence was significantly more obvious than temperature.

At phosphorus fertilization, AE was the best at low applied P_{40} – 35 kg grain/kg fertilizer. Fertilization with P_{80} paid off with 30 kg grain/kg.

Dependencies of grain yield and applied N fertilization in durum wheat were not rectilinear (Table 3). As a result of the regression analysis, the modeled dependencies were represented by equations of second degree and were set high values of the coefficients of determination (R^2), which were in the range from 0.620 (1993) to 0.997 (2011). The regression model showed that the increase in grain yield depending on nitrogen fertilization was slow delayed during all harvest years without exception, as well as an average for the period 1990 – 2014. The expected average grain yield of durum wheat without fertilization for the 25-year study was 2286 kg.ha^{-1}. On average for the period, it was possible to obtain an additional 231 kg grain per kilogram of applied nitrogen fertilizer. The regression model of nitrogen fertilization showed that without nitrogen fertilization can be expected grain yields of up to 1.50 t.ha^{-1} in 4 of the years; 1.50-2.00 t.ha^{-1} in 5 of the years; 2.00-2.50 t.ha^{-1} in 6 of them; 2.50-3.00 t.ha^{-1} in 8 of the experimental years and over 3.00 t.ha^{-1} in 2 of the years. The expected grain yield without fertilization was the lowest – 1031 kg.ha^{-1} in 1999 and highest -3956 kg.ha^{-1} in 2001. For the studied 25-year period only in the very dry 1994, the yield of non-fertilized variant was higher than the yields of nitrogen fertilized variants.

According to the standard interpretation of regression coefficients in a second degree polynomial, any increase in the amount of nitrogen fertilizer with one kg per hectare will lead to an increase in grain yield with 30 kg in seven years of the study period. In 9 years the additional grain yield for every kilogram of fertilizer nitrogen was under 20 kg and in the remaining eight years one kilogram of fertilizer nitrogen resulted in production of 20-30 kg additional grain yield of durum wheat.

Dependencies of durum wheat grain yield on phosphorus fertilization were not straight, similar to the relationship be-

Table 3. Regression model of nitrogen fertilization and grain yield of durum wheat

Years	Equation	Coefficient of determination
1990	$y = 2423 + 365x – 12.5x^2$	$R^2 = 0.947$
1991	$y = 2415 + 300x – 9.2x^2$	$R^2 = 0.957$
1992	$y = 1463 + 193x – 10.4x^2$	$R^2 = 0.989$
1993	$y = 2944 + 55x – 2.9x^2$	$R^2 = 0.620$
1994	$y = 2984 – 454x – 1.7x^2$	$R^2 = 0.967$
1995	$y = 2671 + 285x – 8.5x^2$	$R^2 = 0.857$
1996	$y = 1828 + 211x – 7.7x^2$	$R^2 = 0.965$
1997	$y = 2856 + 437x – 20.2x^2$	$R^2 = 0.918$
1998	$y = 1487 + 256x – 3.7x^2$	$R^2 = 0.942$
1999	$y = 1031 + 239x – 6.6x^2$	$R^2 = 0.945$
2000	$y = 2098 + 248x – 4.9x^2$	$R^2 = 0.987$
2001	$y = 3956 + 145x – 6.4x^2$	$R^2 = 0.895$
2002	$y = 2272 + 323x – 10.6x^2$	$R^2 = 0.966$
2003	$y = 1850 + 369x – 0.2x^2$	$R^2 = 0.959$
2004	$y = 3053 + 111x – 0.4x^2$	$R^2 = 0.991$
2005	$y = 2686 + 183x – 5.0x^2$	$R^2 = 0.948$
2006	$y = 1881 + 303x – 8.5x^2$	$R^2 = 0.996$
2007	$y = 1244 + 177x – 9.7x^2$	$R^2 = 0.925$
2008	$y = 1984 + 286x – 8.4x^2$	$R^2 = 0.992$
2009	$y = 2231 + 142x – 6.5x^2$	$R^2 = 0.823$
2010	$y = 2696 + 215x – 8.4x^2$	$R^2 = 0.971$
2011	$y = 1877 + 343x – 9.8x^2$	$R^2 = 0.997$
2012	$y = 2566 + 186x – 5.0x^2$	$R^2 = 0.981$
2013	$y = 2034 + 275x – 12.7x^2$	$R^2 = 0.968$
2014	$y = 2634 + 149x – 10.1x^2$	$R^2 = 0.790$
Average 1990-2014	$y = 2286 + 231x – 8.1x^2$	$R^2 = 0.982$

tween grain yield and applied N fertilization (Table 4). Data from the regression analysis and modeling dependencies were represented by equations of second degree. In four of the examined years (1992, 1994, 1995 and 2010) the determination coefficient R^2 was in range from 0.410 to 0.511, in nine years R^2 ranged within 0.625-0.897, and for the other twelve years a very high coefficient of determination was estimated – 0.925-0.999 of regression dependence of the grain yield and the studied levels of P_0, P_{40}, P_{80} и P_{120} of durum wheat fertilization. A high coefficient of determination was established average for the period with value $R^2 = 0.889$. The regression model on average for the period 1990-2014 and for nineteen of the studied years indicated that the increase in grain yield depending on phosphorus fertilization was delayed. An expected average yield of 2321 $kg.ha^{-1}$ from durum wheat without phosphorus fertilization can be obtained. The effect of one kilogram imported fertilizing phosphorus on average over the 25-year period resulted in a 37.1 kg additional grain yield. Expected grain yields without P fertilization varied over a wide range from 1070 $kg.ha^{-1}$ in 1999 to 3953 $kg.ha^{-1}$ in 2001. Analysis of the data indicated that only in three of the harvest years (1997, 2001 and 2004) without fertilization can be expected grain yields higher than 3000 $kg.ha^{-1}$. In eight years without phosphorous fertilization can be expected yields of 2500 to 3000 $kg.ha^{-1}$, and in the other fourteen harvest years the elimination of P fertilization results in yields lower than 2500 kg grain per hectare. According to the standard interpretation of regression coefficients in a second degree polynomial, any increase in fertilizer by one kilogram will increase grain yield by more than 100 kg during the two harvest years – 1993 and 2006. In the six years additional grain yield for each kilogram of imported phosphorus was in the range 50-100 kg and in the remaining seventeen years the effect of 1 kg imported phosphorus was expected to produce less than 50 kg additional grain yield of durum wheat.

Table 4. Regression model of phosphorus fertilization and grain yield of durum wheat

Years	Equation	Coefficient of determination
1990	$y = 2581+ 58x + 0.4x^2$	$R^2 = 0.999$
1991	$y = 2571 – 17.0x + 4.3x^2$	$R^2 = 0.925$
1992	$y = 1427 + 12.3x – 0.1x^2$	$R^2 = 0.410$
1993	$y = 2796 + 108.4x – 5.6x^2$	$R^2 = 0.679$
1994	$y = 2969 – 26.8x + 1.4x^2$	$R^2 = 0,511$
1995	$y = 2914 + 32.6x – 2.3x^2$	$R^2 = 0.494$
1996	$y = 1781 + 21.2x + 0.2x^2$	$R^2 = 0.968$
1997	$y = 3038 + 30.6x – 1.7x^2$	$R^2 = 0.625$
1998	$y = 1570+ 25.7x – 0.3x^2$	$R^2 = 0.931$
1999	$y = 1070 + 26.5x – 1.8x^2$	$R^2 = 0,697$
2000	$y = 2172 + 13.6x + 1.3x^2$	$R^2 = 0.941$
2001	$y = 3953 + 86.6x – 4.1x^2$	$R^2 = 0.796$
2002	$y = 2421 + 22.6x – 0.4x^2$	$R^2 = 0.897$
2003	$y = 2035 + 21.1x – 0.4x^2$	$R^2 = 0.943$
2004	$y = 3031+ 40.7x – 0.2x^2$	$R^2 = 0.941$
2005	$y = 2756 + 40.4x – 0.1x^2$	$R^2 = 0.958$
2006	$y = 1782 + 125.8x – 6.4x^2$	$R^2 = 0.704$
2007	$y = 1191 + 1.6x – 1.0x^2$	$R^2 = 0.991$
2008	$y = 1971 + 59.1x – 4.1x^2$	$R^2 = 0.957$
2009	$y = 2309 + 79.3x – 6.3x^2$	$R^2 = 0.929$
2010	$y = 2630+ 53.5x – 3.1x^2$	$R^2 = 0.417$
2011	$y = 1868 + 24.4x – 0.6x^2$	$R^2 = 0.838$
2012	$y = 2495 + 75.1x – 4.1x^2$	$R^2 = 0.926$
2013	$y = 1963 + 50.1x – 2.3x^2$	$R^2 = 0,756$
2014	$y = 2719 – 38.6x + 1.7x^2$	$R^2 = 0.813$
Average 1990-2014	$y = 2321+ 37.1x – 1.4x^2$	$R^2 = 0.889$

Conclusions

NP-fertilization exerted high influence on productivity of durum wheat. Without fertilization the yield was 2.34 $t.ha^{-1}$. At N fertilization the yield increased to N_{120}, which exceeded the unfertilized by 17.2%. With independent phosphorus fertilization the yield reached up to 2.61 $t.ha^{-1}$ at P_{120}, which is 11.8% above the unfertilized. With the increase of the phosphoric rate there was found a tendency for yield decrease due to the established good supply of phosphates. With combined fertilization, the grain yield increased to 4.06-4.33 $t.ha^{-1}$ at $N_{120-160}P_{80-120}$. The highest value was for fertilization with $N_{120}P_{120}$. The agronomic efficiency of the applied fertilizer increased to N_{80} reaching 173 kg grain/kg N. AE decreased to 96 kg **at** a high rate of N_{160}. At phosphorus fertilization with low applied P_{40}AE was best – 35 kg grain/kg fertilizer. Fertilizing with P_{80} paid off with 30 kg grain. The regression model showed that without N fertilization can be expected grain yields of up to 1.50 $t.ha^{-1}$ in 4 of the years; 1.50-2.00 $t.ha^{-1}$ in 5 of the years; 2.00-2.50 $t.ha^{-1}$ in 6 of them; 2.50-3.00 $t.ha^{-1}$ in 8 of the experimental years and over 3.00 $t.ha^{-1}$ in 2 of the years.

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