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33-YEAR OLD GRAIN YIELD FROM *Triticum durum* Desf. AFFECTED BY MINERAL FERTILIZATION WITH NITROGEN AND PHOSPHORUS

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Abstract

The long-term 33-year study was aimed at clarifying the impact of mineral fertilizers under the influence of different weather conditions. The experiment was conducted at the Field Crops Institute, Chirpan, Bulgaria. The data presented in this article are for the period 1990-2022 (33 consecutive years). The following nitrogen (N) and phosphorus (P) rates were applied: 40, 80, 120 and 160 kg ha^{-1}. Each fertilizer rate was introduced alone and in combinations (25 variants). All fertilization rates were compared to non-fertilized variant (N_0P_0). The results showed that the conditions of the year (47.87% of the total variation) and fertilization (33.40% of the total variation) have a significant influence on the productivity of durum wheat. Furthermore, we reported that nitrogen fertilization had a stronger effect than phosphorus, but combined fertilization at the $N_{120}P_{120}$ rate had the highest grain yield. The correlation coefficient (R=0.897) and the coefficient of determination (R^2=0.805) were proven. Through second-order polynomial equations, it was found that the optimum fertilization rate was in the range of 120-130 kg N ha^{-1}.

***Key words**: grain yield, nitrogen, phosphorus, triticum durum.*

INTRODUCTION

For millennia, durum wheat has been an indispensible part of people's daily diet. The written history of wheat science began 2500 years ago when Greek botanist Theophratus (371-287 BC) wrote the study "Enquiry into Plant's" (Xynias et al., 2020). Wheat was introduced into the Balkan Peninsula through migrations from Anatolia in the Neolitic area (Velimirovic et al., 2023). In Bulgaria it is a traditional crop that serves as a material for the production of pasta and is dispensable in this respect from common wheat (Dragov, 2022). In the past (unit 1943) in Bulgaria, the production of durum wheat grain amounted to 550-850,000 tons. However, farmers' interest in this crop is declining with the development of high-yield varieties of bread wheat, and the cultivation of durum wheat remains in the background. At the end of the 1980s, there was grain an increase in interest and areas for cultivation. According to data from the Ministry of Agriculture and Food (2022) the total area sown with durum wheat in Bulgaria in 2022 was 8,962 ha, while the area sown with bread wheat was 1,208,457 ha. Wheat crops occupy about 218 million acres and account for 1/3 of the worlds' cereal production, with 771 million tons of production per year that satisfies the demand of 21% to 36% of the world's population (Ltaief & Krouma, 2023). While globally minor, accounting for less than 7% of the total wheat produced worldwide, it is concentrated in relatively small geographic regions where it can be considered as a main cereal crop, contributing significantly to food production and agricultural income (Martinez-Moreno et al., 2022).

The need to study agrocenosis as a system with interacting components to identify function relationship and find the way to manage them led to the appearance of long-term field experiments more than 175 years ago (Romanenkov et al., 2020). Most of the older experiments were started to provide information on the amounts of nutrients and forms of fertilizer to use to increase crop yield (Jhonston & Poulton, 2018). These field trials provide valuable information on long-term crop production in a particular climate zone. Long-term experiments provide of the means to measure sustainable management systems of agriculture (Patel et al., 2021). Challenges unique to a long-term experiment are discussed, including maintaining relevance to current farming issue, human error, and how changes have been implemented while maintaining the historic experiment treatments (Brooker et al., 2020). In recent decades, have attempted to developed various methods to optimize the application rate of chemical fertilizer to solve the associated economic and environmental problems caused by improper application (Hu et al., 2023). Results obtain from long-term experiments have already substantially improved our knowledge on changes in soil productivity with various fertilization practices (Cai & Qin, 2006). Also, long-term field experiments with different fertilization regimes can provide a good way to separate the impact of climate and soil properties and crop yields (Wei et al., 2021).

In the natural environment, plants often face unfavorable factors affecting their growth and production (Zuluaga et al., 2023). Ambient temperatures and precipitation are some of these factors that cannot be adjusted. The main purpose of nutrient application is to increase the level of soil fertility and crop yield (Azeem et al., 2023). Furthermore, farmers have prioritized grain yield over grain quality, with large amounts of chemical fertilizers being used to increase grain production (Song et al., 2022). Nitrogen (N) is one of the most important essential nutrients in regular in crop physiological processes and determining grain yield (Li et al., 2022). Nitrogen is an element that has greatest influence on the vegetative growth of the plant, photosynthetic capacity and yield (Lalevic et al., 2019). The world applies more than 120 million tons of nitrogen fertilizer every year (Zhao et al., 2023). Given that 15 kg N ha^{-1} is lost at optimal N levels, farmers are probably used to spreading more N fertilizer than necessary to increase grain yield (Sarker et al., 2023). However Xing et al. (2023) warn that excessive blind application of N will fail to achieve the expected yield, and it will increase cultivation costs and decrease grower incomes. One of the main reasons for limited yield and grain quality is the lack of knowledge in nitrogen fertilization practice (Boulelouah et al., 2022). Valuable information can be derived from long-term field experiments with different fertilization rates on the impact of synthetic fertilizers, with some of the most important issues being related to soil microbiota, groundwater and CO_2 emissions. Of course, for scientists in the field of crop production, the question of grain production in quantitative terms and the optimal nitrogen rate remains the most important.

The production of crops for food requires an adequate supply of phosphorus (P) in soil (Khan et al., 2018). P is vital for the growth of crops from seed to the harvest (Rehim et al., 2018). The authors add that it is essential for the transformation of energy and plays an important role in different metabolic processes in plants. Thus, in fear for P deficiency, excess P fertilizers are routinely applied by farmers for producing wheat (Mihoub et al., 2019). The authors add that, however, wheat plants take up and use a small amount of applied phosphorus. Indeed, the greater part of P remains in insoluble form in soil and, hence, unavailable for the plant (Cherchali et al., 2019). Moreover, Sanchez-Rodriguez et al. (2021) estimated that <20% of all added P remained available to plants. For this reason, improvement in phosphorus management is of high priority (Kominko et al., 2019). Long-term experiment, rather than short-term ones are valuable for accurately assessing P-use efficiency (Khan et al., 2018). Unlike nitrogen, which can be restored by air fixation, phosphorus cannot be replenished without external sources (Arsad et al., 2022). For this the optimum rate of phosphorus is important for grain yield improving (Lalevic et al., 2019).

The excess of the unused nutrients gets into ground and surface water as well as to the atmosphere (Piwowar, 2021). So increasing the use of fertilizers will cause more and more problems for the environment in the world in future (Ejraei, 2021). Agricultural policies aiming at lowering environmental impacts by limiting nutrient impost are a main reason for the stagnating yield increase in Europe countries (Kirchmann et al., 2020). Therefore, our long-term 33-year study was aimed at clarifying the impact of mineral fertilizers under the influence of different weather conditions, as well as comparing different fertilizer rates of nitrogen and phosphorus applied alone and in combinations.

MATERIALS AND METHODS

Experimental location and experimental design

The study was started as a multi-year fertilizer experiment in 1966 at the Field Crops Institute, Chirpan, Bulgaria (42°11'58"N, 25°19'27"E). The data presented in this article was from 1990-2022 (33 consecutive years). The experiment was a complete randomized block design with 4 replications. Each plot was 10 m^2 in size and was separated from the neighboring one by concrete slabs in the soil at a depth of two meters to prevent the passage of the imported mineral fertilizers. The experiment included the following rates of nitrogen (N) and phosphorus (P): 40, 80, 120 and 160 kg ha^{-1}. Each fertilizer rate was applied individually and in combinations as follows: $N_{40}P_{40}$, $N_{40}P_{80}$, $N_{40}P_{120}$, $N_{40}P_{160}$, $N_{80}P_{40}$, $N_{80}P_{80}$, $N_{80}P_{120}$, $N_{80}P_{160}$, $N_{120}P_{40}$, $N_{120}P_{80}$, $N_{120}P_{120}$, $N_{120}P_{160}$, $N_{160}P_{40}$, $N_{160}P_{80}$, $N_{160}P_{120}$, and $N_{160}P_{160}$. All fertilization rates were compared with a non-fertilized variant (N_0P_0). Phosphorous fertilizer (triple superphosphate) was incorporated with the last discing of the soil before sowing durum wheat. Nitrogen (ammonium nitrate) was applied in the tillering phase as an early spring top dressing.

Soil analysis

The soil type was *Pellic Vertisols*. In a depth of up to 20 cm there was a high content of humus - 3.85%, and it decreased to 1.9% in the 80-100 cm layer. Total carbonates were below 5% in the deep layers. The salt content was negligible. This shows that the soil have good drainage and there is no danger of a negative impact on the wheat. The soil reaction varies from 6.5 to 7.4 pH and allows the introduction of all types of mineral fertilizers. At a depth of 30 cm, the soil had the following characteristics regarding macronutrients: well stocked with total nitrogen, as in the form of $N\text{-}NH_4^+$ it was 3.2-3.6 kg ha^{-1}, and in the form of $N\text{-}NO_3^-$ – 2.8-3.2 kg ha^{-1}; the amount of P_2O_5 was 6.1 mg/100 g soil, with a large part of phosphorus bound in the form of primary phosphorus minerals, hardly soluble and poorly available to plants. The potassium content was significant at 24.1 mg/100 g soil.

Meteorological data sources

Bulgaria is divided into five climate zones, and the place of the experiment is qualified for the transitional-continental climate zone. Regarding temperature totals during the wheat growing season, seven of the observed years were very warm (2007, 2009, 2013, 2016, 2019, 2020, and 2022), five years were warm, eight years were moderately warm, seven years were normal, three years were moderately cool and three years (1993, 1996 and 2006) were cold (Figure 1). According to the amount of precipitation, the years studied

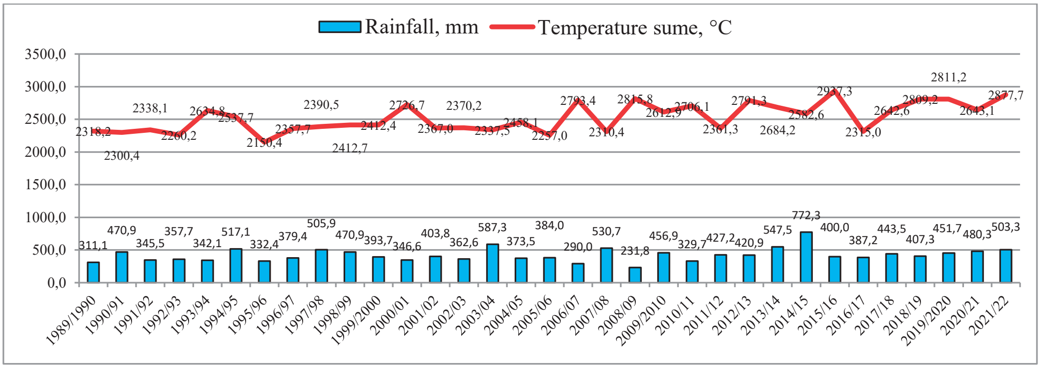

Figure 1. Temperature sum (°C) and precipitation (mm) during wheat vegetation for period 1990-2022

were: very wet (2004, 2015 and 2022); wet (1998, 2008, 2014 and 2018); moderately wet (1991, 1999, 2010, 2012, 2013 and 2017); moderately wet (1995, 2019, 2020 and 2021); moderately dry (1997, 2000, 2002, 2005, 2006 and 2016); dry (1992, 1993, 1994, 1996, 2001 and 2003); very dry (1990, 2007, 2009 and 2011).

Statistical analysis

A one-way ANOVA was used to analyze the differences between fertilization rates and combinations on average over the years of the study. For this purpose, each year was treated as a repetition. Comparisons were performed using least significant difference (LSD) ($P \leq 0.01$). The regression model was done using Statistica 13.

RESULTS AND DISCUSSIONS

The total variance presented in Table 1 revealed a statistically significant influence of both mineral fertilization and year conditions on grain yield (GY) formation. Moreover, the influence of weather conditions has a stronger effect (47.87% of the total variation) than mineral fertilization (33.40% of the total variation). However, year and fertilization were equally statistically significant at $p \leq 0.001$.

On average, over a 33-year period, durum wheat realized a grain yield of 2,346 kg ha^{-1} without fertilization (Figure 2). When nitrogen fertilization was included, there was a tendency to increase the values up to the rate of 120 kg N ha^{-1} (3,987 kg ha^{-1}). Increasing N to 160 kg ha^{-1} resulted in lower GY – 3,795 kg ha^{-1}, respectively. Phosphorous fertilization had a weak and unproven effect on the formation of grain yield. Moreover, when P_{40} was applied, GY was lower than the control.

Table 1. Analysis of variance for durum wheat grain yield under NP fertilization, 1990-2022

Source of variation	df	Sum of squares	Sum of squares, %	Mean squares	F
Total	824	1.037,193E+09	100		
Year	32	4.964,956E+08	47.87***	1.551,549E+07	61.33
Mineral fertilization	24	3.464,038E+08	33.40***	1.443,349E+07	57.05
Error	768	1.942,938E+08	18.73	252,986.7	

, * – significant at p≤ 0.01 and p≤ 0.001 level of probability, respectively

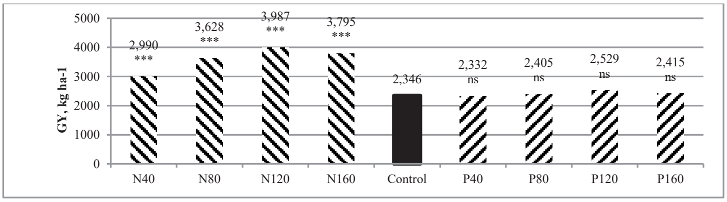

Figure 2. Durum wheat grain yield under nitrogen-phosphorus fertilization, 1990-2022

The GY data showed that all N and P combinations tested had a statistically confirmed effect (Table 2). Analysis of 33 years of durum wheat fertilization showed that phosphorus had no significant effect even in combination with N. Therefore, nitrogen fertilization plays a major role in grain formation. The lowest GY was reported when fertilizing with $N_{40}P_{160}$ – 3,100 kg ha^{-1}. An increase in grain was observed with increasing N dose up to 120 kg ha^{-1} and with the strongest effect on GY formation was fertilization with $N_{120}P_{120}$ – 4,229 kg ha^{-1}. Exceeding this fertilization threshold resulted in a decrease in values.

Since nitrogen fertilization had a major effect, the variation of GY under the influence of N was described by second-order polynomial equations (Figure 3). The correlation coefficient (R = 0.897) and the coefficient of determination ($R^2 = 0.805$) were proven. The GY curve showed that the optimum fertilization rate was in the range of 120-130 kg N ha^{-1}.

Table 2. Durum wheat grain yield (kg ha^{-1}) at NP fertilization, 1990-2022

Fertilizer rate	N_{40}	N_{80}	N_{120}	N_{160}
P_{40}	3,143***	3,835***	4,100***	3,968***
P_{80}	3,144***	3,926***	4,187***	4,081***
P_{120}	3,192***	3,939***	4,229***	4,001***
P_{160}	3,100***	3,893***	4,061***	4,002***
LSD 5%, 1%, 0.1% = 243.1; 319.8; 409.0				

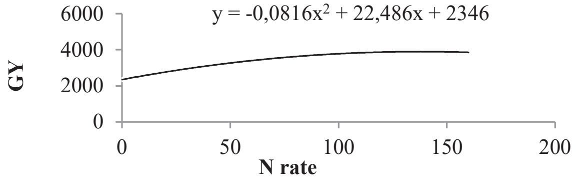

Figure 3. Relationship between wheat grain yield and nitrogen rate

Climate change is a major challenge for the world economy, especially for the agricultural sector, where climate conditions strongly and directly influence crop yields (Rapacz et al., 2022). This statement fully coincides with the results of Table 1 of the total variance for a reliable and strong influence of years on GY, as well as the results obtained by Mangini et al. (2021). The authors reported that ANOVA confirmed the influence of year conditions. Zhang et al. (2018) reported that there was a large interannual variability within the same treatment, which was mainly due to rainfall during the growing season. Application of mineral fertilizers acted as a stabilizing element that reduced the degree of yield inter-annual variability (Hlisnikovsky et al., 2023). This explains the high reliability of applied mineral fertilization and the high percentage of impact from the total variance. In a long-term fertilization experiment started in 2007, a strong effect of year (**) was observed, but fertilization had a stronger effect (***) (Zhang et al., 2019), which was contrary to the results of this research.

Efficient nitrogen fertilizer management is critical for wheat production and the long-term protection of the environment (Tedone et al., 2018). The results obtained in this study for a decrease in GY with increasing N rate (Figure 2) were also reported in other studies. For example, Abera et al. (2021) reported that bread wheat GY was highest when fertilized with 92 kg N ha^{-1} and increases above this rate indicated lower yield. Chen et al. (2022) obtained 1,933 kg ha^{-1} GY from N_{65} fertilization, but increasing N to 135 kg ha^{-1} reduced GY to 1,779 kg ha^{-1}. From 20 years of fertilization, Wei et al. (2021) reported that wheat yield showed significantly decreasing trends with N alone treatment. According to Kizilgeci et al. (2021) this may be due to the higher amount of N application causing more vegetative growth (more succulent leaves and taller strems) which delayed the reproductive growth and ultimately led to suboptimal reproductive yield attributes. Shuklina et al. (2021) even reported the highest GY under the influence of the low nitrogen rate studied (N_{60}) – 3.70 t ha^{-1}, while at the highest dose included in the study (N_{150}) GY decreased to 3.62 t ha^{-1}. However, this trend does not necessarily hold. For example, Mondal et al. (2022) observed that increasing the N rate from 0 to 140 kg ha^{-1} resulted in an increase in GY and Ayadi et al. (2022) confirm the increase in values. Moreover, the authors reported that GY under the influence of N_{75} was significantly different from N_{150}, 3.4 t ha^{-1} and 5.7 t ha^{-1}, respectively. In other cases, as in the study by Tedone et al. (2018), increasing nitrogen rate increased GY, but the difference in grain between low and high fertilization rates was small. Staugaitis et al. (2022) reported that high nitrogen fertilizer rates (N_{180} and N_{240}) had no difference in terms of GY, 7.39 t ha^{-1} and 7.31 t ha^{-1}, respectively. This confirms the assertion of Guerrero et al. (2021) that plant response to N is limited by a threshold, N fertilization above this level does not further increase yield.

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world (Awulachew, 2019). In the study conducted, P fertilization had a weak and insignificant effect (Figure 2). This result confirms the claim of Gao & Grant (2012) that there was no statistically significant effect on grain yield of different P fertilization rates. Similar results can be found in the studies of Lakew (2019) and Chen et al. (2020) in bread wheat. In contrast to these results, Arsad et al. (2022) reported that P fertilization increased GY values proportionally with increasing rate. From the unfertilized control, the authors obtained a grain yield of 2,220 kg ha^{-1}, and at the highest P dose tested (60 kg ha^{-1}) GY was 3,523 kg ha^{-1}. Chen et al. (2019) from a 3-year study on the influence of phosphorus self-application obtained similar results. Arbacauskas et al. (2021) reported that 49 years of P fertilization resulted in soil P accumulation. Continuous application of inorganic P-fertilizer leads to significant accumulation of available P in the soil (Vishwanath et al., 2020). This accumulation may account for inefficient P fertilization. If sufficient resources are available in the soil, the effect of applying a given nutrient cannot be accounted for.

The data from table 2 clearly show that the formation of grain yield was influenced to the greatest extent by nitrogen fertilization. Both in single and combined fertilization, the dose of 120 kg N ha^{-1} has the strongest impact. Above this rate, grain yield decreases. Eshetu et al. (2022) observed the same response in bread wheat. The authors reported that GY increased up to $N_{46}P_{40}$ (7,018.6 kg ha^{-1}), but when fertilization increased to $N_{69}P_{50}$, GY was lower by 1,355.2 kg ha^{-1} (5,663.4 kg ha^{-1}). This result was also confirmed by the mathematical model in Figure 3 from the regression equation, where it can be seen that the rate of 120-130 kg N ha^{-1} was optimal. Although P fertilization did not significantly affect GY in this study, Tudor et al. (2023) reported that phosphorus fertilizers aided plant rooting by increasing N efficiency. This statement was in sync and fully explained the results of this study. However, as a one of the essential nutrient element in the process of plant growth and development, nitrogen contributes 40-50% to the final yield (Chen et al., 2022).

CONCLUSIONS

In this study, special attention was paid to durum wheat grain yield affected by the long-term application of mineral nitrogen and phosphorus fertilizers (33 consecutive years). The results showed that the conditions of the year (47.87% of the total variation) and fertilization (33.40% of the total variation) had a significant influence on the productivity of wheat. Furthermore, we reported that nitrogen fertilization had a stronger effect than phosphorus, but combined fertilization at the $N_{120}P_{120}$ (4,229 kg ha^{-1}) rate had the highest grain yield. The regression model showed that the optimal fertilization rate was in the range of 120-130 kg N ha^{-1}.

REFERENCES

Azeem, K., Inamullah, Naz, F., Nadeem, F., Jhanzab, H. M., Sher, A., Bibi, Y., Syed, A., Bahkali, A. H., Elgorban, A. M., Hussain, M., & Qayyum, A. (2023). Deciphering of microbes × nitrogen source fertilizers interaction for improving nitrogen use efficiency in spring maize. *J. of King Saud Uni. – Sci.*, 35(4): 102633. https://doi.org/10.1016/j.jksus.2023.102633

Ayadi, S., Jallouli, S., Chamekh, Z., Zouari. I., Landi, S., Hammami. Z., Azaiez, F. E. B., Baraket, M., Esposito S., & Trifa, Y. (2022). Variation on grain yield, grain protein content and nitrogen use efficiency components under different nitrogen rate in Mediterranean durum wheat genotypes. *Agriculture*, 12**:** 916. https://doi.org/10.3390/agriculture12070916

Abera, T., Lemma, A., Hundesa, Ch., Husen, A., & Firomsa, T. (2021). Response of yield components and yield of bread wheat to blended NPS and N fertilizer levels at Liban Chukala district, East Shewa Zone, Oromia, Ethiopia. *Int. J. of Res. and Inn. in Earth Sci.*, 8(1): 2394-1375.

Arsad, M. K., Mandal, B. K., Kashive, A. V., & Gupta, A. (2022). Effect of phosphatic fertilizer on growth, yield and uptake of nutrients of wheat crop (*Triticum durum* L.). *The Ph. Inn. J.*, 11(7): 2393-2395.

Arbacauskas, J., Maseviciene, A., Staugaitis, G., Zickiene, L., Sumskis, D. & Vaisvila, Z. (2021). The influence on long-term fertilization on phosphorus dynamic in the soil. *Zemd.-Agr.*, 108(3): 195-202. DOI: 10.13080/z-a.2021.108.025

Awalachew, M. T. (2019). Effects of blanded fertilizer (nitrogen, phosphorus, sulfur and boron) rate on yield, yield components and grain quality of crop (Durum Wheat). *Acta Sci. Agri.*, 3(11): 91-99.

Boulelouah, N., Berbache, M. R., Bedjaoui, H., Selama, N., & Rebouh, N. R. (2022). Influence of nitrogen fertilizer rate on yield, grain quality and nitrogen use efficiency on durum wheat (*Triticum durum* Desf) under Algerian semiarid conditions. *Agriculture*, 12: 1937. https://doi.org/10.3390/agriculture12111937

Brooker, T., Poole, N., Chynoweth, R., Horrocks, A., Rolston, Ph., & Pyke, N. (2020). Challenges of maintaining relevance to current agricultural issue in a long-term cropping establishment experiment in Canterbury, New Zealand. *Long-Term Farm. Sys. Res.*: 71-87. https://doi.org/10.1016/B978-0-12-818186-7.00005-9

Chen, Ch., Zhou, Sh., Afshar, R. K., Franck, W., & Zhou, Y. (2022). Durum wheat yield and protein influenced by nitrogen management and cropping rotation. *J. of Pla. Nut.* https://doi.org/10.1080/01904167.2022.2068432

Chen, Y., Zhang, P., Wang, L., Ma, G., Li, Z., & Wang, Ch. (2020). Interaction of nitrogen and phosphorus on wheat yield, N use efficiency and soil nitrate nitrogen distribution in the North China *Plain. Int. J. Plant Prod*. https://doi.org/10.1007/s42106-020-00093-6

Chen, X., Zhang, W., Liang, X., Liu, Y., Xu, Sh., Zhao, Q., Du, Y., Zhang, L., Chen, X., & Zou, Ch. (2019). Physiological and developmental traits associated with the grain yield of winter wheat as affected by phosphorus fertilizer management. *Sci. Rep.*, 9: 16580. https://doi.org/10.1038/s41598-019-53000-z

Cherchali, A., Boukhelata, N., Kaci, Y., Abrous-Belbacir, O. & Djebbar, R. (2019). Isolation and identification of a phosphate-solubilizing *Paenibacillus polymyxa* strain GOL 0202 from durum wheat (*Triticum durum* Desf.) rhizosphere and its effect on some seedling morphophysiological parameters. *Biocat and Agri. Biotech.*, 19: 101087. https://doi.org/10.1016/j.bcab.2019.101087

Cai, Z. C., & Qin, S. W. (2006). Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Huai-Hai of China. *Geoderma*, 136(3-4): 708-715. https://doi.org/10.1016/j.geoderma.2006.05.008

Dragov, R. (2022). Establishment of phenotypic correlations and genetic distance in a diallel cross of durum wheat. *Sci. P. Ser A. Agromony*, LXV(2): 193-200.

Eshetu, M., Abegeja, D., Gosa, R. Ketama, T., Getachew, G., & Chibsa, T. (2022). Soil test based crop response phosphorus calibration study for bread wheat production in Sinana District of Bale Zone, Southeastern Ethiopia. *Int. J. of Scie. and Qual. Anal.*, 8(1): 1-12. DOI: 10.11648/j.ijsqa.20220801.11

Ejraei, A. (2021). Quantitative recommendation of phosphorus fertilizer based on the correlation between phosphorus of plant organs and soil phosphorus in Washington Navel Oranges. *Res. Squ.* https://doi.org/10.21203/rs.3.rs-512234/v1

Guerrero, A., De Neve, S., & Mouazen, A. M. (2021). Data fusion approach for map-based variable-rate nitrogen fertilization in barley and wheat. *Soil and Till. Res.*, 205: 104789. https://doi.org/10.1016/j.still.2020.104789

Gao, X., & Grant, C. A. (2012). Cadmium and zink concentration in grain of durum wheat in relation to phosphorus fertilization, crop sequence and tillage management. S*oil Man. for Sust. Agric.* https://doi.org/10.1155/2012/817107

Hlisnikovsky, L., Mensik, L., & Kunzova, E. (2023). Development and the effect of weather and mineral fertilization on grain yield and stability of winter wheat following Alfalfa-Analysis of long-term field trail. *Plants*, 12(6): 1392. https://doi.org/10.3390/plants120613392

Hu, J., Yang, Y., Zhang, H., Li, Y., Zhang, Sh., He, X., Huang, Y., Ye, Y., Zhao, Y., & Yan, J. (2023). Reduction in nitrogen rate and improvement of nitrogen use efficiency without loss of peanut yield by regional mean optimal rate of chemical fertilizer based on a multi-site field experiment in the North China Plain. *Plants*, 12(6): 1326. https://doi.org/10.3390/plants12061326

Jhonston, A. E., & Poulton, P. R. (2018). The importance in log-term experiments in agriculture: their management to ensure continued crop production and soil fertility; the Rothamsted experience. *Eur. J. of Soil Sci.*, 69: 113-125. https://doi.org/10.1111ejss.12521

Kizilgeci, F., Yilderim, M., Islam, M. S., Ratnasekera, D., Iqbal, M. A., & Sabagh, A. E. (2021). Normalized difference vegetation index and chlorophyll content for precision nitrogen management in durum wheat cultivars under semi-arid conditions. *Sustainability*, 13(7): 3725. https://doi.org/10.3390/su13073725

Kirchmann, H., Börjesson, G., Bolinder, M., Kätterer, Th., & Djodjic, F. (2020). Soil properties currently limiting crop yield in Swedish agriculture – An analysis of 90 yield survey districts and 10 long field experiments. *Eur. J. of Agr.*, 120: 126132. https://doi.org/10.1016/j.eja.2020.126132

Kominko, H., Gorazda, K., & Wzorek, Z. (2019). Potentiality of sewage sludge-based organo-mineral fertilizer production in Poland considering nutrient value, heavy metal content and phitotoxicity for rapeseed crops. *J. of Env. Man.*, 248. https://doi.org/10.1016/j.jenvman.2019.109283

Khan, A., Lu, G., Ayaz, M., Zhang, H., Wang, R., Lv, F., Yang, X., Sun, B. & Zhang, Sh. (2018). Phosphorus efficiency, soil phosphorus dynamics and critical phosphorus level under long-term fertilization for single and double cropping system. *Agr., Eco. and Env.*, 256: 1-11. https://doi.org/10.1016/j.agee.2018.01.006

Ltaief, S. & Krouma, A. (2023). Functional dissection of the physiological traits promoting durum wheat (*Triticum durum* Desf.) tolerance to drought stress. *Plans*, 12(7): 1420. https://doi.org/10.3390/plant12071420

Li, Y., Chen, J., Tian, L., Shen, Zh., Amby, D. B., Liu, F., Gao, Q., & Wang, Y. (2022). Seedling-stage deficit irrigation with nitrogen application in tree-year field study provides guidance from improving maize yield, water and nitrogen use efficiency. *Plants*, 11: 3007. https://doi.org.10.3390/plants11213007

Lakew, A. (2019). Influence of N and P fertilizer rates on yield and yield components of bread wheat (*Triticum aestivum* L.) in Sekota District of Wag-Himira Zone, North Eastern Ethiopia. *Arch. of Agr. and Env. Sci.*, 4(1): 8-18. https://doi.org/10.26832/24566632.2019.040102

Lalevic, D., Biberdzic, M., Ilic, Z., Milenkovic, L., Tmusic, N., & Stojilkovic, J. (2019). Effect of cultivars and increased nitrogen quantities on some productive traits of triticale. *Agri. and For.*, 65(4): 127-136. DOI: 10.17707/AgricultForest.65.4.11

Martinez-Moreno, F., Ammar, K., & Solis, I. (2022). Global changes in cultivated area and breeding activities of durum wheat from 1800 to data: A historical review. *Agronomy*, 12: 1135. https://doi.org/10.3390/agronomy12051135

MAF (2022). *Crop yields - harvest'21*. Ministry of Agriculture and Forestry. Sofia, Bulgaria. https://www.mzh.government.bg/media/filer_public/2022/10/06/ra407_publication_crops_2021.pdf

Mondal, B. K., Singh, A. K., Arsad, M. K., Kashive, A. V., & Gupta, A. (2022). Studies on nutrient uptake by plants trough the application of nitrogen fertilizer in wheat (*Triticum durum* L.). *The Pha. Inn. J.*, 11(7): 2523-2526.

Mangini, G., Blanco, A., Nigro, D., Signorile, M. A., & Simeone, R. (2021). Candidate genes and quantitative trait loci for grain yield and seed size in durum wheat. *Plants*, 10: 312. https://doi.org/10.3390/plants10020312

Mihoub, A., Amin, A. E. E. A., Asif, N., & Daddi Bouhoun, M. (2019). Improvement in phosphorus nutrition of wheat plant grown in a calcareous sandy by incorporating chemical phosphorus fertilizer with some selected organic substances. *Acta Agri. Slo.*, 113(2): 263-272.

Patel, H., Tiwari, A., Bachkaiya, V., & Samadhiya, V. (2021). Impact of long term fertilization and manuring on sustainability yield index under rice-wheat cropping system in a vetisol of central India. *Int. J. of Env. Sci.*, 3(1): 106-109.

Piwowar, A., 2021. Consumption of mineral fertilizers in the Polish agriculture – trends and directions of changes. *Agri. Res.* https://doi.org/10.1007/s40003-021-00591-7

Rapacz, M., Macko-Podgorni, A., Jurczyk, B., & Kuchar, L. (2022). Modeling wheat and triticale winter hardiness under current and predicted winter scenarios for Central Europe: A focus on deacclimation. *Agr. and For. Met.*, 313: 108739. https://doi.org/10.1016/j.agrformet.2021.108739

Romanenkov, V. A., Shevtsova, L. K., Rukhovich, O. V., & Belichenko, M. V. (2020). Chapter 8 - Geographical network: legacy of the Soviet era long-term field experiments in Russian agriculture. *Long-Term Farm. Syst. Res.:* 147-165. https://doi.org/10.1016/B978-0-12-818186-7.00009-6

Rehim, A., Ali, I., Bashir, M. A., Hussain, S., Hussain, M., Ahmad, Sh., & Ahmad, F. (2018). Evaluating the effective effects of rates and methods of phosphorus application on wheat productivity. *Sci., Techn. and Dev.*, 37(1): 6-12. DOI:10.3923/std.2018.6.12

Sarker, U. K., Uddin, M. R., Kaysar, M. S., Hossain, M. A., Somaddar, U., & Saha, G. (2023). Exploring relationship among nitrogen fertilizer, yield and nitrogen use efficiency in modern wheat varieties under subtropical condition. *Saudi J. of Bio. Sci.*, 30: 103602. https://doi.org/10.1016/j.sjbs.2023.103602

Song, W., Shu, A., Liu, J., Shi, W., Li, M., Zhang, W., Li, Z., Liu, G., Yuan, F., Zhang, Sh., Liu Z., & Gao, Z. (2022). Effect of long-term fertilization of different substation ratios of organic fertilizer on paddy soil. *Pedoshere*, 32(4): 637-648. https://doi.org/10.1016/S1002-0160(21)60047-4

Sanchez-Rodriguez, A. R., Rey, M. D., Nechate-Drif, H., Castillejo, M. A., Jorrin-Novo, J. V., Torrent, J., Campiello, M. C., & Sacristan, D. (2021). Combining R and Zn fertilization to enhance yield and grain quality in maize grown on Mediterranean soils. *Sci. Rep.*, 11: 7427. https://doi.org/10.1038/s41598-021-86766-2

Staugaitis, G., Poskus, K., Bbraziene, Z. & Avizienyte, D. (2022). Effect of sulfur and nitrogen fertilization on winter wheat in Calcaric Luvisol. *Zemd.-Agri.*, 109(3): 211-218. DOI: 10.13080/z-a.2022.109.027

Shuklina, O. A., Langaeva, N. N., Voronchikhina, I. N., Voronchikhin, V. V., & Afanasiev, R. A. (2021). Application of photometry for crops online diagnostics of the nitrogen nutrition of plants. *IOP Conf. Series: Earth and Env. Sci.*, 723: 022064 DOI: 10.1088/1755-1315/723/2/022064

Tudor, V. C., Stoicea, P., Chiurciu, I. A., Soare, E., Iorga, A. M., Dinu, T. A., David, L., Micu, M. M., Smedescu, D. I. & Dumitru, E. A. (2023). The use of fertilizers and pesticides in wheat production in the Main European countries. *Sustainability*, 15: 3038. https://doi.org/10.3390/su15043038

Tedone, L., Ali, S. A., Verdini, V., & De Mastro, G. (2018). Nitrogen management strategy for optimizing agronomy and environmental performance of rainfed durum wheat under Mediterranean climate. *J. of Cle. Pro.*, 172: 2058-2074. https://doi.org/10.1016/j.jclepro.2017.11.215

Velimirovic, A., Jovovic, Z., Perovic, D., Lehnert, H., Mikic, S., Mandic, D., Przulj, N., Mangini, G. & Finetti-Sialer, M. M. (2023). SNP diversity and genetic structure of "Rogosija", an old Western Balkan durum wheat collection. *Plants*, 12(5): 1157. https://doi.org/10.3390/plants12051157

Vishwanath, Kumar, S., Purakayastha, T. J., Datta, S. P., Rosin, K. G., Mahapatra, P., Sinha, S. K., & Yadav, S. P. (2020). Impact of forty-seven years of long-term fertilization and on soil liming soil health, yield of soybean and wheat in an acidic Alfisol. *Arch. of Agr. and Soil Sci.*, 68(4). https://doi.org/10.1080/03650340.2020.1843023

Wei, S., Peng, A., Huang, X., Deng, A., Chen, C., & Zhang, W. (2021). Contributions of climate and soil properties to wheat and maize yield based on long-term fertilization experiments. *Plants*, 10: 2002. https://doi.org/10.3390/plants10102002

Xing, Z., Huang, Z., Yao, Y., Fu, D., Cheng, Sh., Tian, J., & Zhang, H. (2023). Nitrogen use traits of different rice for tree planting modes in a rice-wheat rotation system. *Agriculture*, 13(1): 77. https://doi.org/10.3390/agriculture13010077

Xynias, I. N., Mylonas, I., Korpetis, E. G., Ninou, E., Tsaballa, A., Avdikos, I. D., & Mavromatis, A. G. (2020). Durum wheat breeding in the Mediterranean region: current status and future prospects. *Agronomy*, 10: 432. https://doi.org/10.3390/agronomy10030432

Zhao, C., Gao, Z., Liu, G., Chen, Y., Ni, W., Lu, J., Shi, Y., Qian, Z., Wang, W., & Huo, Z. (2023). Combining controlled-release urea and normal urea to improve the yield, nitrogen use efficiency, and grain quality of singe season late *japonica* rice. *Agronomy*, 13: 276. https://doi.org/10.3390/agronomy130102276

Zuluaga, D. L., Blanco, E., Mangini, G., Sonnante, G., & Curci, P. L. (2023). A Survey of thetranscriptomic resources in durum wheat: stress responses, data integration and exploitation. *Plants*, 12(6): 1267. https://doi.org/10.3390/plants12061267

Zhang, Y., Wang, R., Wang, H., Wang, Sh., Wang, X., & Li, J. (2019). Soil water use and crop yield increase under different long-term fertilization practices incorporated with two-
year tillage rotation. *Agri. W. Man.*, 221: 362-370. https://doi.org/10.1016/j.agwat.2019.04.018

Zhang, J., Balkovic, J., Azevedo, L. B., Skalsky, R., Bouwman, A. F., Xu, G., Wang, J., Xu, M., & Yu, Ch. (2018). Analyzing and modeling the effect of long-term fertilizer management on crop yield and soil organic carbon in China. *Sci. of the T. Env.*, 627: 361-372. https://doi.org/10.1016/j.scitotenv.2018.01.090