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NITROGEN AND PHOSPHORUS FERTILIZERS AFFECTING THE QUALITY AND QUANTITY OF THE DURUM WHEAT

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Abstract

The experiment was based on the block randomized method in four replications, after cotton predecessor in Field Crops Institute, Bulgaria in the period 2018/19-2019/20. Were tested: N_{40}, N_{80}, N_{120}; N_{160}; P_{40}, P_{80}, P_{120} and P_{160}. As a control variant was adopted N_0P_0. Based on the results obtained, we can conclude that the maximum nitrogen rate did not lead to the best results. The norm of 120 kg N ha was the most effective in most parameters – grain yield (76.2%); test weight (113.3%); grain vitreous (32.36%); gluten content (50.2%), respectively compared to the control. Thousand kernel weight was most affected by N_{160} (13.3%). Protein content had the same values in N_{120} and N_{160} (35.1%), and this effect does not justify the high rate of N_{160}. Phosphorus fertilization showed a weaker effect for all studied traits, and grain yield did not have significantly higher values. The other parameters were most affected by fertilization with P_{80}: thousand kernel weight (7.7%); test weight (2.0%); grain vitreous (9.69%); gluten content (22.3%), respectively. Protein content had the same values at P_{80} and P_{160} (9.0%).

***Key words**: environmental conditions, nitrogen, phosphorus, fertilization.*

INTRODUCTION

Durum wheat constitutes one of the most pivotal cereal crops for global security (Toukabri et al., 2021). Is grown on 17 million ha worldwide with a globule production of 33.6 million tons in 2020 (Royo et al., 2021). Demand for wheat is projected to continue to grow over the coming decades, particularly, in the developing world to feed an increasing population (Desta & Almayehu, 2020). Regardless of its tight connection to the dishes of the tradition, durum wheat today is cultivated in developed countries mainly as a cash crop to feed the booming food industry (Sall et al., 2019).

Conventional agriculture is the preferred form of agriculture by most farmers in the world. This technological option (Shopova et al., 2014) provides opportunities for higher crop yields. The production of wheat requires intensive use of farms inputs especially nitrogen (N) fertilizer in order to achieve sufficient yield and good drain quality (Tedone et al., 2018). A significant amount of N applied was lost to environment via nitrification, denitrification, leaching, and volatilization (Cao et al., 2017). Nevertheless, farmers tend to use more mineral and organic N fertilizers than biologically necessary to ensure the highest possible yield (Leslie et al., 2017). A consequence of this trend is a deeply unbalanced soil nutrient composition that ultimately leads to a reduction in crop yield potential (Tonfack et al., 2009). Therefore, reducing the amounts of N fertilizer used in cereal-based cropping systems can be considered as a major driver of sustainability (Zekri et al., 2018). Guerrero et al. (2021) emphasize that, plant response to N is limited to a threshold, N fertilization above this level does not increase crop yield any further. The question of optimal nitrogen fertilizer use has a long history and is still relevant from several perspectives (Mayer-Aurich & Karatay, 2019).

Phosphorus is an essential plant nutrient that is required in large quantities (Neocleous & Savvas, 2019). In fear for P deficiency, excess P fertilizers are routinely applied by farmers for producing wheat (Milhoub et al., 2019). However, the same authors report that wheat plant take and use a small amount of phosphorus applied. Overuse of P fertilizer is a globally recognized problem and more efficient and sustainable cropping systems are needed (Heuer et al., 2017). Indeed, the greater part of P remains in insoluble from in soil and, hence, unavailable for the plant (Cherchali et al., 2019).

The aim of our study was to examine the responsiveness of durum wheat to increasing N and P rates and the impact on qualitative and quantitative traits.

MATERIALS AND METHODS

The experiment was based on the block randomized method in four replications with a plot size of 10 m^2, after cotton predecessor in Field Crops Institute-Chirpan, Bulgaria (42°11′58″N, 25°19'27″E). The data represent 2018/2019 and 2019/2020. Durum wheat Saya variety was sown with 550 germinating kernels. N and P mineral fertilizers were tested in the form of ammonium nitrate (34.4%) and triple superphosphate (46%), respectively, in the following rates: N_{40}, N_{80}, N_{120}; N_{180}; P_{40}, P_{80}, P_{120} and P_{180}. The control was the unfertilized variant (N_0P_0). Phosphorus fertilizer together with ⅓ of nitrogen fertilizer were incorporated into the soil with the last autumn tillage, and ⅔ of nitrogen were imported in tillering phase.

The soil type is Pellic Vertisols. Humus horizon 80-115 cm is observed, and the humus stock is 300 t/ha in one meter depth. The reaction of the soil is 6.5-7.4 pH. The presence of total N is 0.20% and decreases to 0.13% at a depth of up to 40 cm. Up to a depth of 20 cm no $CaCO_3$ is available, while in the layer up to 40 cm it is 0.25%.

The analysis of variance (ANOVA) was performed as a two-factor analysis to assess the impact of environmental conditions and mineral fertilization. Differences were compared using the lowest significance (LSD) at 0.1% probability level. The correlation relationships of the studied parameters were established with the software product Statistica 13.0 software (TIBCO, Software, 2018).

The average values of were studied: grain yield (GY) - kg/ha; thousand kernel weight (TKW) - g; test weight (TW) - kg/hl; grain vitreous (GV) - %; protein content (PC) - %; gluten (G) - %.

RESULTS AND DISCUSSIONS

During the durum wheat vegetation, the two years studied had similar values in terms of the sum of temperatures from April to harvest (Table 1). The first year studied was cooler from the sowing of wheat to the tillering phase. Otherwise, the two years had a higher sum of temperatures than the multy-year period. Regarding precipitation, 2019/20 had well-distributed precipitation in the active wheat vegetation, while 218/19 had a well-defined drought (March) and over moisturization in June.

Table 1. Temperature sum and rainfall during the triticum durum vegetation for 2018/2020 and multy-year period

Year	Mouths								Σ
	XI	XII	I	II	III	IV	V	VI	
Temperature sum, Σ˚C									
1928-2020	216.0	63.6	-3.6	58.6	191.9	355.3	507.7	624.9	2014
2018/19	225	21	54	113	293	335	533	682	2256
2019/2020	336	111	45	154	257	314	516	615	2348
Rainfall, mm									
1928-2020	46.9	51.7	43.7	37.7	39.2	44.2	60.5	65.5	389
2018/19	82	24	29	25	3	51	21	123	358
2019/2020	82	22	2	56	67	62	50	63	404

Grain yield

The sum of squares showed that 76.23% of the total variation was due to mineral fertilization (factor A) in the formation of GY (Table 2). For environmental conditions (factor B) dispersion - showed 13.68%. The interaction of factors represented 6.38% of the total variation and showed a significant influence on the change in GY. The coefficient of variation (5.91%) showed that there was no strong variation between the different fertilizer rates. Grain yield ranges from 2,137 kg/ha to 4,298 kg/ha (Table 3). N fertilizer rates had a significant effect, with the greatest effect observed with N_{120} fertilization (76.2% above control). Shchuklina et al. (2021) reported a similar trend of decreasing GY with increasing N rate. In contrast to our results, Bielski et al. (2020) report that GY in triticale increases with increasing N rate. Phosphorus fertilizer not only has no significant effect, but two of the variants have a lower GY than the control, P_{40} and P_{120}, respectively. May et al. (2008) also report that GY decreases with the application of more P. Gao and Grant (2012) concluded that there was no statistically significant major effect on grain yield from different amounts of P fertilization. On the other hand, in a study of N and P self-fertilization, Lakew (2019) reported that a significant effect on GY was observed in bread wheat.

Table 2. Effect of mineral fertilization on triticum durum yield and yield parameters (mean squares - % of total)

Source of variance	df	Grain yield	Thousand kernel weight	Test weight	Vitreous	Protein content	Gluten content
Replicate	17	96.29***	97.31***	95.47***	100.0***	97.73***	97.39***
A	8	76.23***	46.41***	47.77***	56.60***	79.72***	80.67***
B	1	13.68***	26.85***	5.67***	28.06***	7.82***	7.54-02^{NS}
AxB	8	6.38***	24.06***	42.04***	15.34***	10.19***	16.64***
Error	51	3.12	2.68	3.87	4.72-04	2.22	2.40
VC, %		5.91	1.83	0.33	5.30-02	2.45	3.66
Accuracy indicator, %		2.96	1.30	0.24	3.75-02	1.75	2.58

Thousand kernel weight

The two sources of variation were very significant for TKW (Table 2). Differences in fertilizer rates explain 46.41% of the total variation, and the impact of the environment - 26.85%. The interaction of the two factors was also very significant (24.06%), which ultimately led to a total variation of 97.31%. Thousand kernel weight ranged from 43.1 g to 50.4 g (Table 3). TKW was most affected by N_{160} (13.3% above control). A similar effect of N fertilization was observed by Namvar and Khandan (2013). However, the application of 80 kg N/ha had a similar effect. The effect of this variant resulted in a TKW of 50.3 g, which was 13.0% more than the control. Litke et al. (2017) reported that nitrogen fertilization affects TKW, which confirms our results. Fertilization with P_{160} showed a statistically significant increase in values of 7.7% compared to the control. The same trend is observed by Sial et al. (2018). The authors reported an increase in TKW with increasing P rate. In contrast to our results, Chen et al. (2019) reported that as P rate increases, the TKW decreases.

Test weight

The sum of the squares for the main effect (factor A) explains 47.77% of the total variance in the formation of test weight (Table 2), while the differences between the years explain 5.67%. The complex action of the factors also represented a significant part of the variance - 42.04%. TW values ranged from 75.8 kg/hl to 78.0 kg/hl (Table 3). All fertilization rates included in the study were shown to increase the values, but with the greatest impact was N_{120}, exceeding the control by 2.9%. Campiglia et al. (2014) confirmed our results by finding that N fertilization significantly affects TW. On the other hand, the results obtained by us contradict the study of Fortunato et al., (2019), who reported that with increasing N rate TW values increase. Fana et al. (2012), however, observed the same trend of decreasing values with increasing N rate. The same authors confirm our results for the positive impact of the independent application of P fertilizer and for the increase of the values with the increase of the rate.

Grain vitreous

The sum of the squares in ANOVA for fertilization amounts to 56.60% of the main effect and this factor has the most significant effect on the vitreousness of durum wheat (Table 2). The impact of environmental conditions was also very significant with 28.06%. The interaction of the two factors was proven with high reliability (P = 0.1%). The GV of the grains ranges from 46.5% to 68.3% (Table 4). There was a tendency to increase the values to the rate of N fertilization 120 kg

N/ha, and when the norm increased to 160 kg N/ha, the values decreased. This result contradicts the results of the study by Gerba et al., (2013), who reported that as the fertilizer rate increases, the values also increase. A similar effect was observed with P fertilization. Moreover, the high rates of 120 and 160 kg P/ha were below the control values.

Protein content

The sum of the squares showed a very significant influence on both factors in the formation of the protein (Table 1). Fertilization was by 79.72%, while the influence of the year was by 7.82%. PC ranged from 11.1% to 15.0% (Table 4). All N and P fertilization rates had a proven effect. The greatest effect on protein accumulation was reported by N_{120} and N_{160}. Both variants had the same value, exceeding the control by 35.1%. A number of authors report that as the rate increases, the values increase (Ali et al., 2019; Novak et al., 2019; Woyema et al., 2012). P fertilization had also a large effect, but there was a tendency for the PC to decrease as the rate increased. These results are inconsistent with the study of Chen et al. (2020), who report that P alone has no effect on grain protein in bread wheat.

Table 3. Grain yield (kg/ha), thousand kernel weight (g) and test weigh (kg/hl) average for test period

Fertilization		Grain yield, kg/ha	% of control	Thousand kernel weight, g	% of control	Test weight, kg/hl	% of control
Control		2,439	100.0	44.5	100.0	75.8	100.0
N_{40}		3,197***	131.1	47.9***	107.6	76.8***	101.3
N_{80}		3,796***	155.6	50.3***	113.0	77.5***	102.2
N_{120}		4,298***	176.2	48.5***	109.0	78.0***	102.9
N_{160}		3,778***	154.9	50.4***	113.3	77.0***	101.6
P_{40}		2,324^{NS}	95.3	45.2^{NS}	101.6	77.3***	102.0
P_{80}		2,552^{NS}	104.6	43.1^{NS}	96.9	76.7***	101.2
P_{120}		2,137^{NS}	87.6	44.8^{NS}	101.8	76.5***	100.9
P_{160}		2,517^{NS}	103.2	47.4***	107.7	76.3**	100.7
LSD	*5%*	*178.3*	*7.3*	*1.3*	*3.0*	*0.4*	*0.5*
	1%	*237.6*	*9.7*	*1.8*	*4.1*	*0.5*	*0.7*
	0.1%	*310.1*	*12.7*	*2.4*	*5.4*	*0.7*	*0.9*

NS - no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Table 4. Grain vitreous (%), protein content (%) and gluten content average for test period

Fertilization		Grain vitreous, %	% of control	Protein content, %	% of control	Gluten content, %	% of control
Control		51.6	100.0	11.1	100.0	21.5	100.0
N_{40}		57.1***	110.66	13.4***	120.7	24.1**	112.1
N_{80}		64.2***	124.42	13.9***	125.5	29.1***	135.4
N_{120}		68.3***	132.36	15.0***	135.1	32.3***	150.2
N_{160}		66.8***	129.46	15.0***	135.1	31.9***	148.4
P_{40}		52.7***	102.13	12.6***	113.5	24.9***	115.8
P_{80}		56.6***	109.69	12.1***	109.0	26.3***	122.3
P_{120}		51.1^{NS}	99.03	11.9**	107.2	22.5^{NS}	104.7
P_{160}		46.5^{NS}	90.12	12.1***	109.0	23.0*	107.0
LSD	*5%*	*0.04*	*0.08*	*0.5*	*4.5*	*1.4*	*6.5*
	1%	*0.06*	*0.12*	*0.7*	*6.3*	*2.0*	*9.3*
	0.1%	*0.08*	*0.16*	*0.9*	*8.1*	*2.7*	*12.6*

NS - no significant; *, **, *** significant at P=5%, P=1% and P=0.1%

Gluten content

The change in the gluten content in the grain was mostly due to fertilization – 80.67% of the total variation (Table 1). This was the only trait that was not affected by the environmental condition. However, the interaction of AxB was highly proven. GC ranged from 21.5% to 32.3% (Table 4). Increasing the N rate led to an increase in the values to the norm of 120 kg N/ha, and the higher dose led to a decrease. The same trend was observed for P fertilization. A number of studies support the positive effects of nitrogen on GC. Dinkinesh et al. (2020) observed an increase in GC to the norm of 122 kg N/ha. When increased to 183 kg N/ha, the gluten content decreases. On the other hand, Kizilgeci et al. (2021) reported that the values increase with increasing N rate. Regarding phosphorus fertilization Agapie and Bostan (2020) conclude that unilaterally applied phosphorus does not bring significant changes.

Under the action of N fertilization, the correlation revealed strong and proven relationships between most of the studied parameters (Table 5). The most closely related were GV and GC (0.993***). Holmurodova and Urinova (2021) confirm this result by reporting that there is direct relationship between the glassiness of the grain and the amount of protein and gluten in it.

Under the action of P fertilization, only two proven correlations were found between the TW and the PC (0.928 **) and a strong negative relationship between the TKW and the GV (-0.950**), respectively.

Table 5. Correlation coefficients between the studed traits

	GY	*TKW*	*TW*	*V*	*PC*	*GC*
			N fertilization			
GY	1.000					
TKW	0.804^{NS}	1.000				
TW	0.971**	0.736 ^{NS}	1.000			
V	0.975**	0.846*	0.897**	1.000		
PC	0.946*	0.871*	0.866*	0.959***	1,000	
GC	0.947*	0.814*	0.849*	0.993***	0.941**	1.000
			P fertilization			
GY	1.000					
TKW	0.009 ^{NS}	1.000				
TW	-0.218 ^{NS}	-0.102 ^{NS}	1.000			
V	0.088 ^{NS}	-0.950**	0.363 ^{NS}	1.000		
PC	-0.078 ^{NS}	0.188 ^{NS}	0.928**	0.091 ^{NS}	1.000	
GC	0.346 ^{NS}	-0.418 ^{NS}	0.745 ^{NS}	0.662 ^{NS}	0.710	1.000

***0.01%; **0.05%; *0.1%

CONCLUSIONS

Based on the results obtained, we can conclude that the increase in N fertilizer rates did not lead to maximum results. The rate of 120 kg N/ha was the most effective in most parameters - GY (76.2%); TW (113.3%); GV (32.36%); GC (50.2%), respectively. Only TKW was most affected by N_{160} (13.3%). PC had the same values for N_{120} and N_{160} (35.1%), and this effect does not justify the additional imported N fertilizer at the high rate.

Phosphorus fertilization had a significantly lower effect for all studied traits. Moreover, GY did not have a significant increase in values.

The other parameters were most affected by P_{80} fertilization: TKW (7.7%); TW (2.0%); GV (9.69%); GC (22.3%), respectively. PC had the same values at P_{80} and P_{160} (9.0%), and this effect does not further justify the imported P fertilizer at the high rate.

REFERENCES

Agapie, A. L. & Bostan, C. (2020). The influence of mineral fertilization on the quality of winter wheat. *Journal – Life Science and Sustainable Development 1(2),* 45–50.

Ali, S. A., Tedone, L., Verdini, L., Cazzato, E. & Mastro, G. (2019). Wheat response to no-tillige and nitrogen fertilization in a long-term faba bean-based rotation. *Agronomy, 9,* 50.

Bielski, S., Romaneckas, K. & Sarauskis, E. (2020). Impact of nitrogen and boron fertilization of winter triticale productivity parameters. *Agronomy, 10.* 279. Doi:10.3390/agronomy10020279

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 from* 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 *from* https://doi.org/10.1038/s41598-019-53000z

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

Cao, p. Lu, Ch. & Yu, Z. (2017). Historical nitrogen fertilizer use in agricultural ecosystem of the continental Unated States during 1850-2015: Application rate, timing, and fertilizer types. *Earth Syst. Sci. Data Discuss from* https://doi.org/10.5194/essd-2017-132

Campiglia, E., Mancinelli, R., Radicceti, E. & Baresel, J. P. (2014). Evaluating spatial arrangemen for durum wheat (*Triticum durum* Desf.) and subclover (*Trifolium subterraneum* L.) intercropping systems. *Field Crops Research, 169.* 49–57.

Desta, B. T. & Almayehu, Y. (2020). Optimizing blended (NPSB) and N fertilizer rates for the productivity of durum wheat (*Triticum turgidum* L var. durum) in central highlands of Ethiopia. *Soil and Crop Science from* https://doi.org/10.1080/23311932.2020.1766733

Dinkinesh, A., Tana, T. & Dessalegn, T. (2020). Effect of blanded NSPB fertilizer rate on yield and grain quality of durum wheat (*Triticum turgidum* L.) varieties in Minjar Shenkora District, Central Ethiopia. *Ethiop. J. Agric. Sci. 30(3),* 57–76.

Fortunato, S., Nigro, D., Paradiso, A., Cucci, G., Lacolla, G., Trani, R., Agrimi, G., Blanco, A., Concceta de Pinto, M. & Gadaleta, A. (2019). Nitrogen metabolism at tillering stage differently affect the grain yield and grain protein content in two durum wheat cultivars. *Diversity, 11,* 186. Doi:10.3390/d11100186

Fana, G., Deressa, H., Dargie, R., Bogale, M., Mehadi, S. & Getachew, F. (2012). Grain hardness, hectoliter weight, nitrogen and phosphorus concentrations of durum wheat (*Triticum turgidum* L. var. *Durum*) as influenced by nitrogen and phosphorus fertilization. *World Applied Science Journal, 20(10),* 1322–1327.

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 Tillige Research, 205.* 104789 *from* https://doi.org/10.1016/j.still.2020.104789

Gerba, L., Getachew, B. & Walelign, W. (2013). Nitrogen fertilization effects on grain quality of durum wheat (*Triticum turgidum* L. var. durum) varieties in central Ethiopia. *Agricultural Science, 4*(3)*,* 123–130.

Gao, P. & Grant, C. A. (2012). Cadmium and zink concentration in grain of durum wheat in relation to phosphorus fertilization, crop sequence and tillage management. *Soil Management for Sustainable Agriculture from* https://doi.org/10.1155/2012/817107

Holmurodova, Z. D. & Urinova, G. E. (2021). The importance of winter wheat planting and agrotechnical measures to improve the quality of grain. *Emergent: Journal of Educational Discoveries and Lifelong Learning (EJEDL), 2*(5)*,* 213–217.

Heuer, S., Gaxiola, R., Schilling, R., Herrera-Estrella, L., Lopez-Arredondo, D., Wissuwa, M., Delhaize, E. & Rouached, H. (2017). Improving phosphorus use efficiency: A complex trait with emerging opportunities. *Plant J., 90.* 868–885.

Kizilgeci, F., Yilidirim, 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.* 3725 *from* https://doi.org/10.3390/su13073725

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 Wang-Himira Zone, North Eastern Ethiopia. *Archives of Agriculture and Environmental Science, 4*(1)*,* 8–18. *from* https://doi.org/10.26832/24566632.2019.040102

Leslie, J. E., Weersink, A., Yang, W. & Fox, G. (2017). Actual versus environmentally recommended fertilizer application rates: Implications for water quality and policy. *Agriculture, Ecosystems and Environment, 240.* 109–120. https://doi.org/10.1016/j.agee.2017.02.009

Litke, L., Gaile, Z. & Ruza, A. (2017). Nitrogen fertilizer influence on winter wheat yield and yield components depending on soil tillage and forecrop. *Research for Ruler Development, 2.* 54–61.

Mayer-Aurich, A. & Karatay, Y. N. (2019). Effect of uncertainty and farmers risk aversion on optimal N fertilizer supply in wheat production in Germany. *Agricultural Systems, 173.* 130–139.

Milhoub, A., Amin, A. E. E., Asif, N. & Bouhoun, M. (2019). Improvement in phosphorus nutrition of wheat plant grown in a calcareous sandy soil by incorporating chemical phosphorus fertilizer with some selected organic substances. *Acta Agriculturae Slovenica, 113*(2)*,* 263–272.

May, W. E., Fernandez, M. R., Holzapfer, Ch. B. & Lafond, G. P. (2008). Influence of phosphorus, nitrogen and potassium chloride placement and rate of durum wheat yield and quality. *Agronomy Journal from* https://doi.org/10.2134/agronj2007.0076

Neocleous, D. & Savvas, D. (2019). The effect of phosphorus supply limitation on photosynthesis, biomass production, nutritional quality, and mineral nutrition in lettuce grown in a recirculating nutrient solution. *Scientia Horticulture, 252.* 379–387.

Novak., L., Liubych, V., Poltoretskyi, S. & Andrushchenko, M. (2019). Technological indices of spring wheat grain depending on the nitrogen supply. *Modern Development Paths of Agricultural Production,* 753–761.

Namvar, A. & Khandan, T. (2013). Response of wheat to mineral nitrogen fertilizer and biofertilizer (*Azotobacter* sp. and *Azospirillom* sp.) inoculation under different levels of weed interference. *Ekologija, 59*(2)*,* 85–94.

Royo, C., Ammar, K, Villegas, D. & Soriano, J. M. (2021). Agronomic, physiological and genetic changes associated with evolution, migration and modern breeding in durum wheat. *Front. Plant Sci., 12.* 674470. Doi:10.3389/fpls.2021.674470

Shchuklina, 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 Environmental Science, 723.* 022064. Doi:10.1088/1755-1315/723/2/022064

Sall, A. T., Chiari, T., Leggese, W., Seid-Ahmed, K., Ortiz, R., Ginkel, M. & Bassi, F. M. (2019). Durum wheat (*Triticum durum* Desf.): origin cultivation and potential expansion in Sub-Saharan Africa. *Agronomy, 2019, 9.* 263. Doi:10.3390/agronomy9050263

Sial, N. A., Abro, S. A., Abbas, M., Irfan, M. & Depar, N. (2018). Growth and yield of wheat as affected by phosphate solubilizing bacteria and phosphate fertilizer. *Pak. J. Biotechnol. Vol. 15*(2), 475–479.

Shopova, N., Cholakov, D. & Haytova, D. (2014). Productivity of the plants for late field tomato production depending on the age and planting area of the seeding. Journal of International Scientific Publications: *Agricultural and Food, 2.* 179–191. *from* https://www.scicient-publications.net/ en/article/ 1000025/

Toukabri, W., Ferchichi, N., Hlel, D., Jadlaoui, M., Kheriji, O., Zribi, F., Taamali, W., Mhamdi, R. & Trabelsi, D. (2021). Improvements in durum wheat main crop in weed control, productivity and grain quality trough the inclusion of fenugreek and clovers as companion plants: effect of N fertilization regime. *Agronomy, 11.* 78 *from* https://doi.org/10.3390agromony11010078

Tedone, L., Ali, S. A., Verdini, L. & De Mastro, G. (2018). Nitrogen management strategy for optimizing agronomic and environmental performance of rainfed durum wheat under Mediterranean climate. *Journal of Cleaner Production, 172.* 2058–2074 *from* https://doi.org/10.1016/j.clepro.2017.11.215

TIBCO, Software (2018).

Tonfack, L. B., Bernadac, A., Youmbi, E., Mbouapouognigni, V. P., Ngueguim, M. & Akoa, A. (2009). Impact of organic and inorganic fertilizers on tomato vigor yield and fruit composition under tropical andosol soil conditions. *Fruits, 64*(3)*,* 167–177.

Woyema, A., Bultosa, G. & Taa, A. (2012). Effect of different nitrogen fertilizer rates on yield and yield related traits for seven durum wheat (*Triticum turgidum* L. var. Durum) cultivars at Sinana, South Eastern Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development, 12*(3)*,* 6079–6094.

Zekri, B., Barkaoui, Y., Marrou, H., Mekki, I., Belhouchette, H. & Wery, J. (2018). On farm analysis of the effect of the preceding crop on N uptake and grain yield of durum wheat (*Triticum durum* Desf.) in Mediterranean conditions. *Archives of Agronomy and Soil Science from* https://doi.org/10.1080/03650340.1514111