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THE BEHAVIOR OF FOUR WINTER WHEAT GENOTYPES UNDER DIFFERENT RATES OF NITROGEN FERTILIZER

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Abstract

In agriculture water and nitrogen are the main factors that influence crop production in all regions. Interactions between water and nitrogen fertilization are complicated. The present study investigated the influence of nitrogen fertilization rate and rainfall distribution on plant height, grain yield and grain protein content of four winter wheat varieties in a three years field experiment in Turda, Romania. To establish the relationships between nitrogen fertilization rate, rainfall distribution and grain yield the follow parameters was determined: the rain use efficiencies (RUE), nitrogen agronomic efficiency (NAE) and nitrogen use efficiency (NUE). Andrada and Codru had a significant higher RUE which means that this genotypes produced higher rate of grain yield per unit rainfall than Arieşan and Taisa. The highest NAE was recorded by Taisa which means that this cultivar has the highest ability to increase yield in response to the rate of nitrogen fertilizer applied. Andrada and Codru had the highest value of NUE, which means that these cultivars have the ability to use more efficiently the nitrogen to obtain a higher yield.

Key words*: NAE, NUE, RUE, winter wheat.*

INTRODUCTION

Wheat is one of the most widely grown cereal crops in the world due to its importance for various food and feed products, and its wide genetic adaptability to varying environmental conditions such as temperature, moisture and light (Pavuluri et al., 2015; Muntean et al., 2014).

Although world food needs are increasing, climate changes, such as rise in temperature and decline in rainfall may negatively affect crop yields in some major production regions of the world (Kadar et al., 2019). Wheat genotypes that efficiently capture and convert available soil nitrogen into harvested grain protein are the key to sustainably meeting the rising global demand for grain protein (Guttieri et al., 2017).

In agriculture water and nitrogen are two primary factors in crop production in all regions. Nitrogen fertilization is a common practice to increase food production, but its performance depends on soil water status (Halvorson et al., 2004; Turner, 2004; Turner and Asseng, 2005). Typically rain-fed farming system are characterized by the absence of irrigation, here the main source of soil water supply for crop growth is precipitation. Annual and seasonal precipitation can influence crop response to nitrogen fertilization, accounting for major variations in yield, water use efficiency, and nitrogen use efficiency (Guo et al., 2012). Interactions between water and nitrogen fertilization are complicated and may cause either positive or negative effects on crop growth (Li et al., 2009).

Rain Use Efficiency (RUE) according to Gwenzi et al. (2008) is a parameter defined as grain yield divided by total seasonal rainfall, is an indicator that expresses grain yield per mm of rainfall. It has been used to analyze the variability of vegetation production (Dardel et al., 2014).

Nitrogen use efficiency (NUE) according to Moll et al. (1982), is a parameter that expresses grain dry matter yield per unit available nitrogen. NUE is the net result of N capture (uptake efficiency) and N conversion (utilization efficiency) (Guttieri et al., 2017). Genetic associations between grain yield and NUE, and variation in NUE among genotypes

have been widely recognize in various studies (Foulkes et al., 2009).
Nitrogen agronomic efficiency (NAE), is a parameter that represent the ability of the plant to increase yield in response to the amount of nitrogen rate applied (Delogu et al., 1998).
This study investigated the relationships between nitrogen fertilization rate, rainfall distribution and grain yield based on a three years field experiment with three nitrogen fertilization rates in Turda, Romania. Its objectives were to: study the impact of seasonal precipitation on grain yield and plant height, to determine the rain use efficiencies (RUE), nitrogen agronomic efficiency (NAE) and nitrogen use efficiency (NUE) of four winter wheat varieties under different nitrogen rates and to determine the influence of nitrogen rates on plant height, yield and grain protein content.

MATERIALS AND METHODS

The experiments have been carried out at the Agricultural Research and Development Station Turda (46°35’ N latitude and 23°47’ E longitude, 345-493 m above Adriatic Sea), which is located in the Transylvanian Plain, Romania. The field experiment was established on a clay Chernozem soil, typical for this region. The agrochemical parameters for this type of soil are: the soil reaction is neutral (pH 6.9-7.1) and the humus content is between 3.56-3.92%. The soil is rich in nitrogen (0.183-0.196%), and potassium content (249 ppm), and poor in mobile phosphorus (15 ppm).
The experimental design consists in subdivided plots in a three factorial experimental system. The experimental factors were:

- Genotype (G);
- Nitrogen fertilization (N);
- Season (S).

For this study were used four winter wheat genotypes created at ARDS Turda: Arieşan, Andrada, Codru, Taisa. Nitrogen fertilizer was applied to winter wheat at growth stage GS40 (boot stage). Three treatments were applied in the experiment: (1) no N was applied, (2) N_{50}, 50 kg ha^{-1}, (3) N_{100}, 100 kg ha^{-1}. The field experiment was established in 2015 and had three seasons: (1) 2015-2016, (2) 2017-2018, (3) 2018-2019.
The plots measured 1.5 m × 5 m area and were randomly arranged in three blocks, with a 0.5 m border between blocks.
Nitrogen and phosphorus fertilizer was applied in autumn ($N_{50}P_{50}$ kg ha^{-1}). Winter wheat was sown (550 seeds per square meter) in October, and harvest in July. Pest and weed control were performed according to local farming practices.

Data collection

Plant height was recorded at full stature as the height to the terminal spikelet less awns. Before harvest plant height was measured in every plot. Grain yield after harvest was reported at 14% moisture content. Grain protein content was determined on the whole grain using Infragrain 9500 analyzer.
Rain-use efficiency (RUE) was calculated according to Gwenzi et al. (2008):

$$RUE = \frac{GY}{\text{Total seasonal rainfall}}$$

Nitrogen agronomic efficiency (NAE) was calculated according to Delogu et al. (1998):

$$NAE = \frac{\text{GY at Nitrogen rate} - \text{GY at 0 Nitrogen rate}}{\text{amount of Nitrogen rate applied}}$$

Nitrogen use efficiency (NUE) was calculated according to Moll et al. (1982):

$$NUE = \frac{GY}{\text{amount of Nitrogen rate applied}}$$

Where GY= grain yield.

Statistical analyses

Analysis of variance (ANOVA) and F Test were used to establish the effect of genotype, nitrogen fertilization and season (climatic conditions), and the interactions between these factors. The significance of differences between parameters means were assessed using Duncan's Multiple Range Test at $P \leq 0.05$ level. Direct relationship between rainfall and plant height was analyzed with simple Pearson correlation coefficients.

Climatic conditions

The weather conditions data presented in Table 1 were obtained from a local observation measurement unit located at the Experimental Station. From all three seasons the 2015-2016 was the wettest, followed by the 2018-2019 season, and the 2017-2018 season was the driest. Large amount of precipitations occurred at the end of the winter wheat growing season in 2016 and 2018 in May, June and July. In 2019 it rained heavily in May, after that in June and July the monthly averages were lower than the previous years. From all three seasons 2017-2018 was the warmest, high temperatures at the end of the winter wheat vegetation period determined the speed up of the heading and ripening stages of wheat plants (Table 1).

Table 1. Temperature and rainfall values for the winter wheat vegetation period between 2015-2019, Turda, Romania

Months	Temperature (^{0}C) monthly average				Rainfall (mm) monthly average			
	2015-2016	2017-2018	2018-2019	60 years average	2015-2016	2017-2018	2018-2019	60 years average
October	9.7	11.6	12.7	9.5	45.4	49.2	26.8	35.6
November	6.1	4.9	6	3.9	32	30.8	29.6	28.5
December	0.7	1.0	-0.9	-1.4	6.9	20.7	58.3	27.1
January	-2.8	0.2	-2.2	-3.4	25.0	16.7	46	21.8
February	4.6	-0.3	1.7	-0.9	23.8	33.4	14.7	18.8
March	5.9	3.3	7.3	4.7	47	40.9	12.3	23.6
April	12.4	15.3	11.3	9.9	62.2	26.2	62.6	45.9
May	14.3	18.7	13.6	15	90.4	56.8	152.4	68.7
June	19.8	19.4	21.8	17.9	123.3	98.3	68.8	84.8
July	20.5	20.4	20.4	19.7	124.9	85.7	35.0	77.1
Average	9.12	9.45	9.17	7.49				
Total					580.9	458.7	506.5	431.9

RESULTS AND DISCUSSIONS

Plant height

F test demonstrated that wheat height was significantly influenced by the Genotype by Nitrogen fertilization, by Season and by the interaction between Genotype and Season (Table 2).

For this study the four winter wheat genotypes used had different heights, Arieşan is the taller with a plant height between 90-115 cm, Codru has a plant height between 75-100 cm, Taisa between 90-100 cm and Andrada between 80-95 cm. As Ripberger et al., in 2016, demonstrated that plant height of winter wheat is strongly influenced by the changing of the environmental factors, the plants had higher height under conditions of sufficient moisture. The results of his analysis demonstrated that environmental conditions are responsible for the largest variation of plant height. Voziyan, in 2014, tested 17 winter wheat varieties in the Republic of Moldova for 3 years and concluded that the evaluation of wheat adaptive capacities according to plant height would be more accurate taking into account the dependence of this character on hydrothermal conditions and other biotic and abiotic environmental factors.

Nitrogen fertilization and Season had a strong influence on plant height. The highest plant height was recorded when the nitrogen rate was the highest (Table 3). Also, many authors reported that increasing N level increased plant height (Ali et al., 2000; Iqtidar et al., 2006; Ali et al., 2011).

Environmental conditions had a highly significant effect on plant height, in 2016 when the total rainfall was the highest the plant height increased, in 2018 when the amount of precipitations was the lowest, the plant height recorded was the smallest. The results obtained with the help of Duncan's Multiple Range test demonstrated that the plant height of the four winter wheat cultivars is genetically determinate and this trait is strongly influenced by the environmental factors (Table 2).

As shown in Figure 1 the plant height of all four genotypes from this study was positively correlated with rainfall, the plant height increased as the amount of precipitation was higher. Pearson correlation demonstrated that plant height of Taisa and Andrada was strong correlated with rainfall, and plant height of Arieşan and Codru was moderate correlated with rainfall.

Grain yield

According to F test all the factors of this experience had a significant influence on grain yield, also the interaction between Genotype and Season had a significant influence on yield. Duncan's Multiple Range test demonstrated that Andrada had the highest yield, followed by Codru, Arieşan and Taisa (Table 2).

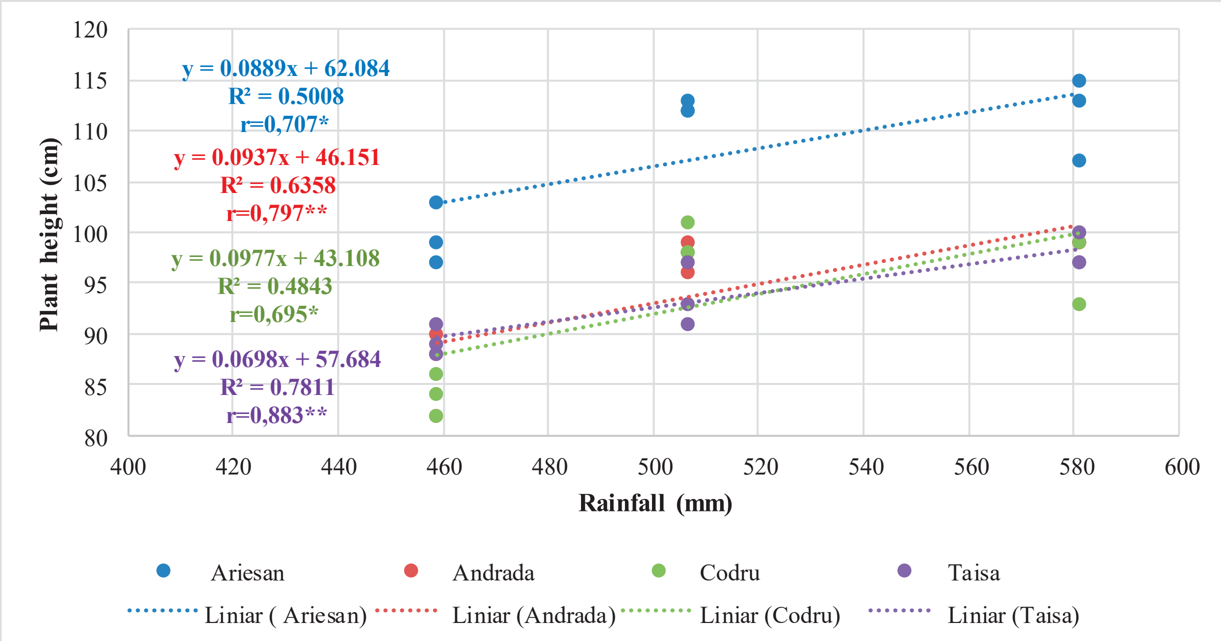

Figure 1. Correlation between rainfall and plant height

Other researchers have reported that generally grain yields increased with increasing nitrogen fertilization rate (Kadar et al., 2019; Guo et al., 2012). Abedi et al. in 2011 demonstrated that different N rates have a significant effect on increasing grain yield. This confirms belonging of winter wheat to the group of plants strongly responding to growth conditions and particularly to fertilization with nitrogen (Buckzek et al., 2018). Our experiment proves the same, the highest grain yield was obtained at the highest rate of nitrogen fertilizer applied (Table 2).

Environmental conditions also play a major role in variation of grain yield, According to Anderson et al,, 2004, even at large rainfall deficits during wheat growth, can be obtained higher yields. As Buckzek et al. (2018) shows, higher yield was obtained when the total rainfall during the growth period of winter wheat was high. Similar to his results the highest yield in our study was obtained in 2016 (total rainfall 580.9 mm), and the smallest in 2019 (total rainfall 458.7 mm) (Table 2).

Grain protein content

The grain protein content is dependent on genotype (Buckzek et al., 2018) but it is also clearly influenced by environmental variables such as nitrogen application, water access and temperature during growth especially through the grain filling period (Daniel and Triboi, 2000; Tea et al., 2004). These factors influence the rate and duration of wheat grain development, protein accumulation and starch deposition (Dupont and Altenbach, 2003). The most effective environmental factor on wheat quality is N fertilization (Abedi et al., 2011).

According to F test Genotype, Nitrogen fertilization and Season had strongly influenced grain protein content of the genotypes used in this study. Also the interaction between Genotype and Nitrogen fertilization, and the interaction between Genotype and Season had a significant influence on this trait (Table 2).

Duncan's Multiple Range test showed that from all four genotypes Arieşan had the highest grain protein content, the other three genotypes had a similar grain protein content. From all three N rates the highest grain protein content was obtained at N 100 kg ha^{-1}, and the environmental condition from 2015-2016 season influenced the most the accumulation of protein in winter wheat grain (Table 2).

Rain use efficiency (RUE) (grain yield/total seasonal rainfall, kg ha^{-1} mm^{-1})

According to Fu et al. (2013), RUE is an accurate indicator of agricultural productivity in relationship to the crop’s consumptive use of water, which is defined as the ratio of the net benefits from crop to the amount of water required to produce those benefits. Put simply, it means growing more food or gaining more benefits with less water.

Table 2. Genotype, nitrogen fertilization rate and season effects on winter wheat traits

Factor		Plant height (cm)	Grain yield (kg ha^{-1})	Grain protein content (%)
Genotype (G)	Arieşan	107.74a	6390b	12.98a
	Andrada	94.26b	7010a	11.44b
	Codru	93.48b	6840a	11.47b
	Taisa	93.67b	6040c	11.43b
Nitrogen fertilization (F)	0	95.31c	6140c	10.44c
	50	97.19b	6620b	11.90b
	100	99.36a	6960a	13.16a
Season (S)	2015-2016	101.25a	7310a	12.42a
	2017-2018	89.97b	6990b	11.66b
	2018-2019	100.64a	5420c	11.41c
F Test	G	105.958***	57.828***	62.070***
	F	16.297***	33.572***	406.602***
	S	127.248***	241.474***	35.721***
	GxF	0.322 ns	0,403 ns	5.574**
	GxS	4.256***	35.187***	5.183**
	FxS	0.474 ns	2.730*	1.020 ns
	GxFxS	1.339 ns	0.512 ns	0.722 ns
Mean		97.28	6572	11.83

Means followed by the same letter within a column are not significantly different according to Duncan's Multiple Range test ($p \leq 0.05$).
*,**,*** Significant at the 0.05, 0.01 and 0.0001 probability levels, respectively; ns: nonsignificant.

Duncan's Multiple Range test (Table 3) showed that Andrada and Codru had a significant higher RUE from all four genotype used in this experience, which means that this genotypes produced higher rate of grain yield per unit rainfall than Arieşan and Taisa. The highest RUE was recorded in 2018 when it rained least, the RUE decreased as mean annual precipitation increased as shown by Huxman et al. (2004). Nitrogen fertilization directly influenced RUE, as the rate of nitrogen increased, RUE increased too.

F test proved that all the experimental factors significantly influenced RUE, and the interaction between Genotype and Season had a significant influence on this parameter (Table 3).

According to Mandic et al. (2015), genotypes with improved RUE are particularly beneficial under low rainfall conditions. Our study shows that Taisa had better use of rainfall, followed by Arieşan, Codru and Andrada, since Taisa RUE value was significantly higher (Table 4).

Nitrogen agronomic efficiency (NAE) (kg grain increase kg^{-1} N applied)

This parameter was calculated to assess the potential yield increase in response to different N fertilizer rates, and it is an indicator of the amount of yield per unit of N fertilizer applied, and it is used to evaluate the ability of wheat plant to produce higher yield as related to N fertilization (Tedone et al., 2018).

The ratio of produced grain to N rate of applied fertilizer may be used to estimate NUE, and this ratio has been defined as agronomic efficiency (NAE) (Ladha et al., 2005; Stevens et al., 2005). As this calculation subtracts the yield of the control from the yield of the N treatment plot, this difference method assumes that N fertilization has had no additional positive effects on plant uptake of soil N, and that all other agronomic factors are considered equal between the respective treatments, (Stevens et al., 2005).

The highest NAE was recorded by Taisa which means that the increased yield obtained by Taisa it is due to the N fertilizer rate applied and this cultivar has the highest ability from all four cultivars to increase yield in response to the rate of Nitrogen fertilizer applied (Table 3).

Ayadi et al. (2015) showed that for durum wheat cultivars, the NAE average was more efficient at a lower nitrogen rate N 75 kg ha^{-1}, and less efficient at N 150 kg ha^{-1}. Similar results obtained López Bellido et al. (2001) after studying NAE for bread wheat cultivars at 50 kg ha^{-1} and 150 kg ha^{-1} rates of nitrogen fertilizer applied.

As the research of Mandic et al. (2015), shows that both NAE and NUE decreased when the amount of nitrogen rate increased, our experience proves the same (Table 3). Serret et al. (2008) reported that NAE significantly reduced in the highest N fertilizer level.

F test demonstrated that all the experimental factors and the interactions between these factors had a significant influence on NAE (Table 3).

Nitrogen use efficiency (NUE) (kg grain kg^{-1} N applied)

Nitrogen use efficiency NUE, which represents the kg of grain yield harvested per kg of N fertilizer applied, can be used as an index of total economic outputs relative to the use of all N sources (soil N and applied fertilizer) (Almaliev et al., 2012).

As other studies showed, our research confirms that N fertilization increased NUE, but the highest N level reduced NUE (Hooper, 2010; Almaliev et al., 2012). Somarin et al. (2010) and Noureldin et al. (2013) reported the same, that increased N level reduced NUE (Table 3).

Good et al. (2004) demonstrated that one of the strategies to improve yields is to choose crops with high N use efficiency (NUE) that can produce economic yield under limited water supply. The use of more nutrient efficient crops and varieties is important for maintaining yields while enhancing environmental sustainability. From our experience Andrada and Codru genotypes had the highest value of NUE which means that these cultivars have the ability to use more efficiently the nitrogen to obtain higher yields, they produces higher yields with less nitrogen fertilizer, followed by Arieşan and on the fourth place comes Taisa (Table 3).

Similar to our findings, Almaliev et al. (2012) proved that there are genotypic differences in nitrogen efficiency of wheat cultivars.

F test proved that. NUE was significantly influenced by all the experimental factors, and by the interactions between these factors, except the interaction between Genotype and Nitrogen fertilization (Table 3).

Table 3. Genotype, Nitrogen fertilization level and season effects on rain-use efficiency (RUE), N agronomic efficiency (NAE), and N use efficiency (NUE)

Factor		RUE kg ha^{-1} mm^{-1}	NAE kg grain increase kg^{-1} N applied	NUE kg grain kg^{-1} N applied
Genotype (G)	Arieşan	12.52b	9.24b	98.62b
	Andrada	13.70a	7.57c	107.04a
	Codru	13.36a	7.77c	105.0a
	Taisa	11.81c	11.37a	93.73c
Nitrogen fertilization (F)	0	11.98c	0c	0c
	50	12.96b	9.80a	132.61a
	100	13.60a	8.18b	69.59b
Season (S)	2015-2016	12.60b	4.39c	110.59a
	2017-2018	15.23a	8.69b	107.19b
	2018-2019	10.71c	13.89a	85.52c
F Test	G	43.034***	140.305***	59.626***
	F	33.348***	199.485***	1114.982***
	S	285.360***	1950.230***	180.956***
	GxF	0.476 ns	41.056***	1.544 ns
	GxS	32.367***	194.657***	36.344***
	FxS	2.656*	344.098***	17.165***
	GxFxS	0.551 ns	61.601***	5.285***
Mean		12.84	8.09	90.90

Means followed by the same letter within a column are not significantly different according to Duncan's Multiple Range test ($p \leq 0.05$).
*,**,*** Significant at the 0.05, 0.01 and 0.0001 probability levels, respectively; ns: nonsignificant.

CONCLUSIONS

Nitrogen fertilization and climatic conditions had a strong influence on plant height. The highest plant height was recorded when the nitrogen rate was the highest. Plant height of the four winter wheat cultivars from this study is genetically determinate and this trait is strongly influenced by the environmental factors. Plant height of Taisa and Andrada was strong correlated with rainfall, and plant height of Arieşan and Codru was moderate correlated with rainfall.

Grain yields increased with increasing nitrogen fertilization rate for all four cultivars. Andrada had the highest yield, followed by Codru, Arieşan and Taisa.

The grain protein content is determined by genotype but it is also clearly influenced by environmental variables such as nitrogen application, water access and temperature during growth especially through the grain filling period. From all four cultivars Arieşan had the highest grain protein content.

Andrada and Codru had a significant higher RUE from all four genotype used in this experience, which means that this genotypes produced higher rate of grain yield per unit rainfall than Arieşan and Taisa. The highest NAE was recorded by Taisa which means that the increased yield obtained by Taisa it is due to the N fertilizer rate applied and this cultivar has the highest ability from all four cultivars to increase yield in response to the rate of Nitrogen fertilizer applied. Andrada and Codru had the highest value of NUE, which means that these cultivars have the ability to use more efficiently the nitrogen to obtain higher yields, they produces higher yields with less nitrogen fertilizer, followed by Arieşan and on the fourth place come Taisa. Both NAE and NUE decreased when the amount of nitrogen rate increased.

REFERENCES

Abedi, T., Alemzadeh, A., Kazemeini, S.A. (2011). Wheat yield and grain protein response to nitrogen amount and timin. *AJCS,* 5(3), 330-336.

Ali, A., Ahmad, A., Syed, W.H., Khaliq, T., Asif, M., Aziz, M. et al. (2011). Effects of nitrogen on growth and yield components of wheat (report). *Science International (Lahore),* 24, 331-332.

Ali, A., Choudhry, M.A., Malik, M.A., Ahmad, R. and Saifullah (2000). Effect of various doses of nitrogen on the growth and yield of two wheat cultivar, *Pakistan Journal of Botany,* 3, 1004-1005.

Almaliev, M., Kostadinova, S., Panayotova, G. (2012). Nitrogen efficiency in Durum wheat. *Eco-Conference 2012, Ecological movement of Novi Sad*. https://www.researchgate.net/publication/321797291.

Anderson, W.K., Sharma, D.L., Shackley, B.J., D'antuono, M.F. (2004). Rainfall, sowing time, soil type and cultivar influence optimum plant population for wheat in Western Australia, *Journal of Agricultural Research*, 55, 921-930.

Ayadi, A., Chamekh, Z., Karmous, C., Jalloli, S., Ahmed, N., Hammami, Z., Rezgui, S., Trifa, Y. (2015). Evaluation of grain yield and nitrogen agronomic efficiency (NAE) in Tunisian durum wheat cultivars (*Triticum turgidum* ssp. *durum*). *Journal of new sciences, Agriculture and Biotechnology*, 15(4), 511-516.

Buckzek, J., Jarecki, W., Bobrecka-Jamro, D. (2018). Productivity and quality of grain of hybrid wheat depending on the selected agro-environmental factors. *Romanian Biotechnological Letters*, 23(6), 14203-14211, DOI: 10.26327/RBL2018.225.

Daniel, C., Triboi, E. (2000). Effects of temperature and nitrogen nutrition on the grain composition of winter wheat: effects on gliadin content and composition. *J. Cereal Sci.,* 32, 45-56.

Dardel, C., Kergoat, L., Hiernaux, P., Grippa, M., Mougin, E., Ciais, P., Nguyen, C.C. (2014). Rain-Use-Efficiency: What it Tells us about the Conflicting Sahel Greening and Sahelian Paradox. *Remote Sens*., 6, 3446-3474; doi:10.3390/rs6043446.

Delogu, G., Cattivelli, L., Pecchioni, N., De Falcis, D., Maggiore, T. and Stanca, A.M. (1998). Uptake and agronomic efficiency of nitrogen in winter barley and winter wheat. *European Journal of Agronomy*, 9, 11-20. https://doi.org/10.1016/S1161-0301(98)00019-7.

Dupont, F.M., Altenbach, S.B. (2003). Molecular and biochemical impacts of environmental factors on wheat grain development and protein synthesis. *J. Cereal Sci.* 38, 133-146.

Foulkes, M.J., Hawkesford, P.B., Barraclough, M.J., Holdsworth, S., Kerr, S., Kightley, S. et al. (2009). Identifying traits to improve the nitrogen economy of wheat: recent advances and future prospects. *Field Crops Research*, 114, 329-342.

Fu, J.E., Pang, Z., Lu, J. (2013). Research on Assessment Method of Winter Wheat Water Use Efficiency Based on ET and Biomass with Remote Sensing. In: Bian F., Xie Y., Cui X., Zeng Y. (eds) *Geo-Informatics in Resource Management and Sustainable Ecosystem. GRMSE 2013. Communications in Computer and Information Science,* Vol. 399. Springer, Berlin, Heidelberg. DOI: https://doi-org.am.e-nformation.ro/10.1007/978-3-642-41908-9_39.

Hooper, P. (2010). *Strategic applications of nitrogen fertiliser to increase the yield and nitrogen use efficiency of wheat*. Thesis MSc. University of Adelaide, School of Agriculture, Food and Wine, Adelaide, South Australia, Australia.

Good, A., Shrawat, A., Muench, D. (2004). Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? *Trends in Plant Science* 9, 597-605.

Guo, S., Zhu, H., Dang, T., Wu, J., Liu, W., Hao, M., Li, Y., Syers, J.K. (2012). Winter wheat grain yield associated with precipitation distribution under long-term nitrogen fertilization in the semiarid Loess Plateau in China. *Geoderma* 189-190, 442-450.

Guttieri, M.J., Frels, K., Regassa, T., Waters, B.M., Baenziger, S.P. (2017). Variation for nitrogen use efficiency traits in current and historical great plains hard winter wheat. *Euphytica* 213(87), DOI 10.1007/s10681-017-1869-5.

Gwenzi, W., Taru, M., Mutema, Z., Gotosa, J. and Mushiri, S.M. (2008). Tillage system and genotype effects on rainfed maize (*Zea mays* L.) productivity in semi-arid Zimbabwe. *African Journal of Agricultural Research,* 3, 101-110.

Halvorson, A.D., Nielsen, D.C., Reule, C.A., (2004). Nitrogen management - nitrogen fertilization and rotation effects on no-till dryland wheat production. *Agronomy Journal,* 96, 1196-1201.

Huxman, T., Smith, M., Fay, P. et al. (2004). Convergence across biomes to a common rain-use efficiency. *Nature,* 429, 651-654. https://doi.org/10.1038/nature02561.

Iqtidar, H., Ayyaz, K.M. and Ahmad, K.E. (2006). Bread wheat varieties as influenced by different nitrogen levels. *Journal of Zhejiang University-SCIENCE B,* 7, 70-78.

Kadar, R., Muntean, L., Racz, I., Ona, A.D., Ceclan, A., Hirişcău, D. (2019). The Effect of Genotype, Climatic Conditions and Nitrogen Fertilization on Yield and Grain Protein Content of Spring Wheat (*Triticum aestivum* L.). *Not. Bot. Horti. Agrobo.*, 47(2), 515-521, DOI:10.15835/nbha47211376.

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J., Van Kessel, C. (2005). Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Advances in Agronomy,* 87, 85-156.

Li, S.X., Wang, Z.H., Malhi, S.S., Li, S.Q., Gao, Y.J., Tian, X.H. (2009). Nutrient and water management effects on crop production, and nutrient and water use efficiency in dryland areas of China. *Advances in Agronomy*, 102, 223-265.

López Bellido, R.J. and López Bellido, L. (2001). Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage crop rotation and N fertilization. *Field Crops Research*, 71, 31-40.

Mandic, V., Krnjaja, V., Tomic, Z., Bijelic, Z., Simic, A., Muslic, D.R., Gogic, M. (2015). Nitrogen fertilizer influence on wheat yield and use efficiency under different environmental conditions. *Chilean J. Agric. Res.* 75(1), 92-97. http://dx.doi.org/10.4067/S0718-58392015000100013.

Moll, R.H., Kamprath, E.J. and Jackson, W.A. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal*, 74, 562-564.

Muntean, L.S., Cernea, S., Morar, G., Duda, M.M., Vârban, D.I., Muntean, S., Moldovan, C. (2014). *Fitotehnie. Ed. a III-a*, Ed. Risoprint, Cluj-Napoca.

Noureldin, N.A., Saudy, H.S., Ashmawy, F., Saed, H.M. (2013). Grain yield response index of bread wheat cultivars as influenced by nitrogen levels. *Annals of Agricultural Science,* 58, 147-152.

Pavuluri, K., Chim, B.K., Griffey, C.A., Reiter, M.S., Balota, M., Thomason, W.E. (2015). Canopy spectral reflectance can predict grain nitrogen use efficiency in soft red winter wheat. *Precision Agric.,* 16, 405-424. DOI 10.1007/s11119-014-9385-2.

Ripberger, E.I., Bome, N.A., Trautz, D., Russ, J. (2016). Variation in the plant height of spring common wheat (*Triticum aestivum* L.) hybrid forms under different ecological and geographical conditions. *Russian Journal of Genetics:Applied Research,* 6(3), 258-263. https://doi-org.am.e-nformation.ro/10.1134/S2079059716030102.

Serret, M.D., Ortiz-Monasterio, I., Pardo, A., Araus, J.L., (2008). The effect of urea fertilization and genotype on yield, NUE, $\delta^{15}N$ and $\delta^{13}C$ in wheat. *Annals of Applied Biology* 153, 243-257.

Somarin, S.J., Mahmoodabad, R.Z., Yari, A., Khayatnezhad, M., Gholamin, R. (2010). Study of agronomical nitrogen use efficiency of durum wheat affected by nitrogen fertilizer and plant density. *World Applied Sciences Journal,* 11, 674-681.

Stevens, W.B., Hoeft, R.G., Mulvaney, R.L. (2005). Fate of Nitrogen-15 in long-term Nitrogen rate study: II Nitrogen Uptake efficiency. *Agronomy Journal*, 97, 1046-1053.

Tea, I., Genter, T., Naulet, N., Boyer, V., Lummerzheim, M., Kleiber, D. (2004). Effect of foliar sulfur and nitrogen fertilization on wheat storage protein composition and dough mixing properties. *Cereal Chem*, 81, 759-766.

Tedone, L., Alhajj, Ali, S., 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. DOI: 10.1016/j.jclepro.2017.11.215.

Turner, N.C. (2004). Agronomic options for improving rainfall-use efficiency of crops in dryland farming systems. *Journal of Experimental Botany,* 55, 2413-2425.

Turner, N.C., Asseng, S. (2005). Productivity, sustainability, and rainfall-use efficiency in Australian rainfed Mediterranean agricultural systems. *Australian Journal of Agricultural Research*, 56, 1123-1136.

Voziyan, V.I. (2014). The productive and adaptive potential of different varieties of soft winter wheat and the impact of environmental conditions on its level. *Zernobobovye Krupyanye Kul't*, 1(1), 100-105.