Acta Alimentaria 51 (2022) 2, 249–258
DOI: 10.1556/066.2022.00022

AKADÉMIAI KIADÓ

The effect of nitrogen fertilisation on yield and quality of maize (*Zea mays* L.)

S. Omar*, R. Abd Ghani, H. Khaeim, A.H. Sghaier and M. Jolánkai

Department of Agronomy, Hungarian University of Agriculture and Life Sciences, H-2100 Gödöllő, Páter Károly utca 1, Hungary

SHORT COMMUNICATION

Received: January 23, 2022 • Accepted: April 13, 2022
Published online: May 31, 2022

ABSTRACT

Nitrogen (N) is one of the most essential nutrients affecting the yield and quality of maize (*Zea mays* L.). A field experiment was conducted at the experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Hungary, to investigate the effect of nitrogen fertilisation on the yield and quality of maize. The experimental site included four observation plots with a net of 2 × 5 m size. Four N levels of T1, T2, T3, and T4 were sprayed at indicated plants in four replications according to treatment viz. 0, 50, 100, and 150 kg N ha^{-1}. Nitrogen application in general does not significantly affect maize yield, its components, or grain quality. However, out of the four N treatments, the optimal N application between 50–100 kg N ha^{-1} potentially increased the yield, also the total expression of protein and starch contents in maize can be achieved with the right amount of N fertiliser, indicating that the treatment could produce a high grain yield as well as high protein and starch contents. Good N fertilising practice will boost the maize's nutritional value and make it more significant in the agriculture in the future. In addition, more research and assessment are essential to acquire the most benefit from the effect of optimal N application on maize yield and quality, and the findings could be beneficial to researchers and growers.

KEYWORDS

maize, nitrogen, yield, yield components, grain quality

* Corresponding author. E-mail: hana@mardi.gov.my

1. INTRODUCTION

Maize (*Zea mays* L.), also known as corn, was the first global grain crop, with 1,125 million tonnes of production accounting for more than 40% of total grain production. Maize is also a valuable grain crop after wheat in Hungary, which is the 3rd largest maize producer in Europe with 8.4 million tonnes at about 12% of total production out of 67.8 million tonnes in 2020 (Eurostat, 2021).

However, now the world faces climate change that will affect potential productivity, soil fertility, and nutrient management. These factors are the main contributors to low yield production. Thus, the development of superior cultivars and improved technology could be the key to doubling yields and reducing the impact of vulnerability to climate change (Loch, 2015). As far as climate change, plant nutrients are both a part of the problem and a part of the solution. Improper use of nitrogen (N) is associated with greenhouse gases emission (GHG), while its deficiency is the main barrier to obtaining high yield and quality (Majumdar, 2018).

Nitrogen (N) is the most important essential element in agricultural production, and its deficiency is one of the main yield-limiting factors for grain production. According to Hammad et al. (2011), maize grain yields positive responses to applied N, but over-fertilisation with N is a common problem for the maize rotation system. Excessive N present in the soil cannot be absorbed by crops and instead reduces N use efficiency, wastes resources, and degrades the environment. The use of N fertiliser for grain production has made a substantial contribution to global food security (Zhai et al., 2019).

Fertiliser consumption in Hungary currently ranges from 60 to 70 kg per hectare for N, with yields production of roughly seven metric tons per hectare. According to Loch (2015), reducing fertiliser application results in decrease in the yield averages of maize. Similarly, Moser et al. (2006) found that maize plots produced higher yields when given large N doses. However, the increase of N application will not stimulate the additional number of grains but increase the 1,000 grain weight. Meanwhile, fertilisation together with plant protection will boost yields. While the effect may not be significant, it does have the potential to minimise the consumption of N (Árendás et al., 2012). According to Nagy (2012) and Árendás et al. (2014), nutrient application, which has a major impact on production and quality, is important. Moreover, proper nutrients application is essential in modern crop production, where without it crop safety would be compromised (Pepó, 2017). Furthermore, water stress caused by climate change might reduce yields; however, choosing stress-resistant maize hybrids can help plants cope with high temperatures (Marton et al., 2012).

In maize, effective nitrogen application improves quality characteristics such as grain protein content (Amanullah et al., 2009) and affects grain protein concentration more consistently, with a large effect size for protein as N fertilizer levels rise (Correndo et al., 2021). However, the low and high N dose rates can also affect the quality of maize. Therefore, ensuring the optimum supply of N dose is essential to improving maize quality (Hammad et al., 2011). Considering the foregoing, the current study was carried out to quantify the effect of N fertilisation on grain yield and its components, and grain quality parameters like moisture, oil, protein, and starch concentrations for maize crops.

2. MATERIALS AND METHODS

2.1. Experimental site

A field experiment was conducted to investigate the effect of N levels on yield and quality of maize at an experimental plot of the Department of Agronomy, The Hungarian University of Agriculture and Life Sciences, Hungary, in 2021. This experimental site is located in a hilly section of the country, near-average climatic zone, 242 m above sea level (47046′N, 19021′E) on sandy loam, brown forest soil (Chromic Luvisol). The humus content was 3.12%, while sand, silt, and clay contents were 10%, 54%, and 36% respectively, at the top of the 20 cm layer (Tóth et al., 2018). The soil had a slightly acidic pH of 6.2 (H_2O) and a pH of 5.1 (KCl) (Dekemati et al., 2020). In 2021, the average annual precipitation in Gödöllő was 531.0 mm (20.91 inches). In Hungary, the precipitation estimation is between 400 and 500 mm (15.8–19.7 inches) per year, the western parts are slightly wetter than the eastern.

2.2. Treatment

The maize hybrid seed variety MV 277 was sown on 26 May 2021 using a Wintersteiger Plotman maize planter machine with a plant density of 75 thousand plant ha^{-1}. The experimental site consisted of four observation plots with N levels of T1 (0 kg N ha^{-1}), T2 (50 kg N ha^{-1}), T3 (100 kg N ha^{-1}), and T4 (150 kg N ha^{-1}) of net sizes 2 × 5 m. Each treatment contained four replications with ten plants per replication. The various treatments were applied as spraying on the indicated plants during the vegetative growth stage (V12). Standard agronomic practices were applied uniformly to all treatments.

2.3. Measurement

At harvest, the total number of cobs was recorded from each plot. The seed obtained from four tagged plants per replications after threshing, cleaning, and sun-drying were measured for cob weight, the number of rows per cob, grain number per cob, also the grain yields per plot were calculated and expressed in kilograms. 1,000 grains was counted using Contador 2 seed counter then weighted on SCALTEC electric weight balance to determine the 1,000 grain weight value. The grain quality parameters like moisture content, oil, protein, and starch concentrations were obtained using the Mininfra Grain Analyser.

2.4. Statistical analysis

One-way ANOVA was used to examine the effect of N fertilisation on grain yield and its components, as well as grain quality parameters (moisture, oil, protein, and starch concentrations) of maize at $P \leq 0.05$ probability level. Differences among treatment means were compared by Post Hoc Multiple Comparison tests using Least Significant Difference (LSD) at $P \leq 0.05$. Analyses were conducted with the IBM SPSS version 23.

3. RESULTS AND DISCUSSION

3.1. Effect of nitrogen on grain yield and its components

The ANOVA table (Table 1) shows that there were no differences in grain yield, cob weight, row number/cob, grain number/row, grain number/cob, 1,000 grain weight, and grain oil

Table 1. Analysis of variance of grain yield, cob number/plot, cob weight, row number/cob, grain number/row, grain number/cob, and 1,000 grain weight at different levels of N treatments (0, 50, 100, and 150 kg N ha^{-1})

Characteristic	Source of variation	Sum of Squares	df	Mean Square	*F*	Sig.
Grain yield/plot (kg)	Between groups	0.515	3	0.172	1.597	0.242
	Within groups	1.289	12	0.107		
	Total	1.804	15			
Cob number/plot	Between groups	26.688	3	8.896	4.798	0.020
	Within groups	22.250	12	1.854		
	Total	48.938	15			
Cob weight (g)	Between groups	6073.122	3	2024.374	2.621	0.099
	Within groups	9270.033	12	772.503		
	Total	15343.154	15			
Row number/cob	Between groups	2.688	3	0.896	0.782	0.527
	Within groups	13.750	12	1.146		
	Total	16.438	15			
Grain number/row	Between groups	38.688	3	12.896	0.898	0.470
	Within groups	172.250	12	14.354		
	Total	210.938	15			
Grain number/cob	Between groups	19556.188	3	6518.729	1.496	0.265
	Within groups	52275.750	12	4356.312		
	Total	71831.938	15			
1,000 grain weight	Between groups	761.612	3	253.871	0.410	0.748
	Within groups	7422.223	12	618.519		
	Total	8183.834	15			

df: Degree of freedom; Sig.: Significance; Significance level = $P \leq 0.05$.

content between the groups for various N treatments (0, 50, 100, and 150 kg N ha^{-1}). However, the different levels of N treatments showed significant differences on cob number (F (3,12) = [4.798], P= 0.02).

The results (Table 2) demonstrate that the maximum grain yield per plot (11.50 kg ± 1.17) was provided by treatment T2 (50 kg N ha^{-1}), while the minimum (9.47 kg ± 1.71) was recorded in the plot with the highest N application T4 (150 kg N ha^{-1}). The cob number/plot produced statistically similar values for N rates of 0, 100, and 150 kg N ha^{-1}, which were significantly lower than for the 50 kg N ha^{-1}. Nitrogen application at T2 (50 kg N ha^{-1}) resulted in maximum cob number/plot (17.25 ± 1.71) followed by T1 (0 kg N ha^{-1}), T4 (150 kg N ha^{-1}), and T3 (100 kg N ha^{-1}) with 14.75 ± 1.26, 14.25 ± 0.96, and 14.00 ± 1.41, respectively.

The maximum cob weight (254.18 ± 2.36 g) was recorded for treatment T3 (100 kg N ha^{-1}) and the lowest (207.75 ± 3.54 g) for the control treatment T1 (0 kg N ha^{-1}). Row number/cob values were statistically similar for all N treatments. N treatment at a rate of 100 kg N ha^{-1} provided the highest row number/cob (16.50 ± 1.00), whereas the lowest value (15.50 ± 1.00) was obtained for treatments T1 and T2 with 0 and 50 kg N ha^{-1}, respectively. The number of grains/row was not significantly affected by the different N rates, with the highest value (44.00 ± 2.00) obtained for T4 (150 kg N ha^{-1}) and the lowest (40.25 ± 2.75) for T1 (0 kg N ha^{-1}).

Table 2. Mean values (± standard deviation) and Post Hoc LSD test results of grain yield and its components at different nitrogen fertilisation levels

Treatment (kg N ha^{-1})	Grain yield/plot (kg)	Cob number/ plot	Cob weight (g)	Row number/ cob	Grain number/ row	Grain number/ cob	1,000 grain weight
T1 (0)	10.41±0.78^{a}	14.75±1.26^{ab}	207.75±3.54^{a}	15.50±1.00^{a}	40.25±2.75^{a}	625.50±76.65^{a}	241.67±36.17^{a}
T2 (50)	11.5±1.17^{a}	17.25±1.71^{a}	210.73±2.71^{a}	15.50±1.00^{a}	43.75±6.13^{a}	675.00±73.86^{a}	250.38±23.56^{a}
T3 (100)	10.47±1.39^{a}	14.00±1.41^{b}	254.18±2.36^{a}	16.50±1.00^{a}	43.75±2.87^{a}	722.00±65.44^{a}	238.73±21.70^{a}
T4 (150)	9.47±1.71^{a}	14.25±0.96^{b}	241.28±2.34^{a}	15.75±1.26^{a}	44.00±2.00^{a}	691.75±42.57^{a}	231.10±11.84^{a}
LSD ($P \leq$ 0.05)	NS	1.33	NS	NS	NS	NS	NS

*Means within columns followed by the same letters are not significantly different at $P \leq 0.05$ level according to Post Hoc LSD test; LDS (0.05) = Least significant difference at $P \leq 0.05$; NS = Not significant.

Grain number/cob of maize was not significantly affected by the different N rates (Table 2), however, treatment T3 (100 kg N ha^{-1}) provided the highest (722.00 ± 65.44) grain number/cob, followed by T4 (150 kg N ha^{-1}), T2 (50 kg N ha^{-1}), and T1 (0 kg N ha^{-1}) with values of 691.75 ± 42.57, 675.00 ± 73.86, and 625.50 ± 76.65, respectively. The application of N did not affect the 1,000 grain weight. Treatment T2 (50 kg N ha^{-1}) resulted in the maximum weight (250.38 ± 23.56) and it was statistically comparable to T1, T3, and T4 with 241.67 ± 36.17, 238.73 ± 21.70, and 231.10 ± 11.84, respectively.

According to our results, nitrogen application had no impact on maize grain yield and its components. This could be due to other factors contributing to maize grain yield, as researchers have shown that yield is influenced by several environmental or technological factors (Băşa et al., 2016). According to Ngoune and Shelton (2020), maize grain yield is affected by a number of factors, including technology (agricultural practices, management decisions, etc.), biology (diseases, insects, pests, weeds), and the environment (climatic conditions, soil fertility, topography, water quality, etc.). Also, an adjusted crop arrangement would increase maize production by an average of 18 percent, making it the most promising component studied according to Eash et al. (2019).

However, many studies have proven that increasing N levels in maize crops can increase grain yields (Reddy et al., 1985; Tsai et al., 1992), as N has a positive effect on plant growth, promoting and increasing the yield (Eltelib et al., 2006). Nitrogen deficiency will reduce vegetative and reproductive growth, which has the potential of reducing yield (Fageria and Baligar, 2005). It was fond in a previous research that grain yield rose as the amount of sprayed nitrogen increased up to a certain point, but levelled off after that, also, maize hybrids required the same amount of nitrogen for optimal grain yield (Tsai et al., 1992). Furthermore, if grain yield does not respond to an increase in N fertiliser rate, it shows that raising the N fertiliser rate is not a smart approach for achieving maximum grain yield (Hammad et al., 2011). In addition, Zhai et al. (2019) claimed that nitrogen application combined with proper tillage procedures has a considerable impact on grain yield, nitrogen uptake, and nitrogen use efficiency. They also indicated that for the best economic results, deep vertical rotary tillage with a N rate of 225 kg ha^{-1} was the best option.

According to the results, grain yield had no positive relationship with the number of cobs, cob weight, row number of one cob, number of grains/row, number of grains/cob, and 1,000 grains. However, according to Băşa et al. (2016), the application of 80 kg N ha^{-1} in maize crops increases the values of yield components (except 1,000 grain weight) and in turn increases grain yield. Similar findings have been revealed by Li et al. (2019), according to their study, there was a relationship between yield and agronomic characteristics such as the number of seeds/tassel, the weight of 1,000 seeds, plant height and tassel length, and all these factors contributed to high grain yields in rice.

3.2. Effect of nitrogen on grain quality

According to Table 3, there were significant differences in grain moisture content (F (3,12) = [74.935], P = 0.00), grain protein content (F (3,12) = [6.404], P = 0.08), and starch concentration (F (3,12) = [3.621], P = 0.45) between the groups with different N treatments (0, 50,100 and 150 kg N ha^{-1}). However, oil content was similar for all treatments (F (3,12) = [2.507], P = 0.11).

Table 3. Analysis of variance of grain quality parameters like moisture, oil, protein, and starch contents at four levels of N fertilisation (0, 50, 100, and 150 kg N ha^{-1})

Characteristic	Source of variation	Sum of Squares	df	Mean Square	*F*	Sig.
Moisture (%)	Between groups	7.213	3	2.404	74.935	0.000
	Within groups	0.385	12	0.032		
	Total	7.598	15			
Oil (%)	Between groups	0.061	3	0.020	2.507	0.108
	Within groups	0.097	12	0.008		
	Total	0.157	15			
Protein (%)	Between groups	0.867	3	0.289	6.404	0.008
	Within groups	0.542	12	0.045		
	Total	1.409	15			
Starch (%)	Between groups	0.962	3	0.321	3.621	0.045
	Within groups	1.063	12	0.089		
	Total	2.024	15			

df: Degree of freedom; Sig.: Significance; Significance level = $P \leq 0.05$.

The results reveal that levels of nitrogen have a considerable impact on grain moisture content (Table 4). Treatment T3 (100 kg N ha^{-1}) provided the highest (14.43 ± 0.15%) grain moisture content, while the highest N rate (treatment T4) provided the lowest (12.65 ± 0.10%) grain moisture content. N treatment at 150 kg N ha^{-1} resulted in the highest oil content (3.53 ± 0.06%), but the differences were not statistically significant. The protein content was significantly affected by levels of N. Maximum protein content (5.23 ± 0.12%) was obtained for treatment T2 (50 kg N ha^{-1}) and T1 (0 kg N ha^{-1}) with no statistical differences, and the lowest (4.64 ± 0.10%) value was presented by T4 (150 kg N ha^{-1}). Starch content was significantly affected by N rates (Table 4), the highest (72.43 ± 0.33% and 72.43 ± 0.22%) values were recorded for treatments T3 and T4, followed by T2 and T1 with 71.98 ± 0.37% and 71.90 ± 0.24%, respectively.

In general, the grain yield of maize crops increases in response to *N*, and this condition is closely related to grain quality such as moisture, oil, protein, and starch content. However, the association between grain quality and *N* value was not significant in this study in contrast to the results discovered by Eltelib et al. (2006), where nitrogen significantly increased the protein

Table 4. Mean values (± standard deviation) and Post Hoc LSD test results of grain quality parameters (moisture, oil, protein, and starch contents) at four levels of N fertilisation

Treatment (kg N ha^{-1})	Moisture (%)	Oil (%)	Protein (%)	Starch (%)
T1 (0)	13.58 ± 0.30^{b}	3.42 ± 0.12^{a}	4.99 ± 0.32^{ab}	71.90 ± 0.24^{b}
T2 (50)	13.00 ± 0.08^{c}	3.39 ± 0.07^{a}	5.17 ± 0.23^{a}	71.98 ± 0.37^{ab}
T3 (100)	14.43 ± 0.15^{a}	3.37 ± 0.10^{a}	5.23 ± 0.12^{a}	72.43 ± 0.33^{a}
T4 (150)	12.65 ± 0.10^{c}	3.53 ± 0.06^{a}	4.64 ± 0.10^{b}	72.43 ± 0.22^{a}
LSD ($P \leq 0.05$)	0.17	NS	0.21	0.29

*Means within columns followed by the same letters are not significantly different at $P \leq 0.05$ level according to Post Hoc LSD test; LDS (0.05) = Least significant difference at $P \leq 0.05$; NS = Not significant.

content of forage maize. Thus, recent research has demonstrated that increased N levels would increase seed protein content (SPC) in maize. On the other hand, low N conditions not only restrict grain yield but also grain quality including moisture and protein contents (Tsai et al., 1992; Hammad et al., 2011).

Since no difference was found in the effects of different N treatments in our study, we can only conclude that the optimal efficiency of N fertilising is between 50–100 kg N ha^{-1}. Further studies are needed to be able to determine the optimal application of N more accurately. Cultivation practices play an important role in improving grain yield and grain quality beside technology, biology, and the environment.

4. CONCLUSIONS

This study assessed the effect of N fertilisation on maize yield and quality. The findings revealed that increased fertiliser application had no significant impact on either yield and its components or grain quality, such as moisture, oil, protein, and starch contents. However, out of the four N levels applied, the optimal N application between 50–100 kg N ha^{-1} might potentially increase the yield, indicating that N treatment has the ability to produce higher grain yield as well as higher protein and starch contents. Furthermore, total expression of protein and starch contents in maize can be achieved with the right amount of N fertiliser, boosting its nutritional value and making it of greater agricultural importance in the future. More research and assessment are essential to acquire the most benefit from N application on maize yield and quality, and the findings will be beneficial to researchers and agricultural producers as well.

ACKNOWLEDGEMENTS

This research was supported by the Doctoral Program of the Hungarian University of Agriculture and Life Sciences, Hungary. The authors would like to express their gratitude to all colleagues and the technical staff both in the field and laboratories for their assistance and valuable contribution to this study.

REFERENCES

Amanullah, Khattak, R.A., and Khalil, S.K. (2009). Plant density and nitrogen effects on maize phenology and grain yield. *Journal of Plant Nutrition*, 32(2): 246–260.

Árendás, T., Berzsenyi, Z., and Bónis, P. (2012). Agronomic research in Martonvásár, aimed at promoting the efficiency of field crop production. *Acta Agraria Debreceniensis,* 49: 89–93. https://doi.org/10.34101/actaagrar/49/2502.

Árendás, T., Bónis, P., Micskei, Gy., Sugár, E., Szőke, Cs., Marton, L.Cs., and Berzsenyi, Z. (2014). A kukorica termésreakciója és termésstabilitása N-trágyázási tartamkísérletekben (Yield reaction and yield stability of maize in N-fertilization duration experiments). In: Pepó, P. and Csajbók, J. (Eds.) *XIIIth congress of the European society for Agronomy (ESA): Book of abstracts*. Debrecen, University of Debrecen, pp. 23–28.

Bășa, A.G., Ion, V., Dumbravă, M., Temocico, G., Epure, L.I., and Ștefan, D. (2016). Grain yield and yield components at maize under different preceding crops and nitrogen fertilization conditions. *Agriculture and Agricultural Science Procedia*, 10: 104–111. https://doi.org/10.1016/j.aaspro.2016.09.025.

Correndo, A.A., Fernandez, J.A., Vara Prasad, P.V., and Ciampitti, I.A. (2021). Do water and nitrogen management practices impact grain quality in maize? *Agronomy*, 11(9): 1851, 14 pages. https://doi.org/10.3390/agronomy11091851.

Dekemati, I., Simon, B., Bogunovic, I., Kisic, I., Kassai, K., Kende, Z., and Birkás, M. (2020) Long term effects of ploughing and conservation tillage methods on earthworm abundance and crumb ratio. *Agronomy,* 10(10): 1552, https://doi.org/10.3390/agronomy10101552.

Eash, L., Fonte, S.J., Sonder, K., Honsdorf, N., Schmidt, A., Govaerts, B., and Verhulst, N. (2019). Factors contributing to maize and bean yield gaps in Central America vary with site and agroecological conditions. *Journal of Agricultural Science*, 157(4): 300–317, https://doi.org/10.1017/S0021859619000571.

Eltelib, H.A., Hamad, M.A., and Ali, E.E. (2006). The effect of nitrogen and phosphorus fertilization on growth, yield, and quality of forage maize (*Zea mays* L.). *Journal of Agronomy,* 5(3): 515–518.

Eurostat (2021). Crop production in national humidity, Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_cpnh1&lang=en (Accessed: 10 January 2022).

Fageria, N.K. and Baligar, V.C. (2005). Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy*, 88: 97–185, https://doi.org/10.1016/S0065-2113(05)88004-6.

Hammad, H.M., Ahmad, A., Khaliq, T., Farhad, W., and Mubeen, M. (2011). Optimizing rate of nitrogen application for higher yield and quality in maize under semiarid environment. *Crop and Environment*, 2(1): 38–41.

Li, R., Li, M., Ashraf, U., Liu, S., and Zhang, J. (2019). Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. *Frontiers in Plant Science*, https://doi.org/10.3389/fpls.2019.00543.

Loch, J. (2015). Nutrient management in Hungary - a review. *Agrokémia és Talajtan*, 64(2): 373–382. https://doi.org/10.1556/0088.2015.64.2.5.

Majumdar, K. (2018). Does improved plant nutrition provide a credible entry point for climate and weather adaptive crop production? *Journal of the Indian Society of Soil Science*, 66: S84–S103.

Marton, L.Cs., Árendás, T., and Berzsenyi, Z. (2012): Martonvásári kukorica hibridek a szárazságban (Martonvásár maize hybrids in drought.). *Martonvásár*, 24(2): 4–7.

Moser, S.B., Feil, B., Jampatong, S., and Stamp, P. (2006). Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. *Agric. Water Manage*, 81(1–2): 41–58.

Nagy, J. (2012). The effect of fertilization and precipitation on the yield of maize (*Zea mays* L.) in a long-term experiment. *Időjárás,* 116: 39–52.

Ngoune, L.T. and Shelton, C.M. (2020). Factors affecting yield of crops. In: Amanullah, A. (Ed.), *Agronomy – climate change and food security*, IntechOpen, London. https://doi.org/10.5772/intechopen.90672.

Pepó, P. (2017). Tartamkísérletek mint a klímaváltozás indikátorai (Duration experiments as indicators of climate change). *Növénytermelés*, 66(3): 33–46.

Reddy, K.P., Subhani, S.M., Khan, P.A., and Kumar, K.B. (1985). Effect of light and benzyladenine on dark-treated growing rice (*Oryza sativa*) leaves II. Changes in peroxidase activity. *Plant and Cell Physiology*, 26(6): 987–994, https://doi.org/10.1093/oxfordjournals.pcp.a077018.

Tóth, E., Gelybó, G., Dencso, M., Kása, I., Birkás, M., and Horel, Á. (2018). Soil CO_2 emissions in a long-term tillage treatment experiment. *Soil Management and Climate Change: Effects on Organic Carbon,* *Nitrogen Dynamics, and Greenhouse Gas Emissions*, 293–307. https://doi.org/10.1016/B978-0-12-812128-3.00019-7.

Tsai, C.Y., Dweikat, I., Huber, D.M., and Warren, H.L. (1992). Interrelationship of nitrogen nutrition with maize (*Zea mays*) grain yield, nitrogen use efficiency and grain quality. *Journal of the Science of Food and Agriculture*, 58(1): 1–8. https://doi.org/10.1002/jsfa.2740580102.

Zhai, L., Xu, P., Zhang, Z., Wei, B., Jia, X., and Zhang, L. (2019). Improvements in grain yield and nitrogen use efficiency of summer maize by optimizing tillage practice and nitrogen application rate. *Agronomy Journal*, 111(2): 666–676. https://doi.org/10.2134/agronj 2018.05.0347.