https://doi.org/10.17221/115/2021-PSE

Effect of agrotechnical factors on soil chemical traits and maize yield on Chernozem in the long-term experiment

*Peter Pepó**

Institute of Crop Sciences, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary

**Corresponding author: pepopeter@agr.unideb.hu*

Citation: Pepó P. (2021): Effect of agrotechnical factors on soil chemical traits and maize yield on Chernozem in the long-term experiment. Plant Soil Environ., 67: 453–459.

Abstract: The effect of agrotechnical elements (crop rotation, fertilisation, irrigation) on maize yield and various chemical characteristics of the soil (pH_{H2O}, pH_{KCl}, hydrolytic acidity (y_1)) were examined in a long-term experiment (established in 1983) on calcareous Chernozem in the Hajdúság region of Hungary. The yield obtained in 2019 showed the favourable water supply of the crop year and outstanding nutrient utilisation of maize. In the control (non-fertilised) treatments, maize yield was 8 t/ha in monoculture, 11 t/ha in biculture and 12 t/ha in triculture, while the highest yield obtained with the optimum fertiliser treatment increased to 13, 13.5 and 14 t/ha, respectively. In the long-term experiment established 35 years ago, the pH values of the soil greatly decreased in comparison to the initial value. The following ranges were observed in monoculture: 5.57–6.49 (pH_{H2O}), 4.69–5.34 (pH_{KCl}), in biculture: 5.22–6.62 (pH_{H2O}) and 4.36–5.68 (pH_{KCl}), and in triculture: 5.46–6.29 (pH_{H2O}), and 4.56–5.24 (pH_{KCl}). Hydrolytic acidity values (mono y_1 = 7.75–14.75, bi y_1 = 11.50–23.00, tri y_1 = 10.13–18.38) showed strong soil acidity. In the long-term experiment, a moderate (0.512^{xx}, $LSD_{0.01}$=xx) correlation between fertilisation and yield and a moderate (0.397^{xx}) correlation between crop rotation and yield could be established on Chernozem. A moderately negative ($pH_{H2O} = -0.594^{xx}$, $pH_{KCl} = -0.543^{xx}$) correlation was found between the yield and pH values, while a moderately positive ($y_1 = 0.409^{xx}$) correlation was found between the hydrolytic acidity and yield.

Keywords: soil acidification; buffer capacity; soil fertility; *Zea mays* L.

Maize is one of the most important field crops globally. Although about 69% of the soils in Hungary have average to favourable properties, the national average yields of maize produced in Hungary (7–8 t/ha) lag significantly behind the important growing countries of the world (e.g. the USA reach 10–11 t/ha on an average of more than 30 million hectares).

Maize yield is significantly influenced by ecological, genetic and agrotechnical factors. Long-term experiments are the most suitable for the complex study of the effects of the factors and the elements of sustainable crop production (Johnston 1997, Hejcman and Kunzová 2010). In long-term experiments, Berzsenyi et al. (2011) found the effect of fertilisation to be 30.6%, that of the given hybrid to be 32.6%, and crop density to be 20.8% in terms of maize yield. The cultivation of maize in crop rotation is particularly important for plant protection reasons. Crop rotation can potentially have a positive effect on the agronomic and biological efficiency of other agrotechnical factors (Kurowski and Adamiak 2007, Vári and Pepó 2011). Sárvári (1995), Nagy (2005), Pepó (2006) and Széll et al. (2011) demonstrated a significant yield-increasing effect of fertilisation on maize in different long-term experiments. However, the yield-increasing effect of fertilisation can be greatly modified by water supply in maize production (Vad et al. 2007, Pepó 2009, Vári and Pepó 2011).

Maize is particularly sensitive to ecological conditions, i.e. high yields can be expected on good soils and with adequate water supply. The pH of Hungarian soils is extremely diverse (Várallyai et al. 1980). It

---

Supported by the EFOP-3.6.3-VEKOP-16-2017-00008, and by the European Union and the European Social Fund.

was found that 43% of soils could be classified as weakly acidic and 13% as strongly acidic. In addition to wet and dry sedimentation from industrial and residential pollution, high-dose fertilisation may have increased soil acidity in recent decades (Máté and Pusztai 1977, Murányi and Rédlyné 1986). At the same time, as a result of fertilisation, the nutrient supply of soils available to plants increased on the basis of long-term experiment data (Kátai 2006, 2015, Kátai et al. 2017). Similarly to many other international and Hungarian measurement results (Zhao et al. 2013, Geissler and Scow 2014), Kátai et al. (2018) observed a significant change in the pH and hydrolytic acidity (y_1) values of Chernozem in a long-term experiment in Debrecen. In monoculture maize production, pH_{H_2O} values of Chernozem ranged from 6.69 to 5.83, pH_{KCl} values from 5.55 to 4.86 and y_1 values from 6.45 to 11.08 during the 30 years after the establishment of the long-term experiment in 1983, depending on the fertiliser treatments (2013 data). Soil acidity increased with decreasing fertiliser doses (decreasing pH, increasing y_1 values). A similar trend was found by Kátai et al. (2018) in triculture crop rotation (pH_{H_2O} = 6.10–6.50, pH_{KCl} = 5.35–4.73, y_1 = 10.90–15.50).

Our study aimed at determining the effects of soil chemical traits (pH_{H_2O}, pH_{KCl}, y_1) on the yields of maize in different crop rotation (mono-, bi- and triculture) in a long-term experiment (Chernozem). Soil acidification is a serious problem not only in Hungary but also in the other well- and under-developed countries. It could modify and decline the soil fertility. This study wanted to examine the correlation among soil acidity traits and the yield of maize in a long-term experiment on Chernozem. Our hypothesis is that high yields can be obtained by optimisation of agrotechnical factors (crop rotation, fertilisation, irrigation, hybrid) even in the acid soil type.

MATERIAL AND METHODS

The long-term experiments are located in Hajdúság, 15 km from Debrecen (47°33'N, 21°27'E) at the Látókép Experiment Site of the Department of Crop Production and Landscape Ecology. The soil of the experimental area is calcareous Chernozem. The most important characteristics of soil at the time of establishment were as follows: the carbon content of the cultivated layer was 1.52–1.62%, the pH_{KCl} ranged between 6.36–6.58, and the AL-soluble P content was 58.5 mg P/kg, while the AL-soluble K content was 199.2 mg K/kg. The soil had favourable water management properties.

In the polyfactorial long-term experiment, the agrotechnical elements of maize cultivation (crop rotation, fertilisation, irrigation, crop density) were studied in special crop rotations. These treatments were as follows:

- crop rotation
- monoculture: maize
- biculture: wheat-maize
- triculture: soybean-wheat-maize
- fertilisation

Five increasing fertiliser doses were used in the experiment, of which the following were involved in this study:

- control
- N_{120} + PK
- N_{240} + PK

The whole amount of P and K, as well as 50% of N were applied in the autumn, while the other 50% of N was applied before sowing. The reason of splitting 50–50% of nitrogen was the leaching of nitrogen in autumn and winter period especially at high doses treatments.

- water supply

Two of the three water supply treatments were examined

- dry = no irrigation
- irrigated = terms (50 mm on 04-05/06/2019, and 50 mm on 14-15/07/2019)
- crop density

Of the three crop density values, the results obtained at the crop density of 72 500 plants per ha are included in this paper.

In the long-term experiment, the agrotechnical operations met the requirements of modern maize production. The P9241 cultivar was tested in the experiment.

Weather data for 2018/2019 (Table 1) show that the precipitation in the autumn-winter months was similar to the average, followed by dry spring with particularly favourable rainfall distribution corresponding to the water demand of maize (103.7 mm in May, 46.9 mm in June, 115.9 mm in July). During the growing season of maize, the average monthly temperatures, with the exception of June, were significantly higher than the 30-year average (1981–2010).

After harvest, soil samples were taken from the ploughed layer (0–30 cm) of the long-term experiment Chernozem of in four replicates per treatment on October 10, 2019. Six soil samples (1–1 kg) were

https://doi.org/10.17221/115/2021-PSE

Table 1. Agrometeorological parameters before and in the vegetation period of maize (Debrecen, 2018/2019)

Month	Temperature (°C)		Rainfall (mm)	
	2018/2019	mean of 30 years	2018/2019	mean of 30 years
October	12.3	10.4	10.1	37.9
November	6.2	4.6	52.0	41.6
December	–0.4	–0.1	50.9	43.7
January	–2.4	–1.4	36.1	29.7
February	2.6	0.1	6.7	31.0
March	8.1	5.1	9.4	30.2
April	12.4	11.1	38.7	52.8
May	13.1	16.6	103.7	64.0
June	22.0	19.4	46.9	66.5
July	20.5	21.3	115.9	66.1
August	22.2	20.7	14.4	49.0
Average (°C)	10.6	9.8		
Total (mm)			484.8	512.5

taken from each plot, from which an average sample was prepared in the chemical analyses. After drying the samples, the measurements were performed in the laboratory of the Institute of Agrochemistry and Soil Science. The pH was measured with 1 part soil and 2.5 parts distilled water (pH_{H_2O}) and with the addition of potassium chloride solution (pH_{KCl}). Hydrolytic acidity was determined as reported by Buzás (1988).

Mathematical-statistical evaluation of the data was performed using Microsoft Excel (2013) (USA) and SPSS for Windows 19.0 (USA).

RESULTS AND DISCUSSION

As a result of the excellent soil quality, relatively favourable precipitation of the 2019 vegetation period and its distribution, as well as the applied, near-optimal production technology, favourable yield results were achieved in our long-term experiment (Figure 1). In monoculture, the yield of maize varied between 8 026–13 451 kg/ha, in biculture between 10 858–13 915 kg/ha, and in triculture between 12 099–13 987 kg/ha, depending on the nutrient and water supply. These results provide good evidence of excellent physical, chemical and biological characteristics of the site soil and significant natural nutrient uptake capacity of maize. In the long-term experiment established in 1983, high yield levels in the control (non-fertilised) treatments were also achieved depending on the crop rotation: mono 8.0–8.4 t/ha, bi 10.9–11.4 t/ha, tri 12.1–12.6 t/ha. Fertilisation had a significant yield-increasing effect in monoculture production (4.0–5.0 t/ha), while much smaller fertilisation yield surpluses were obtained in biculture (2.0–2.5 t/ha) and triculture (1.0–1.5 t/ha). As a result of favourable rainfall and its distribution in the summer months, which is critical for the water supply of maize, the effect of irrigation (2 × 50 mm = 100 mm) was moderate. The yield surplus of irrigation varied between 400–700 kg/ha in monoculture,

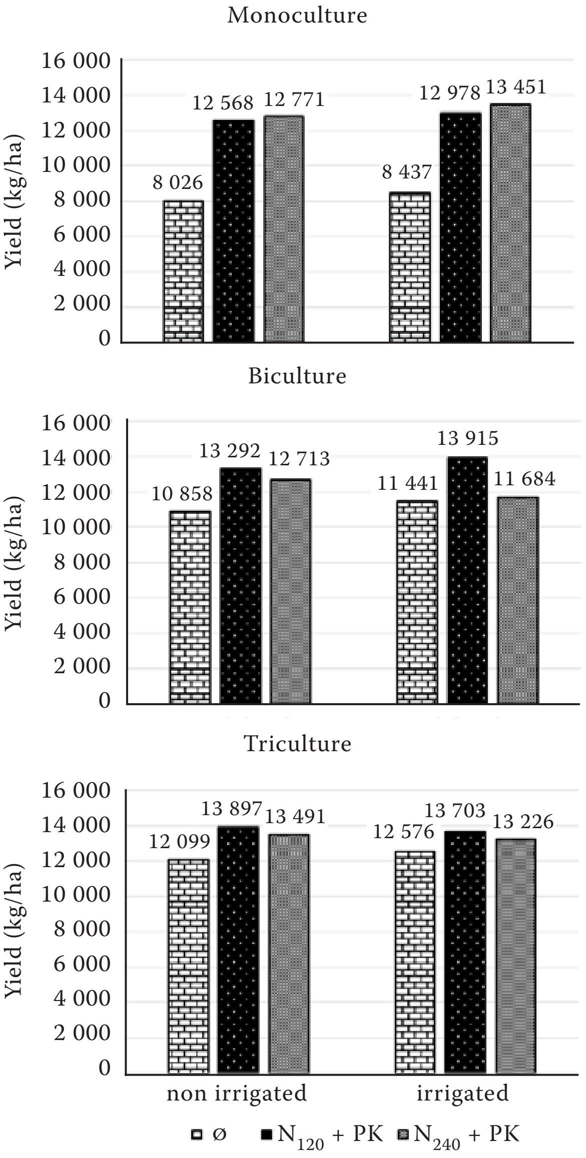

Figure 1. Effects of crop rotation, fertilisation and irrigation on the yield of maize in long-term experiment (Debrecen, Chernozem, 72 500/ha, data of 2019)

Table 2. Effects of croprotation and fertilisation on the chemical traits of Chernozem in a long-term experiment (Debrecen, soil sample: October 10, 2019)

Treatment	Fertilisation	pH_{H_2O}	pH_{KCl}	Hydrolytic acidity
Monoculture (forecrop = maize)				
Non-irrigated	Ø	6.49	5.34	9.38
	N_{120} + PK	6.37	5.33	7.75
	N_{240} + PK	5.93	5.04	13.25
Irrigated	Ø	6.43	5.29	7.88
	N_{120} + PK	6.13	4.96	10.13
	N_{240} + PK	5.57	4.69	14.75
$LSD_{0.05}$		0.21	0.26	0.84
Biculture (forecrop = winter wheat)				
Non-irrigated	Ø	6.12	4.96	12.13
	N_{120} + PK	5.63	4.69	15.38
	N_{240} + PK	5.22	4.36	23.00
Irrigated	Ø	6.62	5.68	7.67
	N_{120} + PK	5.98	5.16	11.50
	N_{240} + PK	5.52	4.76	14.13
$LSD_{0.05}$		0.20	0.24	0.86
Triculture (forecrop = soya bean – winter wheat)				
Non-irrigated	Ø	6.29	5.24	10.13
	N_{120} + PK	5.67	4.79	14.50
	N_{240} + PK	5.46	4.56	18.38
Irrigated	Ø	6.19	5.08	11.50
	N_{120} + PK	5.90	4.94	13.88
	N_{240} + PK	5.54	4.70	14.38
$LSD_{0.05}$		0.17	0.28	0.91

LSD – least significant difference

700–1 400 kg/ha in biculture, and 0–400 kg/ha in triculture in the different fertilisation treatments.

Data of soil analysis of the 35-year long-term experiment, namely the values of pH_{H_2O}, pH_{KCl} and hydrolytic acidity in monoculture, biculture and triculture are shown in Table 2. When establishing the long-term experiment, pH_{KCl} values ranged from 6.36 to 6.58, which, according to the measurements of Kátai et al. (2018) decreased to 5.55 in monoculture and 5.35 in triculture in the control treatment during the 30 years following establishment (2013 data). This decline continued. According to our measurement results (Table 2), the pH_{KCl} values varied between 5.29–5.34 in monoculture, 4.96–5.68 in biculture and 5.08–5.24 in triculture in the non-fertilised control treatment. Similar to pH_{KCl} values, pH_{H_2O} values also demonstrated the acidification processes of soil. In the control treatment, the pH_{H_2O} values varied in the range of 6.43–6.49 in monoculture, 6.12–6.62 in biculture and 6.19–6.29 in triculture. Increasing fertiliser doses (N_{120} + PK and N_{240} + PK) reduced pH_{H_2O} and pH_{KCl} in all three rotation regimes. The extent of this reduction was significant, representing a decrease of 0.3–1.0 absolute units. A similar decrease was obtained by Kátai et al. (2018) in previous studies (2013). Determining the pH_{H_2O} and pH_{KCl} values separately is important from the aspects of pedology and crop science because they have different effects on the acidification processes that take place in the soil. The pH_{H_2O} refers to the current acidity of the soil, while pH_{KCl} indicates the latent (hidden) acidity rate at which the soil acidification process continues. The greater the difference between the two values, the faster the process of soil acidification may progress in the future. If the data of 2013 in monoculture (Kátai et al. 2018) are

Table 3. Effect of agrotechnical factors and crop year on the yield of maize in long-term experiment (Debrecen, Chernozem, non-irrigated, 1986–2019)

Fertilisation treatment	Yield (kg/ha)					
	dry (12 years, 35%)		average (16 years, 47%)		rainy (6 years, 18%)	
Monoculture						
Control	3 743	1 315	6 284	4 344	7 330	5 501
N_{opt} + PK 180–240	5 058		10 628		12 831	
Biculture						
Control	7 279	924	9 439	2 795	9 977	2 101
N_{opt} + PK 120–180	8 203		12 234		12 078	
Triculture						
Control	6 708	891	9 682	1 991	9 916	2 344
N_{opt} + PK 60–120	7 599		11 673		12 260	

Mono: N_{opt} = 180–240; Bi: N_{opt} = 120–180; Tri: N_{opt} = 60–120

compared with our results (2019) the difference between pH_{H_2O} (current acidity) and pH_{KCl} (hidden acidity) shows the same deviation (differences pH_{H_2O}–pH_{KCl} 0.97–1.14 and 0.89–1.15 in 2013 and 2019, respectively). Hence, the acidification trend did not accelerated.

The hydrolytic acidity values (Table 2), which properly express soil acidity, showed significant acidification of the soil in the long-term experiment. In the control (non-fertilised) treatments, y_1 values ranged between 7.88–9.38 in monoculture, 7.67–12.13 in biculture and 10.13–11.50 in triculture. The degree of hydrolytic acidity increased significantly as a result of fertiliser treatments. Using the high fertiliser dose (N_{240} + PK), the y_1 values increased to 13.25–14.75 in monoculture, to 14.13–23.00 in biculture and to 14.38–18.38 in triculture. In addition, these values significantly exceed those of Kátai et al. (2018) measured in 2013 in the same long-term experiment (y_1 values for control monoculture: 6.45, and triculture: 10.90; y_1 values for N_{240} + PK monoculture: 11.08, and triculture: 15.50).

Irrigation either moderately modified pH_{H_2O}, pH_{KCl} and y_1, or the change was different in each crop rotation variant.

Analysis of the yield results of our long-term experiment (1986–2019) proved that maize is especially sensitive to the water supply during the vegetation period (Table 3). However, the effects of agrotechnical elements on maize yield were also important. The analysis of our experimental results over more than 30 years proved that the highest yields were obtained in the crop year characterised by favourable water supply (in optimum fertiliser treatment 12.0–12.8 t/ha, such years took 18%), but only moderate differences were found in average crop years (in optimum fertiliser treatment 10.6–12.2 t/ha, such years took 47%) comparing with the rainy crop years. The weakest yields were obtained in the drought years (in optimum fertiliser treatment 5.1–8.2 t/ha, such years took 35%). The effect of crop rotation on maize yield was significant. Very significant differences were found in the optimal fertiliser doses in each crop rotation system (optimum N + PK doses in mono 180–240 kg/ha, in bi 120–180 kg/ha, in tri 60–120 kg/ha). Our results highlight the importance of divers crop rotation. Especially huge yield differences were among monoculture and bi- and triculture when the ecological conditions were unfavourable for maize growing (drought crop year).

The yield results of the long-term experiments together with the chemical characteristics of the soil showed that Chernozem has an extremely high buffering capacity against various agrotechnical

Table 4. Pearson correlation analysis among soil traits, agrotechnical elements and the yield of maize (Debrecen, Chernozem, 2019)

	Yield	pH_{H_2O}	pH_{KCl}	y_1
Yield	1	-0.594^{xx}	-0.543^{xx}	0.409^{xx}
Fertilisation	0.512^{xx}	-0.578^{xx}	-0.437^{xx}	0.420^{xx}
Crop rotation	0.397^{xx}	-0.361^{xx}	-0.454^{xx}	0.394^{xx}
Irrigation	0.051^{ns}	-0.090^{ns}	0.033^{ns}	0.010^{ns}
y_1	0.409^{xx}	-0.848^{xx}	-0.836^{xx}	1

^{xx}Correlation $LSD_{0.01}$ level; ^{x}Correlation $LSD_{0.05}$ level, ^{ns}non-significant; y_1 – hydrolytic acidity interventions. In their long-term experiments, Bohme and Bohme (2006) found a significant effect of agrotechnical factors on yield. Also based on long-term experimental results, Goyal et al. (2006) demonstrated the interactive effect of fertilisation on the soil's chemical properties, while Perucci et al. (1997) demonstrated the effect of fertilisation and crop rotation. As a result of fertilisation, soil pH value (pH_{H_2O}, pH_{KCl}) decreased significantly and the hydrolytic acidity increased in all crop rotations (mono-, bi- and triculture). Nevertheless, maize as an indicator plant showed high yields on Chernozem (maximum yields: mono 13 t/ha, bi 13.5 t/ha, tri 14 t/ha).

The results obtained from the Pearson correlation analysis (Table 4) showed that maize yield was moderately but significantly affected by fertilisation (0.512^{xx}), while crop rotation had a moderate effect (0.397^{xx}) and irrigation had a negligible effect (0.051) on yield. A medium negative correlation could be shown between the pH values and the yield of maize ($pH_{H_2O} = -0.594^{xx}$, $pH_{KCl} = -0.543^{xx}$), while a positive, medium-strong correlation ($y_1 = 0.409^{xx}$) was shown with hydrolytic acidity. A close negative correlation between the pH values and the y_1 values could be demonstrated in our long-term experiment (-0.848^{xx} and -0.836^{xx}). It is important to underline that the correlation between maize yield and soil traits demonstrates momentary status of long-term experiment (in 2019) but – according to our previous results – the trend should be the same in the future.

The analysis of the crop production (yield) and pedological (pH_{H_2O}, pH_{KCl}, y_1) results of the long-term experiment showed that the agrotechnical factors (fertilisation, irrigation, crop rotation) performed on Chernozem over nearly 40 years caused the deterioration of the soil's chemical properties (pH_{H_2O}, pH_{KCl}, y_1), i.e., soil acidification. However, this unfavourable process was also affected by ecological factors, as evidenced by the values of control treatments. Despite the unfavourable chemical properties of the site soil, outstandingly high yields could be obtained with the appropriate agrotechnical measures in the long-term experiment, which proved the extremely favourable buffering properties of Chernozem.

REFERENCES

Berzsenyi Z., Arendas T., Bonis P., Micskei G., Sugár E. (2011): Long-term effect of crop production factors on the yield and yield stability of maize (*Zea mays* L.) in different years. Acta Agronomica Hungarica, 59: 191–200.

Bohme I., Bohme F. (2006): Soil microbiological and biochemical properties affected by plant growth and different long term fertilisation. European Journal of Soil Biology, 42: 1–12.

Buzás I. (ed.) (1988): Methods of Soil and Agricultural Chemistry Analyses 2. Physical-Chemical and Chemical Methods of Soil Alalyses. Budapest, Agricultural Publisher, 90–93.

Geisseler D., Scow K.M. (2014): Long-term effects of mineral fertilizers on soil microorganisms. A review. Soil Biology and Biochemistry, 75: 54–63.

Goyal S., Sakamoto K., Inubushi K., Kamewada K. (2006): Long-term effects of inorganic fertilization and organic amendments on the organic matter and soil microbial properties Andisols. Archives of Agronomy and Soil Science, 52: 617–625.

Hejcman M., Kunzová E. (2010): Sustainability of winter wheat production on sandy-loamy Cambisol in the Czech Republic: results from a long-term fertilizer and crop rotation experiment. Field Crops Research, 115: 191–199.

Johnston E.A. (1997): The value of long-term experiments in agricultural, ecological and environmental research. Advances in Agronomy, 59: 291–333.

Kátai J. (2006): Changes in soil microbiological properties in long-term fertilization experiments. Agrokémia és Talajtan, 48: 348–358. (In Hungarian)

Kátai J. (2015): Effect of extreme precipitation on nutrient content and microbiological processes in soil. Növénytermelés, 64. Suppl. 2/2015. The Impact of Climate Change on Agriculture. Debrecen, Herman Ottó Institute, 91–100. ISSN 0546-8191

Kátai J., Pepó P., Sárvári M. (2017): Research Study in Soil and Crop Sciences. 70 Year Anniversary prof. Dr. Blaskó Lajos. Debrecen, University of Debrecen, 173–189. (In Hungarian) ISBN 978-963-473-966-1

Kátai J., Tállai M., Vágó I., Balláné Kovács A. (2018): Changes some soil chemical and microbiological characteristics in a long-term fertilization experiment in Hungary. Acta Agraria Debreceniensis, 150: 253–265.

Kurowski T.P., Adamiak E. (2007): Occurence of stem base diseases of four cereal species grown in long term monocultures. Polish Journal of Natural Sciences, 22: 574–583.

Máté F., Pusztai A. (1977): Artificial fertilization and soil acidity. In: Proceeding of the Chemicalization in Agriculture. Keszthely, NEVIKI-KAE, 11–16. (In Hungarian)

Murányi A., Rédlyné L. (1986): Using of titration curves for comparative analysis of the effect of acid loads on soil. Agrokémia és Talajtan, 35: 49–62. (In Hungarian)

Nagy J. (2005): 30 Years in Research and Extension of Corn. Corn Consortium. Adaptability and Yield Stability of Corn Hybrids. Debrecen, University of Debrecen, 8–53. (In Hungarian)

Pepó P. (2006): Development alternatives in Hungarian corn production. Gyakorlati Agrofórum Extra, 13: 11–17. (In Hungarian)

Pepó P. (2009): Yield and stem lodging of maize in dry and rainy crop year on chernozem soil. Növénytermelés, 58: 53–66. (In Hungarian)

Perucci P., Bonciarelli U., Santilocchi R., Bianchi A.A. (1997): Effect of rotation, nitrogen fertilization and management crop residues on some chemical, microbiological and biochemical properties of soils. Biology and Fertility of Soil, 24: 311–316.

Sárvári M. (1995): Role of plant density in hybrid-specific technology of maize. Növénytermelés, 44: 261–270. (In Hungarian)

Széll E., Búza L., Győri Z. (2010): Results of fertilization experiments of maize carried out on four different soil types. Növénytermelés, 59: 41–61. (In Hungarian)

Vad A., Zsombik L., Szabó A., Pepó P. (2007): Critical crop management factors in sustainable maize (*Zea mays* L.) production. Cereal Research Communications, 35: 1253–1256.

Várallyay Gy., Szűcs L., Murányi A., Rajkai K., Zilahi P. (1980): 1:100 000 scale map of the factors determining the crop production of Hungary. Agrokémia és Talajtan, 29: 35–76. (In Hungarian)

Vári E., Pepó P. (2011): Effects of agrotechnical factors on the agronomic traits of maize in long-term experiment. Növénytermelés, 60: 115–130. (In Hungarian)

Zhao B., Chen J., Zhang J., Xin X., Hao X. (2013): How different long-term fertilization strategies influence crop yield and soil properties in a maize field in the North China Plain. Journal of Plant Nutrition and Soil Science, 176: 99–109.

Received: March 5, 2021
Accepted: June 10, 2021