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Dynamics of dry matter production and potassium uptake of maize in a long-term field experiment on chernozem soil

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The nutrient supplying ability of soil ideally should correspond to the needs of plants (BUZÁS, 1987), which change dynamically during the plant growth phases (BERGMANN & NEUBERT, 1976; KÁDÁR & LÁSZTITY, 1981). The aim of the present research work was to study – as precisely as possible – how the dynamics of growth and nutrient uptake of the plant change during the vegetation period. Based on these results it is possible to follow and determine the nutrient supply of soils during vegetation, just like all the effects influencing it. In addition to the growth of plants, the change in their nutrient demand over time can be studied, which can be taken into account in fertilization.

Similar studies were carried out previously at the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Science. TOLNER et al. (1982) studied the growth and nutrient uptake dynamics of perennial ryegrass in a pot experiment. The kinetics of the cumulated N uptake dynamics of the plant material harvested at different vegetation stages were described successfully by a model of a first-order process. In case of P uptake the increasing phase at the beginning of vegetation was attributed to the increase in the speed of P uptake, related to root development, and a function was used in their model as well.

BICZÓK et al. (1982, 1985) elaborated a phenomenological model to describe the dynamics of plant dry matter accumulation. The bio-mathematical model used for the calculations included two compartments. One compartment was a logistical function that is well-known and widely used for the description of autocatalytic processes in chemistry and mainly for the description of biological growth. The other was similar to the first function, only with a negative sign, making it possible to describe the increasing nutrient loss at the end of plant vegetation.

The represented model was successfully used for the modelling of dry matter accumulation (LÁSZTITY et al., 1985a) and nutrient uptake (LÁSZTITY et al., 1985b) of maize.

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In the present publication the effects of genotypes, nutrient and water supply on the dry matter production and potassium uptake dynamics of maize *(Zea mays* L.) were studied on the fertile chernozem soil of the Debrecen-Látókép long-term field experiment (Eastern Hungary).

Materials and methods

The basis of present research work was a long-term fertilization and irrigation monoculture maize field experiment set up in 1984 near Debrecen (Hungary) (NAGY, 1997), as long-term experiments are suitable for following changes in soil and plant characteristics (GYŐRI et al., 2005). Some properties of the medium-heavy, loamy calcareous chernozem soil based on loess are as follows: K_A (upper limit of plasticity according to Arany, determined according to BUZÁS, 1988): 39; humus soil layer: 70–90 cm; humus content: 2.4%; total C content: 1.89%; AL-soluble P content: 101 mg $P_2O_5 \cdot kg^{-1}$; AL-K content: 232.4 mg $K_2O \cdot kg^{-1}$. According to BUZÁS et al. (1979) the soil has a sufficient natural N supply, a rather weak P supply and medium K supply. Its upper 30 cm layer has become leached due to the intensive production in the past decades, so its $CaCO_3$ content is insignificant. Therefore, under stressed conditions (drought, soil acidity) it can buffer and compensate the negative effects of the unfavourable circumstances only to a limited extent.

The soil pH(H_2O) value is 6.05, slightly acidic in the production layer, which is mostly favourable from the aspect of nutrient mobilization and nutrient uptake. The minimal water retention capacity is 27–29 V/V%. The experimental field represents the production conditions of chernozem soils with excellent productivity in the region of Eastern Hungary.

The experimental site consists of two parts: one half – in most years, if necessary – can be irrigated, the other half is non-irrigated, on which only the water amount from natural precipitation and the stored moisture content of soil are available for plants. This makes it possible to track the effects of different crop years, just as weather anomalies, and gather information on the achievable yield increment in case the plants' demand is satisfied in the critical periods.

The selection of maize hybrids for the study was based on the length of their vegetation period (FAO-number). Three Hungarian-bread hybrids with varying vegetation periods were used: Mv 251 (FAO 280), Mv Koppány (FAO 420) and Mv 500 (FAO 510), as according to authors' hypothesis and knowledge there are characteristic differences in both the extent and the dynamics of their nutrient uptake.

In the 4-repetition small-plot long-term field experiment the effects of macronutrient fertilization are studied – in addition to the control variant – on five nutrient levels with fixed 1.0:0.77:0.90 $N:P_2O_5:K_2O$ rate; the yearly applied N doses being 0, 30, 60, 90, 120 and 150 kg $N \cdot ha^{-1}$ respectively. The total number of investigated treatments (plots) was 2 water supply levels × 3 genotypes × 6 fertilization levels = 36 in both years.

The total number of plant samples – collected 7 times (in 2008) and 6 times (in 2009) during the vegetation period – amounted to 252 and 216 in the studied years, respectively. At the first sampling time 8, at the second 6, at the third 4, and at all of the remaining 4 or 3 sampling times 2 maize plants were collected per plot. The total above-ground dry matter mass was determined. The shoots were homogenized and analysed for their nutrient element contents. The nutrient uptakes of shoots up to each sampling time were calculated.

Results and discussion

For the characterization and description of plant growth and nutrient uptake dynamics, several classical types of equations were analysed. According to the results, authors worked out a new combined function that was the most suitable for their purposes, the so-called “S-type” (acceleration – saturation) equation, as follows:

$$y = \frac{A \cdot (1 - b \cdot x)}{1 + e^{-k \cdot (x - x0)}}$$

where: the variable y is the actual value of the measured (dependent) factor (t·ha^{-1} or kg·ha^{-1}), x is the day after plant shooting (days); parameter A is the maximum value of y (t·ha^{-1} or kg·ha^{-1}), $x0$ is the day of maximum growth rate of y, point of inflexion, (days), b is the rate of decrease of the dependent value by one unit (days^{-1}); k is the growth constant (days^{-1}).

The theory of deriving this function was: this system is the combination of a biological growth (logistic part of function) and a decreasing commensurable to the size of plant (linear decreasing part of function).

Biomass production

The amount of produced biomass of maize (Fig. 1) was mainly determined by the weather conditions, which basically differed in the studied two vegetation periods.

In 2008, as the amount of precipitation in the vegetation period of maize was quite high (420 mm), no irrigation was required in any of the treatments. Nevertheless, the differences between the dry matter production of previously irrigated and non-irrigated treatments were significant: the yields of non-irrigated plots (upper curve) were higher than those of the previously irrigated treatments of the long-term field experiment (second curve top-down). Earlier, the produced yields of non-irrigated treatments had regularly been lower than those of the methodically irrigated ones, which led to the fact that – from the time the long-term experiment was set up in 1984 – plant biomass had extracted smaller amounts of nutrients from the soil of the non-irrigated treatments.

In the 2009 crop year the dry matter production of maize was lower during the whole vegetation (Table 1), in contrast to the previous crop year (Table 2). In this

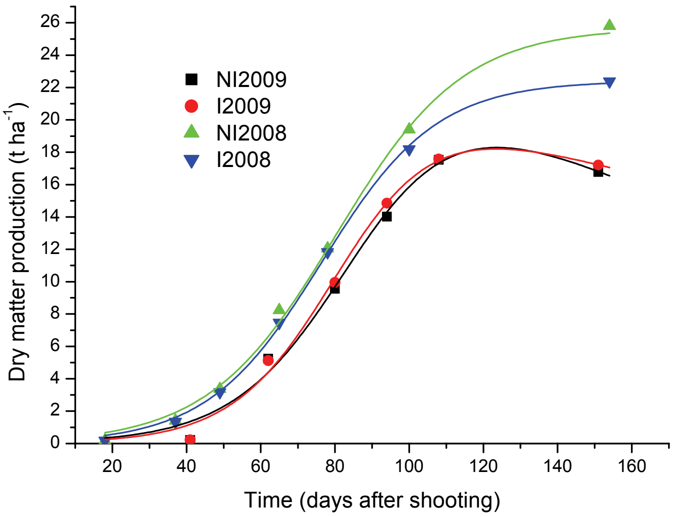

Fig. 1

Dry matter production (t·ha^{-1}) of maize in non-irrigated (NI) and irrigated (I) treatments of the long-term field experiment (Debrecen-Látókép) during its vegetation period in 2008 and 2009, on the average of nutrient supply levels and hybrids

period the amount of relevant precipitation was only 167 mm, making the application of irrigation essential in the respective treatments. Nevertheless, regarding the average of the genotypes and nutrient supply levels, the extent and dynamics of maize biomass production was practically similar (see the two 2009 curves on Fig. 1). The application of irrigation water (25 mm irrigation water added 2 times) had no significant effect on dry matter accumulation. The possible reason for this is that the average temperature between April and the harvest was consequently 3–5 ºC higher than the respective 30-year average values.

The curves in Fig. 2 show that the dry matter production of the three hybrids differed significantly. In the first 90–95 days of the 2008 crop year (upper three curves) there was no difference between the hybrids, but at the end of vegetation the difference in the genetic potential of the hybrids manifested, parallel to their increasing FAO-number their dry matter production increased as well. The difference between Mv 251 and Mv 500 hybrids was more than 5 t·ha^{-1} in this year. In the 2009 crop year – due to the dry and warm weather conditions – Mv 500 did not produce the yield expectable of its genetic potential, while the lowest yield loss – in contrast to that of 2008 – was recorded for Mv Koppány (the hybrid with lower demand).

On Figs. 3 and 4 it can be observed that – according to authors' hypothesis – on the average of the genotypes and water supply, the dry matter yield increasing effect of NPK supply could be observed in both crop years.

Table 1

Shoot and grain production of maize (t·ha^{-1}) grown in 2009 (“dry” vegetation period) in the irrigated and non-irrigated treatments of the long-term fertilization field experiment in Debrecen-Látókép

Water supply	Hybrid	Fertilization	Dry matter of produced shoots, t·ha^{-1}						Grain yield, t·ha^{-1}
			1st	2nd	3rd	4th	5th	6th	
			sampling time						
Irrigated	Mv 251	control	0.23	4.2	9.28	10.5	12.08	11.03	2.75
		N_{30}	0.21	5.25	7.88	12.6	13.13	12.95	4.85
		N_{60}	0.25	5.25	9.1	15.58	16.45	16.28	5.59
		N_{90}	0.23	5.78	10.85	16.1	17.85	18.2	6.38
		N_{120}	0.26	5.78	10.68	18.2	19.6	19.43	5.91
		N_{150}	0.38	5.95	11.55	15.75	21.18	21.35	6.81
	Mv Koppány	control	0.18	3.85	7.0	10.85	13.65	13.48	5.41
		N_{30}	0.17	3.85	8.93	14.53	13.3	13.3	6.25
		N_{60}	0.12	5.08	11.73	16.28	19.25	19.43	7.24
		N_{90}	0.31	6.13	10.5	16.63	20.13	20.48	8.27
		N_{120}	0.22	6.48	13.3	16.8	22.4	23.1	8.41
		N_{150}	0.19	6.13	14.0	16.1	22.05	22.58	8.58
	Mv 500	control	0.15	4.2	7.53	10.85	12.6	12.08	4.08
		N_{30}	0.17	3.5	7.7	10.85	14.53	14.18	6.17
		N_{60}	0.21	4.9	9.28	14.0	18.73	14.35	6.60
		N_{90}	0.19	3.85	9.8	16.45	18.55	17.85	7.17
		N_{120}	0.25	5.95	10.33	17.68	21.53	20.83	7.85
		N_{150}	0.25	6.13	9.63	17.5	19.43	18.73	8.08
Non-irrigated	Mv 251	control	0.13	4.38	5.6	11.9	11.03	11.55	2.31
		N_{30}	0.2	5.43	7.7	10.5	15.75	13.65	4.46
		N_{60}	0.13	4.55	8.05	13.13	15.93	15.58	5.03
		N_{90}	0.28	5.78	10.5	12.6	19.95	19.95	4.59
		N_{120}	0.26	6.48	11.2	15.58	18.03	21.18	5.28
		N_{150}	0.32	5.78	10.5	14.53	17.15	21.18	5.48
	Mv Koppány	control	0.16	4.2	9.45	12.95	15.05	15.4	5.26
		N_{30}	0.18	3.85	7.7	11.73	18.38	17.15	5.95
		N_{60}	0.27	5.6	9.28	14.7	19.95	16.8	7.05
		N_{90}	0.27	5.6	10.68	15.75	21.0	19.95	6.97
		N_{120}	0.21	5.95	11.9	20.3	19.25	19.25	7.03
		N_{150}	0.33	6.65	12.6	20.3	25.9	18.9	8.56
	Mv 500	control	0.15	3.85	7.7	9.45	11.38	10.85	3.91
		N_{30}	0.18	4.9	9.45	15.4	12.6	11.2	5.45
		N_{60}	0.18	3.68	7.0	12.6	12.95	13.3	6.5
		N_{90}	0.2	5.6	9.1	12.43	19.43	19.43	6.87
		N_{120}	0.17	5.95	12.25	12.43	19.25	19.6	6.96
		N_{150}	0.22	5.95	11.38	16.1	22.58	17.15	7.89

Remarks: Fertilization: control: no fertilizer; N_{30}: 30, 23, 27; N_{60}: 60, 46, 54; N_{90}: 90, 69, 81; N_{120}: 120, 92, 108; N_{150}: 150, 115, 135 kg·ha^{-1} N, P_2O_5, K_2O, respectively

Table 2

Shoot and grain production of maize (t·ha^{-1}) grown in 2008 (“wet” vegetation period) in the irrigated and non-irrigated treatments of the long-term fertilization field experiment in Debrecen-Látókép

Water supply	Hybrid	Fertilization	Dry matter of produced shoots, t·ha^{-1}							Grain yield, t·ha^{-1}
			1st	2nd	3rd	4th	5th	6th	7th	
			sampling time							
Irrigated	Mv 251	control	0.18	1.62	2.12	4.55	7.0	9.8	10.15	4.89
		N_{30}	0.15	1.29	2.74	5.9	8.05	16.8	17.5	5.29
		N_{60}	0.14	1.54	3.74	6.05	12.6	16.1	18.2	7.06
		N_{90}	0.14	1.34	3.56	6.65	11.2	22.4	23.1	7.29
		N_{120}	0.23	1.43	3.1	9.1	15.75	22.4	24.15	8.39
		N_{150}	0.23	1.73	3.75	9.45	12.25	22.05	22.75	8.78
	Mv Koppány	control	0.13	1.21	2.05	4.9	7.35	9.45	13.3	5.84
		N_{30}	0.16	1.17	2.33	6.65	9.8	16.1	17.5	7.9
		N_{60}	0.21	1.39	3.28	9.45	10.85	19.25	25.2	9.72
		N_{90}	0.21	1.18	3.83	9.37	14.35	22.05	22.4	9.61
		N_{120}	0.19	1.32	4.0	8.22	15.05	22.05	22.75	10.87
		N_{150}	0.21	1.88	4.29	9.1	15.4	23.1	30.45	11.46
	Mv 500	control	0.12	1.44	2.38	4.55	6.3	8.05	17.85	5.24
		N_{30}	0.13	0.85	2.78	5.6	12.6	9.1	21.0	7.29
		N_{60}	0.15	0.99	2.7	6.73	10.5	18.2	27.65	9.68
		N_{90}	0.16	1.11	3.38	7.7	15.75	21.7	35.35	9.5
		N_{120}	0.16	1.29	2.66	9.8	14.7	24.15	28.0	12.27
		N_{150}	0.2	1.29	4.48	10.5	13.3	24.5	25.55	13.05
Non-irrigated	Mv 251	control	0.16	1.27	2.38	5.25	6.3	12.6	14.7	6.3
		N_{30}	0.13	1.49	2.89	6.3	8.75	17.5	23.8	7.12
		N_{60}	0.21	1.47	2.68	8.4	13.3	19.95	23.8	9.97
		N_{90}	0.27	1.58	3.8	10.15	11.9	21.0	21.7	9.06
		N_{120}	0.25	1.6	4.28	9.8	12.95	22.05	33.95	10.57
		N_{150}	0.19	1.75	4.81	12.25	17.85	21.0	25.9	10.54
	Mv Koppány	control	0.17	1.45	1.75	4.55	8.75	11.55	20.3	9.32
		N_{30}	0.21	1.51	3.19	7.7	11.55	16.45	23.45	11.44
		N_{60}	0.25	1.41	3.43	8.05	11.55	17.85	21.0	12.35
		N_{90}	0.23	1.46	4.04	9.1	13.65	22.05	28.7	12.21
		N_{120}	0.2	1.48	3.97	8.75	12.95	21.7	30.8	13.28
		N_{150}	0.2	1.8	4.8	8.75	14.7	23.45	31.5	12.73
	Mv 500	control	0.1	1.54	1.94	7.0	8.4	15.05	15.75	7.46
		N_{30}	0.14	0.97	3.16	7.7	10.15	19.95	31.85	9.79
		N_{60}	0.17	0.99	2.8	7.0	12.25	19.25	22.4	11.35
		N_{90}	0.16	1.39	2.51	7.24	12.6	18.55	32.9	12.14
		N_{120}	0.17	0.97	4.3	9.8	16.1	25.2	25.55	14.48
		N_{150}	0.16	1.35	3.92	10.5	13.3	24.15	36.4	14.35

Remarks: See Table 1

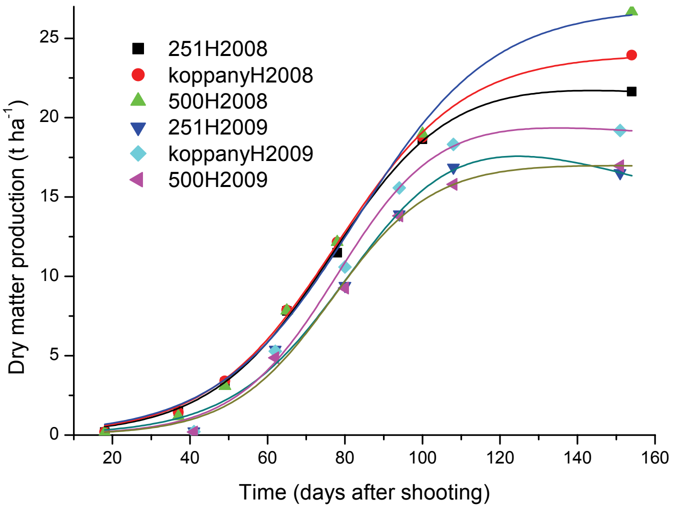

Fig. 2

Dry matter production (t·ha^{-1}) of the Mv 251, Mv-Koppány and Mv500 maize hybrids grown in 2008 and 2009 crop years in the long-term fertilization field experiment in Debrecen-Látókép, on the average of nutrient and water supply

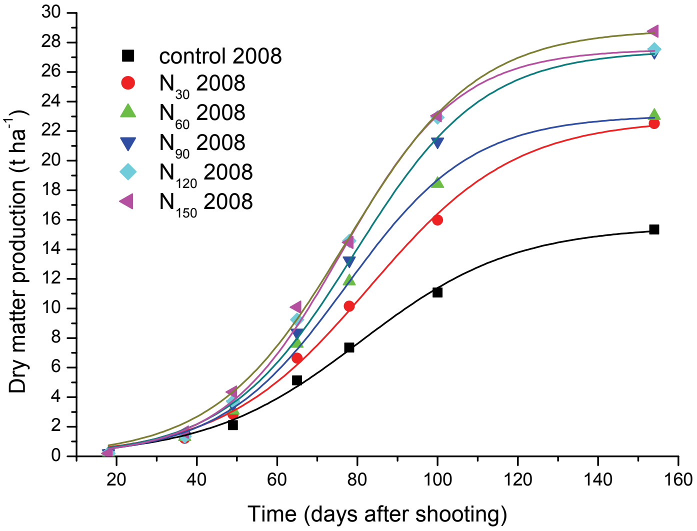

Fig. 3

Dry matter production (t·ha^{-1}) of maize hybrids in 2008 as affected by different nutrient supply levels in the long-term fertilization field experiment in Debrecen-Látókép. *Legend:* Nutrient level supplies: control: no fertilizer; N_{30}: 30, 23, 27; N_{60}: 60, 46, 54; N_{90}: 90, 69, 81; N_{120}: 120, 92, 108; N_{150}: 150, 115, 135 kg·ha^{-1} N, P_2O_5, K_2O, respectively

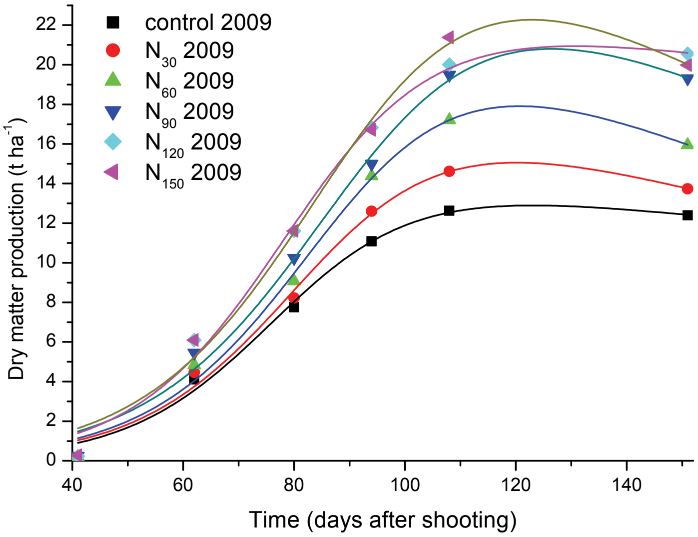

Fig. 4

Dry matter production (t·ha^{-1}) of maize hybrids in 2009 as affected by different nutrient supply levels in the long-term fertilization field experiment in Debrecen-Látókép. *Legend:* Nutrient level supplies: See Fig. 3

Potassium uptake

It is inevitable that the K supply level of soils plays a major role in plant potassium uptake. At the same time, plant potassium uptake is affected by many factors (such as plant age and development state) that affect the potassium demand as well, and soil moisture and NP content (LOCH & NOSTICZIUS, 1982). The field experiment was suitable for following the nutrient uptake dynamics of plants, but due to the limited extent of present paper only the uptake dynamics of one element can be discussed. Potassium was chosen, in case of which both uptake and loss of the element could be observed (SCHILLING, 2000).

Increasing nutrient supply levels increased plant potassium uptake (Fig. 5), for on the one hand the increasing NPK supply increased plant dry matter accumulation (Fig. 4), on the other hand plant potassium concentration was higher in treatments with higher potassium supply. The amount of potassium taken up by plants was higher in all treatments than the amount added with fertilization. This was especially spectacular in the control treatment (the lowest curve in Fig. 5 – there was no additional potassium fertilization for 24 years). In this case it can be observed that approx. 100 kg K·ha^{-1} was mobilized each year from the potassium stock of the chernozem soil. This proves the excellent nutrient mobilization and supplying ability of this soil type.

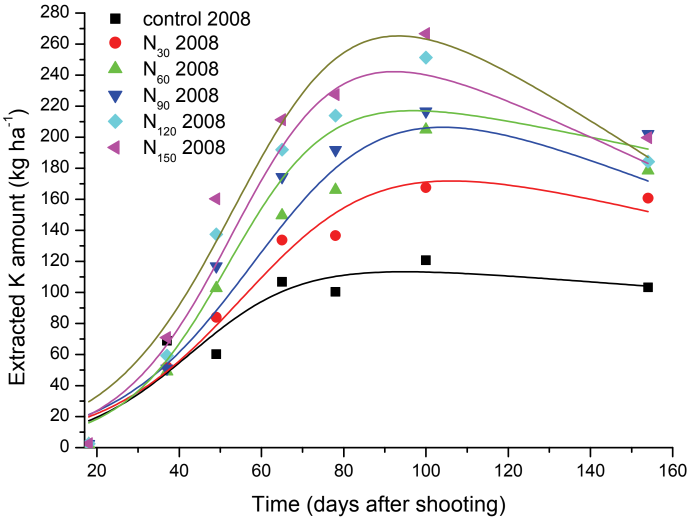

Fig. 5

Potassium uptake dynamics of maize as affected by different nutrient supply levels in crop year 2008 in the long-term fertilization field experiment in Debrecen-Látókép.
Legend: Nutrient level supplies: See Fig. 3

Summary

The effects of genotypes, nutrient and water supply on the dry matter production and potassium uptake dynamics of maize *(Zea mays* L.) were studied on chernozem soil in the Debrecen-Látókép long-term field experiment (Eastern Hungary).

According to the experimental results and calculations it can be concluded that – in addition to the previously used and considered soil and plant nutrient contents – the calculation of the plant-extracted nutrient amount (depending on the applied hybrid, NPK nutrient levels and water supply) is suggested to enable the characterization of the growth and nutrient demand dynamics of maize genotypes. This parameter gives information not only about the available nutrient amount at a given sampling time, but about the supply level of plants up to the sampling time as well. For the proper characterization of the mentioned dynamics of maize plants authors suggest to take the following sampling times into consideration: the intensive vegetative growth period, the switch between the vegetative and generative growth phases (silking), and the grain filling phase.

Keywords: chernozem, *Zea mays* L., biomass production, potassium uptake dynamics

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