EFFECTS OF NITROGEN FERTILISING ON THE DYNAMICS OF MINERAL NITROGEN IN THE SOIL UNDER MAIZE INBRED LINES

UTICAJ ĐUBRENJA INBRED LINIJA KUKURUZA NA DINAMIKU MINERALNOG AZOTA U ZEMLJIŠTU

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***Abstract**. The study was carried out in the experimental filed of the Maize Research Institute, Zemun Polje, on calcareous chernozem in the period 2001-2003. The traits of two maize inbred lines (L_1–FAO 400 and L_2–FAO 600) were observed in dependence on the two fertiliser variants: N_o–control without fertilising; N_{min}–PK (const.) + fertilising in spring on the basis of the Nmin method, and forms of applied nitrogen: Urea (amidic form), KAN (ammonium-nitrate form) and $(NH_4)_2SO_4$ (ammonium form). The highest amount of (NH_4+NO_3)–N in the soil (0–120 cm) in the silking stage of maize inbred lines was recorded in 2002 (72.6 kg ha^{-1}), under the inbred line L_2 (84.0 kg ha^{-1}) and in the treatment with Urea (86.4 kg ha^{-1}). The amount of NH_3^-–N and (NH_4+NO_3)–N in the soil (0-120 cm) measured at the end of the growing season of observed maize inbred lines was the highest in the second year of investigation (48.9 and 55.8 kg ha^{-1}, respectively). The application of nitrogen in the amidic form highly significantly affected the increase of the amount of accessible nitrogen in the soil at the end of the growing period in the inbred L_1 (46.3 kg ha^{-1}), while the application of different nitrogen forms did not express statistical significance in the inbred L_2*

***Abstrakt**. Istraživanja su obavljena na oglednom polju Instituta za kukuruz "Zemun Polje", 2001., 2002. i 2003. godine, na zemljištu tipa karbonatni černozem. U radu su ispitivane osobine dve inbred linije kukuruza (L_1 – FAO 400 i L_2 – FAO 600) u zavisnosti dve varijante đubrenja (N_o - Kontrola bez primene đubriva; N_{min} - PK (const.) + đubrenje u proleće na bazi N-min metode, i oblika primenjenog azota: urea (amidni oblik), KAN (amonijum-nitratni oblik) i $(NH_4)_2SO_4$ (amonijum oblik). Najveća prosečna količina $(NH_4^+ + NO_3^-)$-N u zemljištu (0-120 cm) u fazi svilanja ispitivanih inbred linija kukuruza izmerena je u 2002. godini (72,6 $kgha^{-1}$), pod inbred linijom L_2 (84,0 $kgha^{-1}$) i na tretmanu sa ureom (86,4 $kgha^{-1}$). Izmerena količina NO_3^--N i $(NH_4^+ + NO_3^-)$-N u zemljištu (0-120 cm) na kraju vegetacije ispitivanih inbred linija kukuruza bila je najveća u drugoj godini ispitivanja (48,9 $kgha^{-1}$, odnosno 55,8 $kgha^{-1}$). Primena azota u amidnom obliku uticala je vrlo značajno na povećanje količine pristupačnog azota u zemljištu na kraju vegetacije kod linije L_1 (46,3 $kgha^{-1}$), dok kod linije L_2 primena različitih oblika azota nije pokazala statističku značajnost.*

***Key words**: nitrogen fertilizing, nitrogen form, mineral nitrogen in soil, maize inbred lines*
***Ključne reči**: đubrenje azotom, oblik azota, mineralni azot u zemljištu, inbred linije kukuruza*

INTRODUCTION

Nitrogen is one of the most important nutritive elements and it is used worldwide to enhance and sustain the production of agricultural crops. During the Green Revolution, nitrogen fertilisers contributed to the increase and sustainability of yields within different agroecological systems. Nitrogen was also a key of economic variability of the agricultural production all over the word, and by it of world population food. On the other hand, anthropogenic factors (combustion of fossil fuels) contribute to a greater release of gases (carbon dioxide and nitrogen oxides) that affect global warming of our planet (IPCC, 1994).

The application of organic and mineral nitrogen fertilisers can result in losses of nitrogen in gaseous forms, as well as, in nitrite leaching. Therefore, as stated by *Newbould* (1989), drinking water contamination with nitrates has been becoming a serious problem all over the world. These are principal reasons for continuation of the development of new technologies and methods of nitrogen applications that can increase efficiency of its utilisation. Procedures such as: band fertilisation, nitrogen application during the growing season, testing of new varieties with a greater efficiency of the nitrogen utilisation, crop rotation and alternation of crops, irrigation by the drop by drop system, determination of the nitrogen content in the soil with the aim to calculate necessary rates of fertilisers–are globally used as a conventional method of the agricultural production.

New technologies in the application of nitrogen fertilisers and cropping, such as: precise technique of the plant production, fast in situ tests for the analysis of the nitrate nitrogen concentration in plant tissues, fast tests for the chlorophyll determination, use of the computer simulation models to improve planning and organisation of the production–can affect the increase of the average efficiency of the nitrogen utilisation within different agroecosystems by more than 50%. Moreover, the application of nitrification inhibitors and slow–release nitrogen fertilisers significantly affect a higher crop use of both, nutrient and water, and the reduction of nitrogen losses from the soil by approximately 50% (*Delgado and Mosier*, 1996; *Detrick*, 1996; *Engelsjord et al*., 1997). The maize seed production is mainly performed on soils of higher quality. Soil quality is a capability of the soil to satisfy requirements of crops (and therefore of animals), to provide transport and regulation of water and other compounds present in the soil or gotten (added) to the soil (*Doran and Parkin*, 1994; *Karlen et al*., 1998). Since there is usually no sufficient amounts of nitrogen in the soil available to plants for obtaining high yields of good quality, soil fertilisation is necessary.

The application of N fertilisers in the maize seed production represents an important cropping practice as it significantly affects the yield level and certain seed traits.

The objective of the present study was to determine the dependence of the three stated seed traits of the most important ZP maize inbred lines on the form and dates of nitrogen application on calcareous chernozem under the Zemun Polje agroecological conditions, and according to determined parameters to optimise and rationalise the application of N fertilisers in these two maize inbreds.

MATERIAL AND METHOD

The trials were carried out on calcareous chernozem at the Maize Research Institute, Zemun Polje, during 2001, 2002 and 2003.

The following factors were observed:

(I) Two inbred lines of different growing seasons:
1. PL 142 (FAO 400)–60,000 plants ha^{-1};
2. PL 167 (FAO 600)–60,000 plants ha^{-1}.

(II) Mineral fertilisers applied in the following two variants:
1. (N_{min})–PK: 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} applied in autumn (const.) + fertilising on the basis of N-min method, with the addition up to 100 kgNha^{-1} (in spring);
2. (No)–Control without fertilisers.

(III) Nitrogen fertilisers applied in the following three forms:
1. Amidic nitrogen (Urea);
2. Ammonium-nitrate nitrogen (KAN);
3. Ammonium nitrogen/$(NH_4)_2SO_4$.

This trial is a segment of studies performed at the Maize Research Institute, Zemun

Polje in the periods 1998–1999 and 2001–2003 (*Hojka*, 2001, 2004; *Hojka and Grubišić*, 2002). According to obtained results, it was determined that the nitrogen requirements of maize inbred lines depended on a genotype and amounted, on the average, to 100 kg ha^{-1}. The mineral fertilisers applied in this study were as follows: superphosphate (33% P_2O_5), KCl (60% K_2O), KAN (27% N, 8% Ca), UREA (46% N), $(NH_4)_2SO_4$ (20.5–21% N).

Meteorological data were measured in the course of the trail performance. Nitrate and ammonium nitrogen were determined by the method of Scharpf and Wehrmann (*Manojlović et al.*, 1995). The F–test was done on the basis of obtained values for mean squares in the analysis of variance and by their equalising with expressions of the expected mean squares. The comparison of means among various treatments was carried out by the LSD test.

RESULTS AND DISCUSSION

1. Meteorological conditions in the course of the trial performance

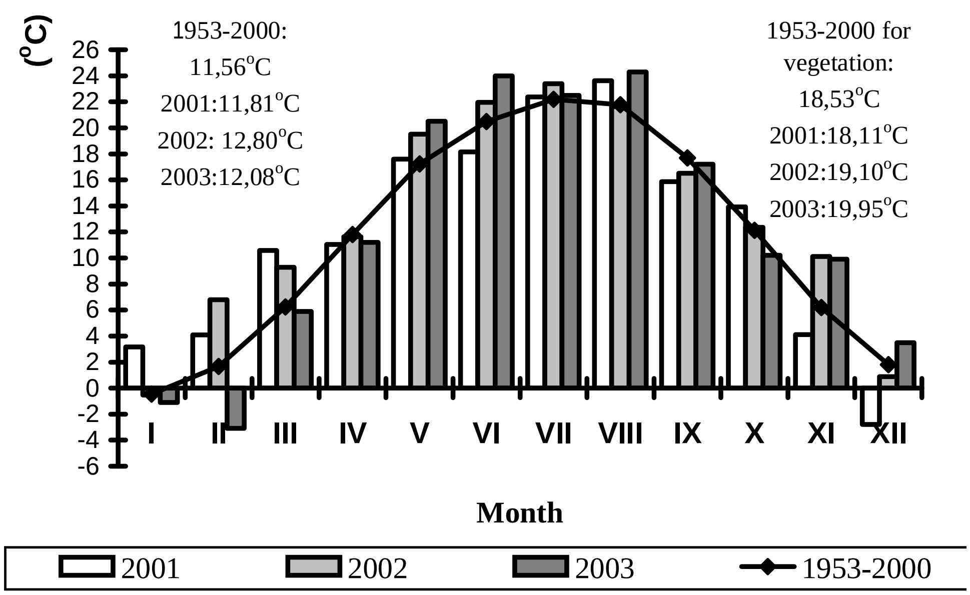


Figure 1. Long–term mean (1953–1999) of average monthly air temperatures at Zemun Polje, compared to 2001, 2002 and 2003.

The average annual air temperatures in 2001, 2002 and 2003 were higher than average temperatures in the period 1953–1999. Data presented in Figure 1 show that the mean annual air temperatures amounted to 11.81^0C, 12.80^0C and 12.08^0C in investigation years, respectively, and that they were a somewhat higher than the long-term mean (11.56°C).

The average temperatures of the growing season in 2002 and 2003 also deviated from the long-term mean for vegetation (by $+0.57^0$C and $+1.42^0$C).

The total precipitation in 2001 amounted to 740.4 mm, i.e. it was higher than the long term mean by 138.0 mm (Figure 2).

Years 2002 (570.4 mm) and 2003 (459.2 mm) were characterised by a lower sum of precipitation. Moreover, the growing season of 2001 had precipitation sum higher by 158.6 mm, while the growing season of 2002 and 2003 were characterised by precipitation sum lower by 7.4 mm and 113.4 mm, respectively, than the long term average.

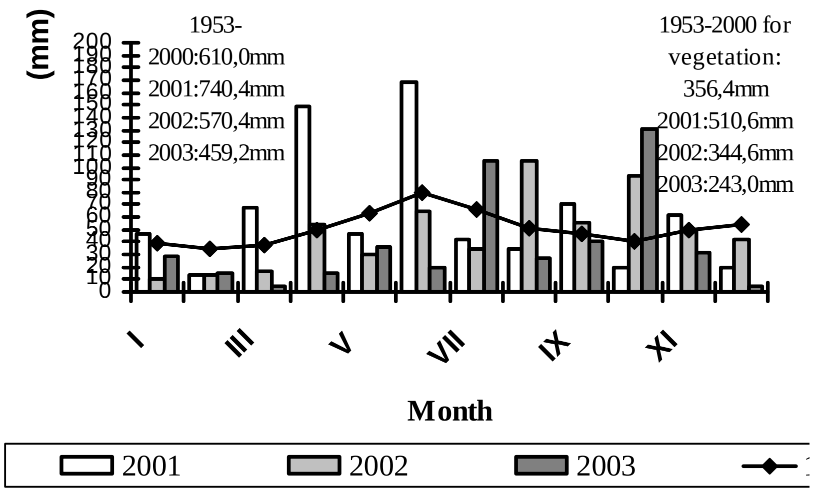


Figure 2. Long–term (1953–1999) mean precipitation sum at Zemun Polje compared to 2001, 2002 and 2003.

2. Mineral nitrogen in the soil prior to sowing of maize inbred lines

The nitrogen amount was measured in the soil down to the depth of 120 cm early in the spring during each year of investigation. Based on the estimated values, nitrogen rates to be applied in the treatment by the Nmin method were established. Results of the analyses are presented in Figure 3.

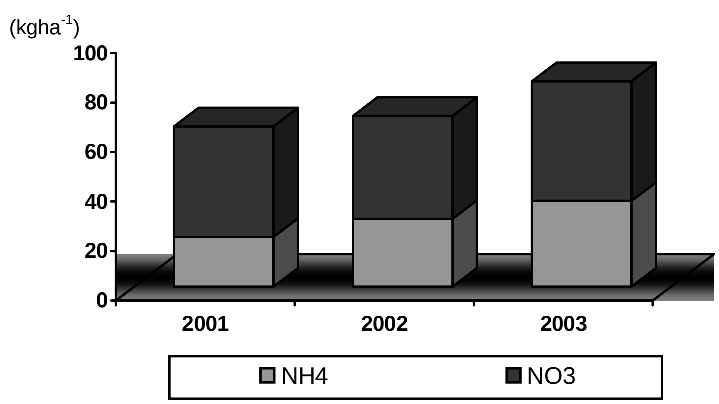
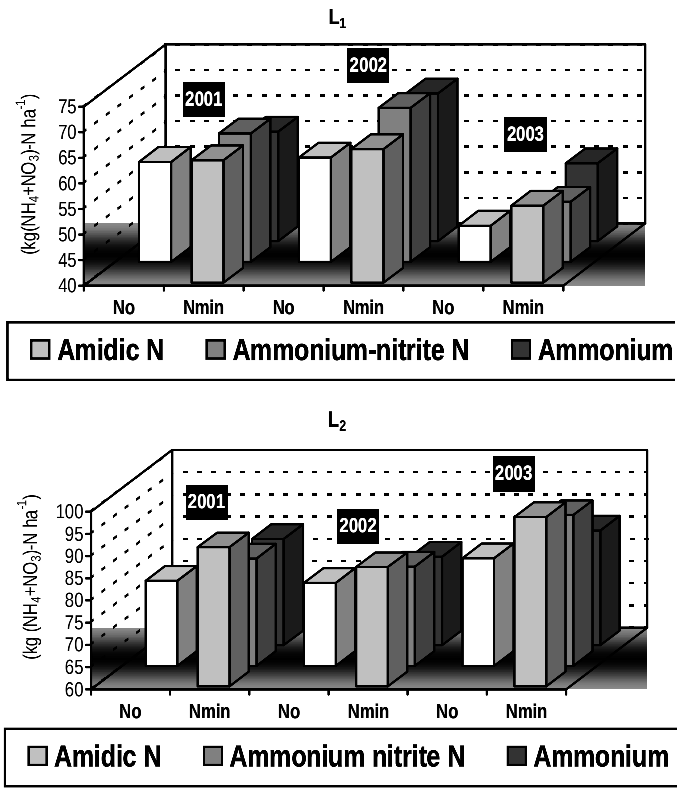


Figure 3. Amount of (NH_4+NO_3)-N in the soil prior to sowing of maize inbred lines (L_1 and L_2) over investigation years (kg ha^{-1})

The highest amount of mineral N in the soil was recorded in 2003 and amounted to 83.0 kg ha^{-1}. The corresponding amounts in 2002 and 2001 were 69.0 and 65.0 kg ha^{-1}, respectively. The amount of nitrate nitrogen in the soil was a somewhat lower than the amount of (NH_4+NO_3)–N, which indicates that the process of nitrification was very intensive.

3. **Mineral nitrogen in the soil in the silking stage of the tested maize inbred lines**

According to the LSD–test, it is observable, that a higher amount of nitrogen in the soil, on the average, was recorded in the silking stage of the maize inbred lines in 2002 (72.6 kg ha^{-1}) and 2001 (72.1 kg ha^{-1}) than in 2003 (69.5 kg ha^{-1}) (Figure 4). A statistically significantly higher amount of mineral nitrogen in the soil ($p < 0.01$) was detected in the inbred line L_2 than in the inbred line L_1, as well as, in the Nmin method than in the control.



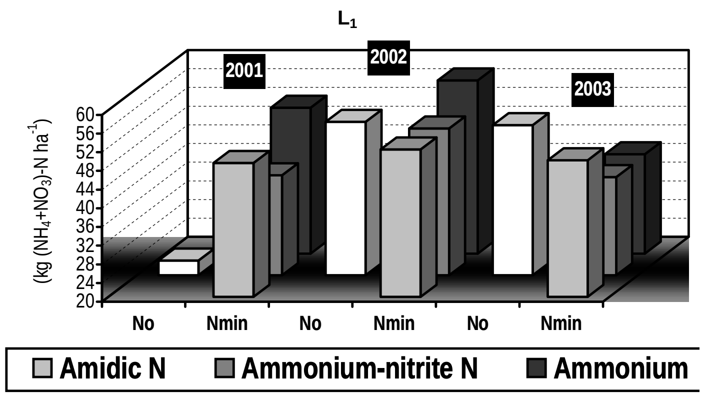
		Year	Genotype	Fertilisation dates	N form
LSD	0.05	0.692	2.399	2.399	0,692
	0.01	0.928	3.220	3.220	0,928
		Year x genotype		Year x fertilisation dates	Year x N form
LSD	0.05	0.979		0.979	1.199
	0.01	1.313		1.313	1.608
		Genotype x fertilisation date		Genotype x N form	Fertilisation date x N form
LSD	0.05	0.799		0.979	0.979
	0.01	1.072		1.313	1.313

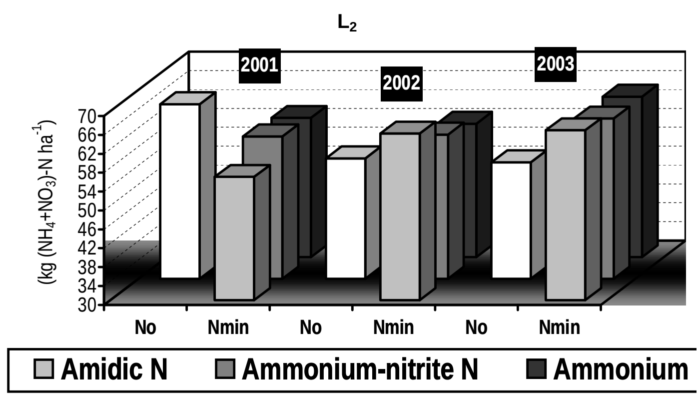
Figure 4. Effects of different nitrate forms on the amount of (NH_4+NO_3)-N in the soil in the silking stage of the maize inbred lines (L_1 and L_2) over investigation years (kg ha^{-1})

The application of nitrogen in the amidic form statistically very significantly increased the amount of mineral nitrogen in the soil in the silking stage (due to a slower hydrolysis of nitrogen in the amidic form) in the inbred line L_2 (86.4 $kgha^{-1}$), in relation to the application of nitrogen in the ammonium-nitrate form (83.7 kg ha^{-1}) and ammonium form (81.9 kg ha^{-1}).

The application of different forms of nitrogen did not result in statistically significant differences in the mineral nitrogen content in the soil in the inbred line L_1.

4. **Mineral nitrogen in the soil at the end of the growing season of the studied maize inbred lines**





		Year	Genotype	Fertilisation dates	N form
LSD	0.05	1.308	4.537	4.537	1,308
	0.01	1.754	6.088	6.088	1,754
		Year x genotype		Year x fertilisation dates	Year x N form
LSD	0.05	1.850		1.850	2.266
	0.01	2.481		2.481	3.039
		Genotype x fertilisation date		Genotype x N form	Fertilisation date x N form
LSD	0.05	1.511		1.850	1.850
	0.01	2.026		2.481	2.481

Figure 5. Effects of different nitrate forms on the amount of (NH_4+NO_3)-N at the end of the growing season of the maize inbred lines (L_1 and L_2) over investigation years (kg ha^{-1})

Weather conditions (air temperatures and precipitation sums during the growing season (Figures 1 and 2) affected the amount of nitrogen in the soil at the end of the growing seasons of the studied maize inbred lines. The amount of nitrogen in the soil was statistically significantly higher ($p < 0.01$) in 2002 (55.8 kg ha^{-1}) than in 2001 (48.9 kg ha^{-1}) (Figure 5).

Furthermore, the amount of nitrogen under the inbred line L_2 (60.3 kg ha^{-1}) was statistically very significantly higher than under the inbred L_1 (45.4 kg ha^{-1}). In treatments with the application of nitrogen in amidic and ammonium forms, the amount of mineral nitrogen in the soil at the end of the growing season (46.3 kg ha^{-1}) was statistically very significantly higher than the amount of mineral nitrogen in the treatment in which nitrogen had been applied in the ammonium–nitrate form (43.7 kg ha^{-1}), but only for the inbred line L_1. There were no statistically significant differences in the amount of mineral nitrogen in the soil under the inbred L_2 at the end of the growing season regardless of the form in which nitrogen had been applied.

The values of the NO_3–N content in the soil profile and the sum of (NH_4+NO_3)–N are a measure of the soil supply with available nitrogen most often used to determine amounts of fertilisers necessary for plants. The amount of nitrate nitrogen in the soil profile directly depends on the process of mineralisation, which is affected by numerous factors: composition and quality of the organic matter that is mineralised, humidity, temperature, pH value, content of other necessary macro– and microelements, then processing, application of mineral and organic fertilisers, soil microorganisms, presence of plants, etc. Due to a great dynamics of NO_3–N in the soil, especially under climatic conditions in which there are no significant leaching and de-nitrification during the growing season, it is necessary to annually establish its content prior to the beginning of the growing season.

The utilisation of nitrogen fertilisers in agriculture has been increasing in certain parts of Asia, North America and Western Europe since 1960 (*FAO,* 2000). Furthermore, maize yields have been increasing since the same year. On the other hand, the adverse effect of nitrogen on atmosphere, underground waters and other components of the ecosystem was recorded in the industrially developed countries (*Socolow,* 1999). The anthropogenic effect on the soil, first of all, via the agricultural production resulted in the increase of nitrogen losses from the soil. It has been leading to doubling of its application in many regions, especially in Europe, since 1950 (*Goulding et al.,* 1998–*cit. Britto and Kronzucker,* 2002). A greater intensification of the production, growing leaning on the application of mineral fertilisers and pesticides, resulted in the yield increase of agricultural crops, but at the same time, led to the reduction of the organic matter content in the soil, increased intensity of erosion, as well as, to pollution of surface and underground waters (*Matson et al.,* 1997*; Tilman,* 1999*; Cassman,* 1999).

The maize yield, measured in the period from 1967 to 1997 in the long–term trial set up in the USA (*Aref and Wander,* 1997), was some kind of an indicator of differences in soil quality. The application of organic and mineral fertilisers was used as the input data in these experiments, while grain yields obtained in certain treatments served as biological indicators of soil quality. Furthermore, the decrease of efficiency of the use of the applied nutrients and yields was recorded in stated studies in the trials in which maize had been grown in continuous cropping in comparison to trials in which maize had been grown in crop rotation with soybean, sugar beet, red clover or alfalfa.

The rational application of nitrogen in the agricultural production should be a priority, as its irrational utilisation can result in pollution of underground waters with nitrates (*Moreno et al.,* 1996). The application of nitrogen in the amounts exceeding requirements of plants leads to the increase of the nitrate levels in the soil profiles, and a higher concentration of NO_3–N in the soil after harvest increases the risk of their leaching in the underground waters (*Schepers et* *al.,* 1991). *Sexton et al.* (1996) state that nitrate leaching is undoubtedly increased if annual rates of applied fertilisers exceed 100 kg N ha^{-1}, when maize is grown on sandy loams in central Minnesota.

Malešević (1989) and *Dušanić* (1994) established that the amount of mineral nitrogen in fertilised variants was higher than the sum of mineral nitrogen in the control variant and the added nitrogen amount from mineral fertilisers. The same authors explain this phenomenon by means that previously incorporated nitrogen (under previous crops) was partially immobilised into the soil organic matter and that its intensified mineralisation occurred under favourable conditions.

Monitoring mineral nitrogen, especially nitrates, in the soil provides the safest information on available amounts of nitrogen accessible to plants (*Manojlović,* 1988). *Bogdanović* (1986) and *Manojlović* (1988) state that there is no nitrate leaching in the underground waters in the chernozem type of soil and its subtypes and varieties, that there is only migration of NO_3^- in the profile within the root zone, and outside of the root system zone only in the extremely rainy period (October–March).

The amounts of mineral nitrogen measured over years in these studies were greater in spring than in autumn. This is in accordance with results obtained by *Maksimović* (1999).

CONCLUSIONS

Results obtained in the three–year study on effects of the application dates and forms of nitrogen on the yield and properties of seeds of maize inbred lines lead to conclusions, which could be recommended in practice, that under agroecological the Zemun Polje conditions (and similar) it is desirable to pay attention to the rates of applied fertilisers, dates of their application, as well as, to the nitrogen form in them in order to increase and stabilise seed yields of maize inbred lines and to obtain as a high number of seeds of better properties and quality as possible.

The amount of (NH_4+NO_3)–N in the soil (0–120 cm) in the silking stage of the observed maize inbreds lines also depended on studied factors. The highest average amount of mineral nitrogen in the soil in this developmental stage of the maize inbred lines was recorded under the inbred line L_2 in the treatment in which nitrogen had been applied in amidic form in 2002.

The established amounts of NO_3–N and (NH_4+NO_3)–N in the soil (0-120 cm) at the end of the growing season of the maize inbred lines were the highest in the second year of investigation (2002). The application of nitrogen in the amidic form very significantly affected the increase of available nitrogen in the soil at the end of the growing season of the maize inbred line L_1, while the application of nitrogen in different forms did not show any statistical difference in the inbred L_2.

The content of (NH_4+NO_3)–N in the soil in the silking stage of the observed maize inbred lines ranged, on the average for all years and genotypes, from 55.7 to 80.7 kg ha^{-1} in the control (No), while the corresponding amounts in the Nmin treatment ranged from 61.4 to 92.1 kg ha^{-1}.

The content of (NH_4+NO_3)–N in the soil at the end of the growing season of the maize inbred lines, ranged, on the average for all years and genotypes, from 42.7 to 59.0 kg ha^{-1} in the control (No), while the corresponding amounts in the Nmin treatment ranged from 44.6 to 62.4 kg ha^{-1}. These values of mineral nitrogen in the soil are within ecological norms, i.e. they are not a direct danger to pollution of agroecosystems with nitrates.

LITERATURE

AREF., S., WANDER, M.M. (1997): *Long–term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments*. Adv. Agron., 62, 153–197.

BOGDANOVIĆ, D. (1986): *Kretanje azota po profilu u zavisnosti od vlage i temperature zemljišta pri različitim dozama i sistemima primene đubriva*. Zbornik referata, XX seminar agronoma, Kupari, 42–56.

BRITTO, D.T., KRONZUCKER, H.J. (2002): NH_4^+ toxicity in higher plants: a critical rewiew. J. Plant Physiol., 159, 567–584.

CASSMAN, K.G. (1999): *Ecological intensification of cereal production systems: Yield potentials, soil quality and precision agriculture*. Proc. Natl. Acad. Sci. USA, 96, 5952–5959.

DELGADO, J.A., MOISER, A.R. (1996): *Mitigation Alternatives to Decrease Nitrous Oxide Emissions and Urea–Nitrogen Loss and Their Effect on Methane Flux*. Journal of Environmental Quality, 25, 1105–1111.

DETRICK, J. (1996): RCL *Membrane Encapsulated Fertilizer Technology Can Deliver High Value Benefits for Agriculture. Proceedings,* Great Plains Soil Fertility Conference, Denver, CO, March 4-6, 330–340.

DORAN, J.W., PARKIN, T.B. (1994): *Defining and assessing soil quality. In Doran et al. (ed.) Defining soil quality for a sustainable environment*. SSSA Spec. Publ. 35. SSSA and ASA, Madison, WI.

DORAN, J.W., PARKIN, T.B. (1994): Defining and assessing soil quality. In Doran et al. (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA and ASA, Madison, WI.

DUŠANIĆ, N. (1994): *Dinamika mineralnog azota u zemljištu i njegov uticaj na prinos, kvalitet zrna i iznošenje azota usevom suncokreta*. Magistarski rad, Poljoprivredni fakultet Novi Sad.

ENGELSJORD, M.E., FOSTAD, O., SINGH, B.R. (1997): *Effects of Temperature on Nutrient Release From Slow-Release Ferilizers*. Nutrient Cycling in Agroecosystems, 46, 179-187.

FAO (2000): *FAO Statistical Databases* (Online). Available at http:/apps.fao.org/.

HOJKA, Z. (2001): *Zavisnost prinosa inbred linija kukuruza od sadržaja nitratnog azota u zemljištu i biljci u fazi svilanja*. Magistarski rad. Poljoprivredni fakultet, Novi Sad.

HOJKA, Z. (2004): *Uticaj vremena primene i oblika azota na prinos i osobine semena inbred linija kukuruza*. Doktorska disertacija. Poljoprivredni fakultet, Novi Sad.

HOJKA, Z., GRUBIŠIĆ, M. (2002): *Uticaj đubrenja na dinamiku mineralnog azota u zemljištu pri gajenju inbred linija kukuruza*. J. Sci. Agric. Research/Arh. poljopr. nauke, 63 (221–222): 75–86.

INTERGORNMENTAL PANEL ON CLIMATE CHANGE (IPCC) (1994): Radiative Forcing of Climate Change. The 1994 Report to the Scientific Assessment Working Group of IPCC, Summary for Policymakers.

KARLEN, D.L., GARDNER, J.C., ROSEK, M.J. (1998): A soil quality framework for evaluating the impact of CRP. J. Prod. Agric., 11, 56–60.

MAKSIMOVIĆ, L. (1999): *Zavisnost prinosa i morfoloških karakteristika kukuruza od vlažnosti zemljišta i sistema đubrenja u navodnjavanju*. Doktorska disertacija, Poljoprivredni fakultet Novi Sad.

MALEŠEVIĆ, M. (1989): *Značaj temperarura i padavina za određivanje optimalne količine azota i njihov uticaj na visunu prinosa ozime pšenice* (*Triticum aestivum* L.). Doktorska disertacija, Poljoprivredni fakultet Novi Sad.

MANOJLOVIĆ, S. (1988): *Aktuelni problemi upotrebe đubriva sa posebnim osvrtom na mogućnosti zagađivanja zemljišta i predlozi za njihovo rešavanje, kroz uvođenje i funkcionisanje sistema kontrole plodnosti zemljišta i upotrebe đubriva*. Agrohemija, 5–6, 393–442.

MANOJLOVIĆ, S., UBAVIĆ, M., BOGDANOVIĆ, D., DOZET, D. (1995): *Praktikum iz agrohemije*. Poljoprivredni fakultet, Institut za ratarstvo i povrtarstvo, Novi Sad, 43-48.

MATSON, P.A., PARTON, W.J., POWER, A.G., SWIFT, M.J. (1997): *Agricultural intensification and ecosystem properties*. Science, 277, 504–509.

MORENO, F., CAYUELA, J.A., FERNANDEZ, J.E., FERNANDEZ-BOY, E., MURILLO, J.M., CABRERA, F. (1996):

Water balance and nitrate leaching in an irrigated maize crop in SW Spain. Agric. Water Manage., 32, 71–83.

NEWBOULD, P. (1989): *The Use of Nitrogen Fertilizer in Agriculture: Where Do We Go Practically and Ecologically*? Plant Soil, 115, 297–311.

SCHEPERS, J.S., MORAVEK, M.G., ALBERTS, E.E., FRANK, K.D. (1991): Maize production impacts on groundwater quality. J. Environ. Qual., 20, 12–16.

SEXTON, B.T., MONCRIEF, J.F., ROSEN, C.J., GUPTA, S.C., CHENG, H.H. (1996): *Optimizing nitrogen and irrigation inputs for corn based on nitrate leaching and yield on a coarse-textured soil*. J. Environ. Qual., 25, 982–992.

SOCOLOW, R.H. (1999): *Nitrogen management and the future of food: Lessons from the management of energy and carbon*. Proc. Natl. Acad. Sci. USA 96: 6001–6008.

TILLMAN, D. (1999): *Global environmental impacts of agricultural expansion: The need for sustainable and effects practices*. Proc. Natl. Acad. Sci. USA, 96, 5995–6000.