Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 13(62) No. 2 – 2020
https://doi.org/10.31926/but.fwiafe.2020.13.62.2.12

EFFICIENT USE OF SOLID AND WATER-SOLUBLE FERTILIZERS FOR CORN PRODUCTION IN THE NORTHERN PART OF THE STEPPE ZONE OF THE UKRAINE

Dmytro M. ONOPRIIENKO[1]

Abstract: *A high efficiency of fertigation was established after three years of research at an ordinary chernozem on the production of corn hybrid DKC 4351 instead of traditional mineral fertilizing methods. Nitrates are washed out of the root layer after spreading urea on the soil surface before the cultivation in the spring. The nitrate content in the soil in the last two phases was 16-26% higher than in the 5-6 leaf phase after applying the KAC - 32 solution with a sprayer on the soil surface.The mass of 1000 grains was the highest after several times urea application in dose N_{200} depending on irrigation rate. The maximum yield of corn grain was obtained by applying urea with rate N_{200} and KAC - 32 with irrigation water during corn vegetation period. There is a tendency to increase the protein in corn grain during fertigation with urea and KAC - 32. The data obtained show that the combination of irrigation with mineral fertilizer application is an effective way to save energy and material resources, increase the yield and grain quality.*

Key words: *corn, mineral fertilizers, irrigation, fertigation, yield, grain quality.*

1. Introduction

As a major type of irrigated crop, corn belongs to the first four main crops including wheat, rice and sorghum [7, 12, 16, 17]. The great potential of corn is reached in conditions of favorable nutrient, water and air conditions of the soil, which first can be created when it is grown on irrigated lands. Irrigation water, nutrition elements and growth stage had significant effects on the canopy height [20]. The correct combination of fertilizers and irrigation is one of the most important factors in the intensification of silage corn production in areas of irrigated agriculture [4]. Great importance is given to finding out the influence of nutrition and

[1] Dnipro State Agrarian and Economic University, Serhii Yefremova no. 25, Dnipro 49600, Ukraine; Correspondence: Dmytro M. Onopriienko; e-mail: dmo_gidrofac@ukr.net.

moisture in the development of plants and crop formation [24]. The application of nitrogen up to 200 kg N/ha increased the maize growth traits and yield [26]. The traditional technology of applying mineral fertilizers in irrigated agriculture has been transferred from non-irrigation agriculture, where fertilizers are distributed over the field surface with the help of trailer or centrifugal spreaders, followed by incorporation into the soil by plowing, cultivation or harrowing [14, 15, 19]. Unevenness and instability of fertilizer spreading reaches 20–40% [21] and leads to loss of grain yield [27]. A significant increase of water use efficiency can be achieved by the improvement of cultivation technology with the aim of providing the highest crop productivity under particular agro-environmental conditions. The application of fertilizers simultaneously with irrigation makes it possible to optimize the supply of plants with moisture and easily accessible forms of nutrients almost throughout the growing season [22]. Dnieper River with numerous tributaries is a main source of water for irrigation [23]. Fertigation definitely solves the problem of uniform distribution over the area of fertilizers in the active soil layer to the level of uniform distribution of irrigation water with a variation coefficient not higher than 20 % [3]. An important advantage of this method is the ability to supply fertilizers in small doses during the growing season, when plants are most in need without leaf damage [13]. The mineral fertilizer promoted the highest maize grain yield and N uptake by the plants, but also resulted in the highest residual NO_3^-–N levels in the soil [5]. Also, it was established that the corn kernel quality is affected by the availability of nutrients and water [1]. The main objective of research is to study the influence of various methods of applying solid and water - soluble mineral fertilizers on the efficiency of corn grain production in the conditions of the northern part of the steppe zone of the Ukraine.

2. Material and Methods

The research was carried out over 3 years (from 2016 to 2018) of growing seasons in the private farm "Aist" in the Sinelnykovo district of the Dnipropetrovsk region. The soil in the field experiment is ordinary low-humus heavy-loam chernozem with its main characteristics presented in Table 1.

Table 1

The main characteristics of the soil

Depth (cm)	WC, %	AC, %	BD g/cm^3	Porosity, %	Humus, %	N-NO_3, mg/kg	P_2O_5, mg/kg	K_2O, mg/kg	pH (H_2O)
0-40	24.1	18.9	1.74	51.3	2.8	14.4	139.5	181.5	7.5

WC- water capacity; AC- air capacity; BD- bulk density

Groundwater lies at a depth of more than 15 m. The repetition rate is four times. During the research period weather conditions were generally favorable for growing corn under irrigation conditions (Figures 1 and 2).

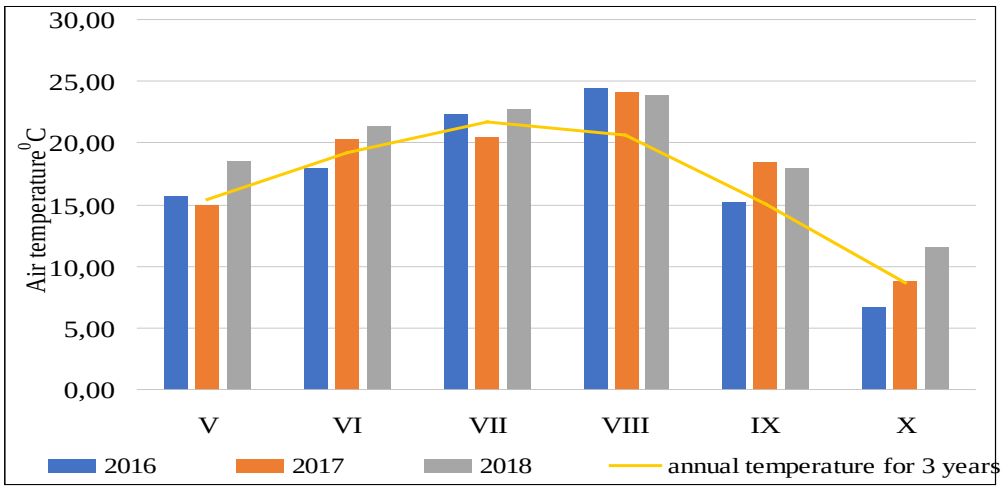

Fig. 1. *Average monthly temperatures from May to October 2016–2018, °C*

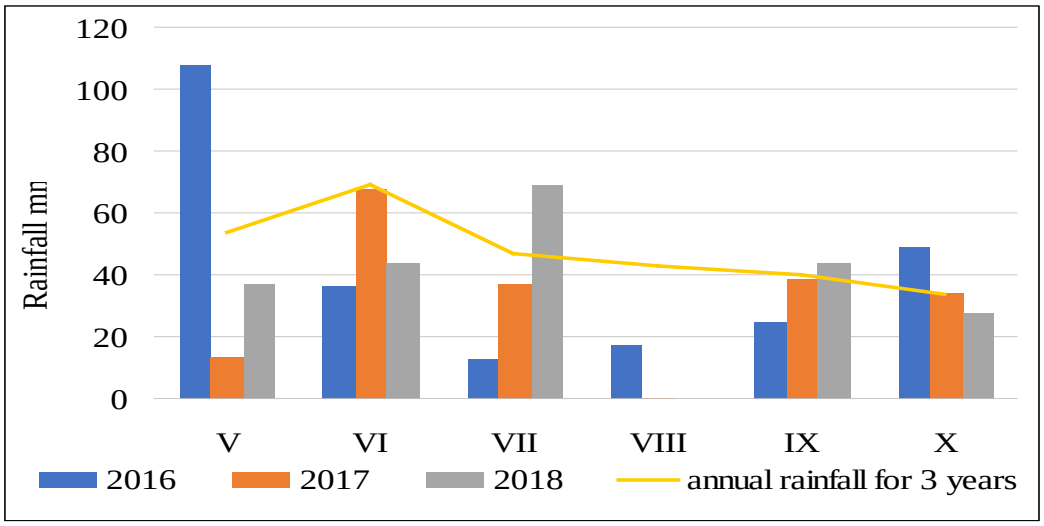

Fig. 2. *Average monthly rainfall from May to October 2016 – 2018, mm*

During the study period, the average annual temperature from May to October in the Sinelnykovo district was 17.2°C in 2016, 17.9°C in 2017, 19.4°C in 2018. Throughout the vegetation period (May-September), 2016, 373 mm of precipitation fell, in 2017 it was 177 mm, and in 2018 it was 157 mm.

Middle - ripening hybrid corn DKC4351 (FAO 350) was sown in experiments with a density of 80 thousand plants per hectare in the field experiment. The technology of growing corn was generally accepted for this crop in the area of the northern part of the steppe zone of the Ukraine. Irrigation was carried out with a wide-reach front-action sprinkler system produced by the Reinke company (USA, System Serial No: 1212-54432-2065/2060 MAXI). The dosage of mineral fertilizer solution in the irrigation water was prepared by a special apparatus of the MILTON ROY company

(USA, Manual No: 53873) with a maximum capacity of 416 liters per hour. The irrigation regime provided for maintaining minimum soil moisture in the active layer of at least 70-80 %. The irrigation rate was 2,100 m^3/ha in 2016, 2,400 m^3/ha in 2017, and 2,500 m^3/ha in 2018. Solid mineral fertilizers were represented by nitrogen (urea), nitrogen and phosphorus ('amophos') and potash fertilizers (Kalium Makosh Company, Poland). The water - soluble fertilizer KAC-32 was used as a source of nitrogen. Liquid potash fertilizers with the K_{60} norm were applied with a self-propelled sprayer for pre - sowing cultivation. The doses of mineral fertilizers for the planned corn grain yield of 12 t/ha were calculated using the balance method, taking into account the content of basic nutrition elements in the arable soil layer. The calculated doses were $N_{200}P_{90}K_{60}$. The "Powerfol Zincate" fertilizers were applied annually by a sprayer with a dose of 150 ml per 100 liters of water in all variants of experiments in the 3-4 leaf phase to prevent chlorosis and zinc deficiency in plants. The "Elumis 105 od" herbicide was introduced in the phase of 9-10 leaves with a sprayer of 1.7 l/ha to protect crops from annual and perennial grasses and dicotyledonous weeds. The "Coragen Du Pont" insecticide was introduced with a self-propelled sprayer with a rate of 150 ml/ha to control the corn stalk moth in the phase of hair ejection.

The trials of the mineral fertilizers' application are as follows:

A. The control option - on irrigation, but without fertilization;
B. Application of fertilizers on irrigation before sowing for cultivation: urea - scattered with the rate of N_{200}, 'ammophos' with the rate of P_{90} for autumn plowing;
C. Application of KAC - 32 on irrigation for cultivation before sowing with the rate N_{200} self-propelled sprayer, application of ammophos for autumn plowing with the rate P_{90};
D. Urea fertigation retail with irrigation water with the rate N_{200} during corn vegetation period;
E. KAC - 32 fertigation with irrigation water with the rate N_{200} during corn vegetation period.

The total area of the field measures 120 ha, the sown area of the experimental plots is of 16.2 ha, and the examined area is of 12.5 ha, the repetition rate is four times. Agrochemical analyses of soil samples were carried out according to accepted approaches [9]. The N - NO_3 content in soil samples was measured in accordance with the potentiometric method by means of the ion-selective electrode. Seed samples were analyzed using the Kjeldahl method to determine the total nitrogen. The crude protein content was calculated by multiplying total nitrogen value with a coefficient of 6.25. The crude oil percentage was determined by means of the Soxhlet extraction technique, fiber – through the sequential washing method, starch – by the polarimetric method based on Evers' principle.

The mathematical processing of the results was conducted using the ANOVAs statistical software with a calculation of the low sufficient difference LSD at a level of 95 %.

4. Results and Discussion

The data on the N - NO_3 content in the top and subsoil layers depending on the methods of nitrogen fertilizer input (an average for the 2016–2018 period) in order

to reach the yield of 12 t/ha is shown in Figure 3. Nitrates are washed out of the root layer after spreading urea on the soil surface before cultivation in the spring. The nitrates content decrease in the soil before the period of intensive demand of maize plants for nitrogen (10-12 leaves) was 15.3 % and 41.0 % (in the phase of milk ripeness of the grain) in comparison with the period of 5-6 leaves. The nitrate content in the soil in the last two phases was 16-26 % higher than in the 5-6 leaf phase after applying the KAC - 32 solution with a sprayer on the soil surface.

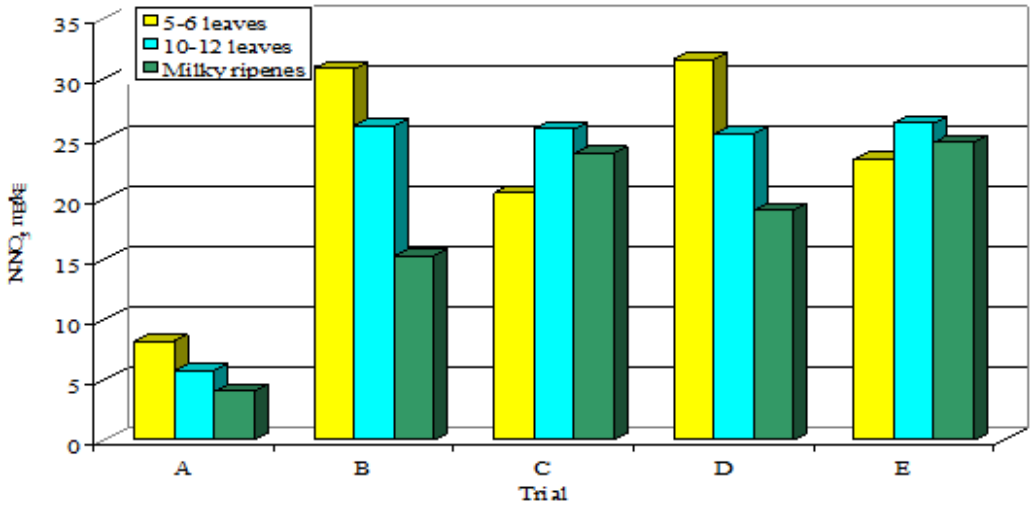

Fig. 3. *The content of nitrates (N - NO_3) in the arable topsoil depending on the methods of applying nitrogen fertilizers (average for 2016-2018), mg/kg*

This indicates a significant consumption of nitrogen by maize in the main phases of ontogenesis. The maximum amount of mineral nitrogen in the soil was observed at the beginning of the growing season when urea was introduced for cultivation. The fluctuations of nitrates in the soil when applying fertilizers with a dose of N_{200} together with irrigation water for this period were less significant. In the phase of milk ripeness of the grain, their content in the soil was significantly higher. This had a positive impact on the corn yield. The application of watersoluble mineral fertilizers KAC - 32 with irrigation water during corn vegetation period provided the maximum amount of nitrate nitrogen in the phase of milk ripeness of the grain. The main productive parameters of the hybrid corn DKC 4351 data is shown in Table 2. The number of corn cobs was almost the same in all trials. It was significantly higher for the application of mineral fertilizers with irrigation water. Fertigation with urea and KAC - 32 created favorable conditions for the growth and development of the corn crop. Its positive effect was observed in the increase in the mass of 1000 grains, the average mass of heads and the yield of grain.

Table 2

Main productive parameters of the corn hybrid DKC 4351 (average for 2016-2018)

Trial	Number of cobs per 100 plants	One cob mass, g	Grain output, %	Weight of 1000 grains, g
A	97	161	80	268.3
B	101	202	87	332.1
C	101	203	88	334.0
D	101	236	87	370.1
E	101	238	89	366.1

The ANOVA results showed that there was a significant difference in the mean of each trial parameter between repetitions ($p < 0.05$).

A stable increase in grain yield was obtained when nitrogen fertilizers were applied with irrigation water over a period of three years (Table 3). The maximum yield of corn grain was obtained in two trials, D and E, during the vegetation period when sprinkling irrigation had been used.

Table 3

Influence of mineral fertilizers application methods on corn hybrid grain yield DKC 4351, t/ha

Trial	2016	2017	2018	Average
A	4.8	5.2	5.7	5.3
B	12.3	12.4	12.7	12.4
C	12.4	12.5	12.7	12.5
D	12.8	12.9	13.0	12.9
E	12.8	12.7	12.8	12.7
$LSD_{0.05}$ – 0.24 t/ha				

It is known that the water-soluble fertilizers are mostly used as conventional fertilizers and can clog drip emitters with suspended and undissolved particles in case of drip irrigation [18]. The use of sprinkler irrigation for fertigation allows for a decrease of production cost and leads to a better productivity of corn yield. Similar results regarding the effect of the fertigation rate on corn yield were obtained in several case studies [6, 8, 25]. The results of three nitrogen levels (120, 180 and 240 kg/ha) indicated that the interaction of nitrogen and irrigation has no significant effects on maize height. However, the signal factor had a significant effect on the plant height in the whole growth period. It was established that irrigation levels significantly affected the maize grain yield, except crude protein and crude oil [11]. In another case study, the protein contents of silage corn ranged from 6.63 to 9.78 % depending on the volume of irrigation water applied and the effect of the N fertigation frequency [28].

The qualitative evaluation of corn hybrid DKC 4351 data grain depending on the methods of applying nitrogen fertilizers with irrigation is shown in Table 4. The analysis also showed that there were significant differences in the mean of crude protein and starch between control and fertilization trials D and E ($p < 0.05$).

The greatest effect of increasing the protein and starch content in corn grains was observed after fertigation with urea and KAC-32. The Iran case study was carried out to evaluate the effects of four nitrogen treatments (50, 100, 150 and 200 kg urea / ha). It was shown that the treatment of 200 kg/ha urea had the highest protein content of 8% [2]. The application of nitrogen fertilizer increased

the amount of grain and forage protein content and decreased the fiber content in maize hybrids. There was no significant difference among the N fertilizer levels on oil and moisture. The method of nitrogen fertilizers applied in our research did not affect the oil and fiber content in the corn grain either. This may be due to the form of nitrogen fertilizers. Similar results were obtained in the field experiments to study the effect of treated municipal wastewater with organic and inorganic fertilizers on silage yield and yield components, protein and oil content [10]. Meanwhile, the highest level of oil content was obtained from manure. The efficient use of various water - soluble mineral fertilizers in the system of growing corn for grain under irrigation conditions will be continued taking into account the periods of maximum consumption of soil moisture and nutrition elements as well as the differences in biotypes of hybrids.

Table 4

Grain quality of corn hybrid DKC 4351

Trial	Content in grain, %			
	Crude protein	Oil	Starch	Fiber
A	7.11	3.28	61.8	2.9
B	7.61	3.52	62.9	2.9
C	7.83	3.58	62.7	2.9
D	8.15	3.12	63.1	3.0
E	7.95	3.47	63.2	3.0

4. Conclusions

High efficiency of fertigation was established after three years of research on ordinary black soil in the production of corn hybrid DKC 4351, instead of traditional mineral fertilizing methods. Nitrates are washed out of the root layer after spreading urea on the soil surface before cultivation in the spring. The nitrates content decreased in the soil before the period of intensive demand of maize plants for nitrogen (10-12 leaves) to 15.3 % and 41.0 % (in the phase of milk ripeness of the grain) in comparison with the period of 5-6 leaves. The nitrate content in the soil in the last two phases was 16-26 % higher than in the 5-6 leaf phase after applying the KAC-32 solution with a sprayer on the soil surface. The mass of 1000 grains was the highest after the urea application several times with rate N_{200} by fertigation. The maximum yield of corn grain during three years of research was obtained by applying the urea norm N_{200} and KAC - 32 with irrigation water during vegetation irrigation. There is a tendency to increase the protein content in corn grain during fertigation with urea and KAC - 32. Several times these fertilizers application with irrigation water has also contributed to an increase in the amount of protein per area unit. The obtained data show that the combination of irrigation with the application of mineral fertilizers is an effective way to save energy and material resources, increase the yield and quality of the corn crop.

References

1. Abbas H., Ranjan R.S., 2016. Effect of overhead irrigation on corn yield and quality under shallow water table conditions. In: Canadian Biosystems Engineering, vol. 58, pp. 33-44.
2. Almodares A., Jafarinia M., Hadi M.R., 2009. The effects of nitrogen fertilizer on chemical compositions in corn and sweet sorghum. In: American-Eurasian Journal of Agricultural and

Environmental Sciences, vol. 6(4), pp. 441-446.
3. Asadi M.E., Clemente R., Gupta A.D. et al., 2002. Impacts of fertigation via sprinkler irrigation on nitrate leaching and corn yield in an acid–sulphate soil in Thailand. In: Agricultural Water Management, vol. 52(3), pp. 197-213. doi:10.1016/S0378-3774(01)00136-6.
4. Barlog P., Frckowiak-Pawlak K., 2008. Effect of mineral fertilization on yield of maize cultivars differing in maturity scale. In: Acta Scientiarum Polonorum. Agricultura, vol. 7(4), pp. 5-17.
5. Biau A., Santiveri F., Mijangos I. et al., 2012.The impact of organic and mineral fertilizers on soil quality parameters and the productivity of irrigated maize crops in semiarid regions. In: European Journal of Soil Biology, vol. 53, pp. 56-61. doi.org/10.1016/j.ejsobi.2012.08.008.
6. Bibe S.M., Jadhav K.T., Chavan A.S., 2017. Response of irrigation and fertigation management on growth and yield of maize. In: International Journal of Current Microbiologu and Applied Sciences, vol. 6(11), pp. 4054-4060. doi.org/10.20546/ijcmas.2017.611.474.
7. Bondar V., Makarenko N., 2020. Winter wheat growing in Ukraine: ecological assessment of technologies by the influence on soil fertility. In: Acta Agriculturae Slovenica, vol. 115(1), pp. 67-78. doi:10.14720/aas. 2020.115.1.982.
8. Chauhdary J.N., Bakhsh A., Arshad M. et al., 2017. Effect of different irrigation and fertigation strategies on corn production under drip irrigation. In: Pakistan Journal of Agricultural Sciences, vol. 54(4), pp. 855-863. doi: 10.21162/pakjas/ 17.5726.
9. Dokuchaev Soil Institute, 1965. Agrochemical methods of soil investigation (in Russian). 4th Edition, Edited by USSR Academy of Science, Science Publishers, Moscow, Russia, 436 p.
10. Esmailian Y., Ghanbari A., Babaeian M. et al., 2011. Influence of organic and inorganic fertilizers and wastewater irrigation on yield and quality traits of corn. In: American-Eurasian Journal of Agricultural and Environmental Sciences, vol. 10(4), pp. 658-666.
11. Karasu A., Kuşcu H., Öz M. et al., 2015. The effect of different irrigation water levels on grain yield, yield components and some quality parameters of silage maize (zea mays indentata Sturt.) in Marmara Region of Turkey. In: Notulae Botanicae Horti Agrobotanici Cluj-Napoca, vol. 43(1), pp. 138-145. doi:10.15835/ nbha4319602.
12. Kharytonov M., Martynova N., Babenko M. et al., 2019.The production of biofuel feedstock on reclaimed land based on sweet sorghum biomass. In: Agriculture and Forestry Journal, vol. 65(4), pp. 233-240. doi:10.17707/ AgricultForest.65.4.21.
13. King B.A., Wall R.W., Karsky T.F., 2009. Center-pivot irrigation for independent site-specific management of water and chemical application. In: Applied Engineering in Agriculture, vol. 25(2), pp. 187-198.
14. Kobets A.S., Ponomarenko N.O., Kharytonov M.M., 2017. Construction of centrifugal working device for mineral fertilizers spreading. In:

INMATEH – Agricultural Engineering Journal, vol. 57(1), pp. 5-14.
15. Kobets A.S., Ponomarenko N.A., Kobets O.M. et al., 2019. Study of fertilizer spreader centrifugal type under field conditions. In: INMATEH – Agricultural Engineering Journal, vol. 57(1), pp. 161-168.
16. Lupu M., Pădureanu V., Canja C.M., 2014. Wheat resistance analysis on the subject of energy consumption in the grinding process. In: Bulletin of the Transilvania University of Braşov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 7(56), no. 2, pp. 59-62.
17. Lykhovyd P.V., Lavrenko S., Lavrenko N. et al., 2019. Agro-environmental evaluation of irrigation water from different sources, together with drainage and escape water of rice irrigation systems, according to its impact on maize. In: Journal of Ecological Engineering, vol. 20(2), pp. 1-7. doi.org/10.12911/22998993/94916.
18. Munir J.M., Hammouri A., Ferdows A.E., 2004. Phosphorus fertigation and pre-plant conventional soil application of drip irrigated summer squash. In: Journal of Agronomy, vol. 3, pp. 162-169. doi:10.3923/ja.2004.162.169.
19. Nazli R.I., Kuşvuran A., Inal İ. et al., 2014. Effects of different organic materials on forage yield and quality of silage maize (*Zea mays* L.). In: Turkish Journal of Agriculture and Forestry, vol. 38, pp. 23-31.
20. Nilahyane A., Islam M.A., Mesbah A.O. et al., 2018. Effect of irrigation and nitrogen fertilization strategies on silage corn grown in semi-arid conditions. In: Journal of Agronomy, vol. 8(10), pp. 1-14. doi:10.3390/agronomy 8100208.
21. Nukeshev S., Dzhadyger E., Gennady L. et al., 2016. Theoretical substantiation of the design of a seeding device for differentiated intra soil application of mineral fertilizers. In: Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, vol. 64(1), pp. 115-122.
22. Onopriienko D., Kharytonov M., 2019. The effects of irrigation and nitrogen application rates on yield and quality of corn in the Steppe zone of Ukraine. In: Agriculture and Forestry Journal, vol. 65(1), pp. 157-164. doi:10.17707/AgricultForest.65.1.16.
23. Pichura V.I., Potravka L.A., Skrypchuk P.M. et al., 2020. Anthropogenic and climatic causality of changes in the hydrological regime of the dnieper river. In: Journal of Ecological Engineering, vol. 21(4), pp. 1-10. doi.org/10.12911/22998993/119521.
24. Reetz H.F.Jr., 2016. Fertilizers and their efficient use. In: International Fertilizer Industry Association (IFA) Paris, France, 116 p.
25. Sampathkumar T., Pandian B.J., 2010. Effect of fertigation frequencies and levels on growth and yield of maize. In: Madras Agricultural Journal, vol. 97(7-9), pp. 245-248.
26. Shrestha J., Chaudhary A.A., Pokhrel D., 2018. Application of nitrogen fertilizer in maize in Southern Asia: a review. In: Peruvian Journal of Agronomy, vol. 2(2), pp. 22-26. doi.org/10.21704/pja.v2i2.1201.
27. Tekin A.B., Sındır K., 2014. Performance assessment of variable rate spinner disc fertilizer spreader – "PreFer". In: Agricultural Engineering, vol. 2, pp. 43-52.

28. Yolcu R., Cetin O., 2015. Nitrogen fertigation to improve nitrogen use efficiency and crude protein on silage corn. In: Turkish Journal Field Crops, vol. 20(2), pp. 233-241. doi:10.17557/tjfc.58656.