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# Response of maize hybrids to irrigation methods and primary tillage in the Ukrainian Steppe

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**Abstract.** The aim of the study was to determine the response of maize hybrids to drip irrigation compared to traditional sprinkler irrigation under conventional plowing (30-32 cm) and deep tillage (35-37 cm) as the primary soil cultivation methods. The article presents the results of evaluating the effectiveness of drip irrigation and sprinkler irrigation, as well as the impact of deep non-inversion tillage versus classical plowing on maize yield across different FAO maturity groups in the Ukrainian Steppe. The research was conducted in an irrigated crop rotation on southern solonetsic chernozem soils with a humus content of 2.9-3.2% and a pH of 6.2. The preceding crop was sunflower. The total water application rate during the growing season was 4,000 $m^3$/ha. The study included 11 hybrids with FAO numbers ranging from 210 to 370. A low yield variation (CV = 12.7-13.4%) indicates a uniform response of the studied hybrids to changes in growing conditions. Maize yield significantly increased under drip irrigation by +0.75 to +2.13 t/ha (+7.5 to +18.3%). Deep tillage provided a notable yield increase of +0.46 t/ha under sprinkler irrigation and +0.70 t/ha under drip irrigation. The hybrids VN 63 (FAO 280) showed a strong positive response to deep tillage (+1.0 to +1.35 t/ha), as did Gran 6 (FAO 300) with +0.87 to +1.23 t/ha, Tesla (FAO 350) with +0.66 to +0.99 t/ha, and Gran 1 (FAO 370) with +0.89 to +1.12 t/ha under both irrigation methods. The study established that hybrids with FAO less than 280 are not suitable for cultivation in the Southern Steppe due to lower grain yield. Among the FAO 200-300 group, VN 63 and Gran 6 achieved significant yield increases of +0.5 to +2.5 t/ha, with yields of 10.93 and 11.99 t/ha, respectively. In the FAO 320-400 group, Tesla and Gran 1 demonstrated substantial yield gains of +0.61 to +2.08 t/ha, with average yields of 14.06 and 13.92 t/ha, respectively. The highest grain yields of 15.57 and 15.49 t/ha were achieved by the Tesla (FAO 350) and Gran 1 (FAO 370) hybrids under deep tillage combined with drip irrigation, significantly ($>CI_{0.99}$) outperforming the standard. The analysis indicates the high effectiveness of drip irrigation and deep tillage in enhancing maize yields in the Southern Ukrainian Steppet

**Keywords:** yield; drip irrigation; sprinkler irrigation; plowing; soil loosening

## INTRODUCTION

Agricultural production in the arid conditions of the Steppe requires the use of advanced technologies for soil tillage, sowing, crop protection against diseases and pests, and the introduction of new high-yielding varieties and hybrids with a complex of economically valuable traits. Maize is one of the oldest crops and plays a significant role in Ukraine's economy. It provides livestock with concentrated feed, silage, and green mass. Maize grain contains carbohydrates (about 70%), oil (up to 8%), protein (9-12%), and amino acids. In terms of feed value, it equals 1.34 feed units and is an important ingredient in the food and processing industries as well

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as in livestock fattening (Polishchuk & Khavhun, 2023). Given its value in feed and food chains and its positive economic effect, maize is one of the essential crops in irrigated crop rotations. However, the expansion of Ukrainian maize hybrids to larger areas across diverse soil and climatic conditions is limited by a lack of information regarding their response to different primary tillage methods and the potential of various irrigation types. This issue has not received adequate attention in recent publications.

The effectiveness of irrigation has been studied by both Ukrainian and foreign researchers. Noteworthy contributions have been made by scientists from the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences of Ukraine (IIA NAAS) and Kherson State Agrarian University (KhSAU). Their studies focused on the cultivation efficiency of maize hybrids under drip and sprinkler irrigation with various plant protection regimes, and they examined the influence of irrigation methods and plant density on the seed productivity of maize parental lines. Research in Ukraine's Steppe zone has shown that drip irrigation is more efficient than traditional sprinkler irrigation, especially for medium-late hybrids, where yield increases of 1.02-2.35 t/ha were recorded (Ivaniv & Repilevsky, 2021). As noted by A.P. Shatkovskyi *et al*. (2021), irrigation methods are a key factor in intensifying grain production and implementing environmentally safe, energy- and resource-saving technologies. Classical drip irrigation can ensure maize yields of up to 20.69 t/ha. Studies from around the world confirm the advantages of drip irrigation compared to other methods of supplying water to crops (Shatkovskyi *et al*., 2020). In Israel, maize yield increased by 72% under drip irrigation (up to 25 t/ha), and in Ukraine, by 60% (up to 16 t/ha). In the USA, 2023 harvest data showed a new world record maize yield of 39.14 t/ha, although on a limited area (~4.9 ha) under no-till and drip irrigation technology (Gusarova, 2023).

Cost reduction in cultivation technology is also possible through energy-saving soil tillage methods (Yeshchenko *et al*., 2014). Modern tillage systems such as Mini-till, Strip-till, and No-till, as well as mulching, help reduce moisture evaporation from the soil surface and decrease energy costs. Combining new technologies with irrigation, balanced fertilisation, and plant protection enables full realisation of the genetic potential of new hybrids (A new world record…, 2024). Research by R. Vozhegova *et al*. (2022) demonstrated that shallow surface tillage does not provide economically viable high maize yields, particularly in dry Steppe regions. Deep non-inversion tillage offers advantages, reducing energy consumption by 20-22% and increasing maize yields in Ukraine's Steppe (Tomashuk, 2019). Yields of up to 11-12 t/ha were recorded with non-inversion tillage. According to M. Marenych & K. Koba (2024), maize parental line yields are influenced primarily by genetic factors (54%) and tillage methods (41%). Thus, improving maize cultivation technologies is a crucial factor in ensuring global food security.

Therefore, the study of the response of maize hybrids of various genetic origins under drip irrigation in the arid conditions of the Southern Steppe, combined with different primary tillage methods, is highly relevant for optimising cultivation technologies and realising the genetic potential of hybrids of different maturity groups. The aim of this study was to determine the specific yield response of Ukrainian-bred maize hybrids of various maturity groups under drip and sprinkler irrigation with different soil tillage methods. The objective was to assess the impact of irrigation method and primary tillage type on the grain yield of maize hybrids.

## MATERIALS AND METHODS

**Experimental conditions.** The experiment was conducted in southern Ukraine at the farm "Matros" (Private Farm Enterprise) in Novotroitske District, Kherson Region, under irrigated conditions during 2019-2020. The soil type was southern solonetsic chernozem of heavy texture, with a humus content of 2.9-3.2% and pH of 6.2. Drip irrigation was applied using tape with emitters spaced 20 cm apart and row spacing of 140 cm. A total of 14 irrigation events were performed under the drip method, and 7 events using sprinkler irrigation with a "Fregat" system. In both cases, the total irrigation water applied during the growing season was 4,000 $m^3$/ha. Precipitation during the maize growing season (April 1 to August 31) was 134.6 mm in 2019 and 195.8 mm in 2020 (Meteopost, 2025). According to literature, maize total water consumption depends on the irrigation regime and ranges from 3,250 to 4,762 $m^3$/ha. Under ideal conditions (optimal soil moisture), the maximum consumption reaches 4,762-5,525 $m^3$/ha (Shatkovskyi *et al*., 2021). These values justified the irrigation rate, considering long-term average rainfall in the region (Meteopost, 2025). Fertilisation included pre-plant application of 100 kg/ha ammonium sulfate and 150 kg/ha nitroammophoska. In January-February, urea was applied at a rate of 250 kg/ha during the winter fertilisation window for winter crops (under minimal snow cover). The total nutrient input per hectare in active ingredient terms was $N_{160}P_{24}K_{24}S_{24}$ and was kept consistent across all years and treatments. Weed control was performed using the post-emergence herbicide MaisTer (0.15 kg/ha) with Biopower (1.5 L/ha) at the 5-leaf stage. Foliar feeding was applied at the 6-leaf and 8-leaf stages using nitrogen in the form of urea (N5 + N5), insecticide, zinc, magnesium, and potassium humate – applied uniformly across all experimental treatments.

**Experimental design and research objects.** The study evaluated maize hybrids with FAO maturity indices ranging from 210 to 370. The following hybrids were studied: Gran 220 (FAO 210), Gran 310 (FAO 250), VN 63 (FAO 280), Gran 6 (FAO 300), VN 6763 (FAO 320), Amarok 290 (FAO 320), Amarok 300 (FAO 320), Tesla (FAO 350), and Gran 1 (FAO 370). For the FAO 200-300 group, the standard control hybrid was DKC 3795 (FAO 250); for the FAO 320-400 group, it was KWS 381 (FAO 350). Seeding rates were 90,000 seeds/ha for hybrids in the FAO 200-300 group and 80,000 seeds/ha for those in the FAO 320-370 group. Seeding rates were based on prior experimental data from the region under irrigation. The preceding crop was sunflower. Each plot area was 0.224 ha. The experiment included three replications, and plots were arranged in a randomized complete block design. The sowing pattern for hybrids remained identical across years, tillage types, and irrigation methods. Two types of primary tillage were tested: conventional moldboard plowing to a depth of 30-32 cm and deep chiseling with a disk-chisel harrow to a depth of 35-37 cm. Sowing was performed in the first ten days of April, when soil temperatures exceeded +11°C. Harvesting was carried out using a Claas Tucano 470 combine equipped with a maize header. Yield was determined using the weigh method and adjusted to 14% grain moisture. Statistical analysis was performed using two-factor analysis of variance (ANOVA) according to V.O. Ushkarenko *et al.* (2013). Factor A included irrigation methods and primary tillage type, while Factor B represented the maize hybrids of various maturity groups.

## RESULTS AND DISCUSSION

The results of the study revealed the response of maize hybrids of various maturity groups to different irrigation methods and primary tillage practices. Two-factor ANOVA was conducted for each year and for each combination of irrigation method and tillage type. Additional analyses were performed by isolating irrigation method as factor A and tillage method as factor A, with maize hybrids as factor B in each case. The calculated data were consistent across the different statistical approaches. The statistical results of the two-factor experiment are presented in Table 1. According to the results, there was only slight variation in grain yield across the years and treatments among the studied maize hybrids (CV = 12.7-13.4%). This indicates a uniform response of the hybrids to changes in growing conditions and highlights the strong direct influence of the studied factors – irrigation method and tillage system on grain yield.

Hybrids Gran 220 (FAO 210) and Gran 310 (FAO 250) consistently produced significantly lower grain yields ($<CI_{0.99}$) than the standard hybrid DKC 3795 (FAO 250) for the FAO 200-300 maturity group across all treatments in both years. The difference ranged from −0.20 to −1.38 t/ha, or −8% to −14%. Similar trends were observed in the FAO 320-400 group, where Amarok 290 (FAO 320) and Amarok 300 (FAO 320) mostly showed significantly lower yields ($<CI_{0.95}$) than the standard hybrid KWS 381 (FAO 350), regardless of irrigation method or tillage type. In absolute values, this difference ranged from −0.22 to −0.86 t/ha, or −2% to −7% compared to the standard. Therefore, the cultivation of Gran 220, Gran 310, and Amarok 290 hybrids under irrigation in southern Ukraine is not advisable, as they do not provide yield advantages over the standard hybrids and are not economically viable under these soil and climatic conditions.

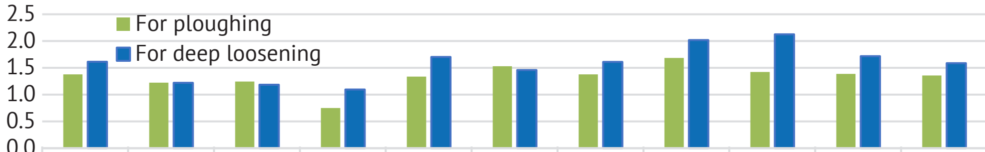
An exception was observed for Amarok 300 (FAO 320) under drip irrigation combined with deep tillage, where a significant yield increase ($>CI_{0.99}$) was recorded: +0.56 t/ha (+4.0%) in 2019 and +0.49 t/ha (+3.6%) in 2020 compared to the standard. Thus, Amarok 300 can be considered suitable for cultivation in the Steppe zone under drip irrigation with deep soil loosening as the primary tillage method. Other combinations involving Amarok 300 were not effective in increasing yield and are not recommended for production. All other tested hybrids consistently outperformed the standard hybrids of their respective maturity groups across all treatments over the two-year period. Therefore, hybrids VN 63, Gran 6, VN 6763, Tesla, and Gran 1 demonstrated significantly higher grain yields compared to the standards and are well-suited for cultivation under irrigation in the Steppe zone of southern Ukraine. Detailed results by irrigation method and tillage system are presented in Table 1 and illustrated graphically in Figures 1 and 2.

In 2019, under deep moldboard plowing, drip irrigation resulted in an increase in maize hybrid yields compared to sprinkler irrigation by +1.18 to +2.03 t/ha, which represented a yield gain of +11.9% to +18.0%. In 2020, the yield increase ranged from +0.32 to +1.53 t/ha (+3.2% to +13.4%). Under deep chiseling, the yield increase in 2019 due to drip irrigation was even greater-ranging from +1.32 to +2.46 t/ha (+14.5% to +21.7%). In 2020, the increase was between +0.66 and +1.91 t/ha (+5.9% to +16.5%). These results indicate a clear and positive response of the studied maize hybrids to the method of irrigation and demonstrate the significantly higher efficiency of drip irrigation compared to sprinkler irrigation using the "Fregat" system. The average yield increase over the two-year period (2019-2020) is presented graphically in Figure 1.

***Table 1.*** *Results of the analysis of variance (ANOVA) for grain yield of maize hybrids of different maturity groups under drip and sprinkler irrigation with various primary tillage methods, 2019-2020*

| Irrigation method (Factor A) | Hybrid, experimental variant (Factor B) | Hybrid maturity group (FAO) | 2019 p. | | | | | | 2020 p. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ploughing | | | loosening | | | ploughing | | | loosening | | |
| | | | Average for hybrid (variant), x̄, t/ha | Variance by factor | | Average for hybrid (variant), x̄, t/ha | Variance by factor | | Average for hybrid (variant), x̄, t/ha | Variance by factor | | Average for hybrid (variant), x̄, t/ha | Variance by factor | |
| | | | | A | B | | A | B | | A | B | | A | B |
| Sprinkler machine type "Fregat" | DKC 3795 (st.) | 250 | 9.63 | | | 9.33 | | | 9.68 | | | 9.96 | | |
| | Gran 220 | 210 | 9.16 | | -0.47 | 9.13 | | -0.20 | 8.58 | | -1.11 | 9.09 | | -0.87 |
| | Gran 310 | 250 | 8.34 | | -1.29 | 8.55 | | -0.78 | 8.74 | | -0.95 | 9.31 | | -0.65 |
| | VN 63 | 280 | 9.88 | | 0.25 | 10.75 | | 1.42 | 10.05 | | 0.66 | 11.20 | | 1.23 |
| | Gran 6 | 300 | 11.03 | | 1.40 | 11.86 | | 2.53 | 10.55 | | 1.17 | 11.45 | | 1.49 |
| | KWS 381 (st.) | 350 | 11.74 | | | 11.36 | | | 11.59 | | | 12.16 | | |
| | VN 6763 | 320 | 11.92 | | 0.18 | 11.73 | | 0.37 | 11.43 | | -0.16 | 12.51 | | 0.35 |
| | Amarok 290 | 320 | 11.13 | | -0.61 | 10.90 | | -0.46 | 10.87 | | -0.72 | 11.48 | | -0.68 |
| | Amarok 300 | 320 | 11.27 | | -0.47 | 11.65 | | 0.29 | 11.37 | | -0.22 | 11.58 | | -0.58 |
| | Tesla | 350 | 12.80 | | 1.06 | 13.50 | | 2.14 | 13.10 | | 1.52 | 13.73 | | 1.57 |
| | Gran 1 | 370 | 12.81 | | 1.07 | 13.75 | | 2.39 | 12.67 | | 1.08 | 13.50 | | 1.34 |
| Drip irrigation | DKC 3795 (st.) | 250 | 11.09 | 1.46 | | 11.37 | 2.04 | | 10.98 | 1.29 | | 11.16 | 1.19 | |
| | Gran 220 | 210 | 10.62 | 1.46 | -0.48 | 10.46 | 1.32 | -0.91 | 9.57 | 0.99 | -1.28 | 10.21 | 1.12 | -0.95 |
| | Gran 310 | 250 | 9.71 | 1.37 | -1.38 | 10.22 | 1.67 | -1.15 | 9.85 | 1.11 | -0.75 | 10.01 | 0.70 | -1.14 |
| | VN 63 | 280 | 11.06 | 1.18 | -0.03 | 12.29 | 1.54 | 0.92 | 10.37 | 0.32 | 0.06 | 11.85 | 0.66 | 0.70 |
| | Gran 6 | 300 | 12.29 | 1.26 | 1.20 | 13.51 | 1.65 | 2.14 | 11.96 | 1.42 | 1.65 | 13.21 | 1.76 | 2.06 |
| | *KWS 381 (st.)* | 350 | 13.34 | 1.60 | | 13.43 | 2.07 | | 13.05 | 1.46 | | 13.01 | 0.85 | |
| | VN 6763 | 320 | 13.14 | 1.22 | -0.19 | 13.92 | 2.19 | 0.49 | 12.97 | 1.53 | 0.08 | 13.54 | 1.03 | 0.53 |
| | Amarok 290 | 320 | 13.08 | 1.95 | -0.25 | 13.36 | 2.46 | -0.07 | 12.30 | 1.42 | -0.76 | 13.06 | 1.58 | 0.06 |
| | Amarok 300 | 320 | 13.30 | 2.03 | -0.04 | 13.99 | 2.34 | 0.56 | 12.19 | 0.82 | -0.86 | 13.49 | 1.91 | 0.49 |
| | Tesla | 350 | 14.65 | 1.84 | 1.31 | 15.57 | 2.08 | 2.14 | 14.03 | 0.93 | 1.39 | 15.09 | 1.36 | 2.08 |
| | Gran 1 | 370 | 14.53 | 1.72 | 1.19 | 15.49 | 1.75 | 2.06 | 13.66 | 0.99 | 1.19 | 14.93 | 1.43 | 1.92 |
| **$CI_{0.95}$** by factors | | | | **0.36** | **0.43** | | **0.15** | **0.18** | | **0.21** | **0.25** | | **0.25** | **0.30** |
| **$CI_{0.99}$** by factors | | | | **0.84** | **0.61** | | **0.35** | **0.26** | | **0.48** | **0.35** | | **0.57** | **0.42** |
| **$CI_{0.95}$** search | | | | **0.55** | | | **0.23** | | | **0.24** | | | **0.26** | |
| **$CI_{0.99}$** search | | | | **0.73** | | | **0.31** | | | **0.32** | | | **0.48** | |
| **CV,%** | | | | **13.34** | | | **13.41** | | | **12.71** | | | **13.39** | |
| **T, %** | | | | **98.36** | | | **99.31** | | | **99.26** | | | **98.91** | |

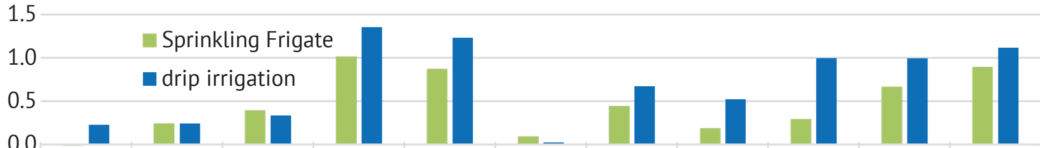
***Source:*** *compiled by the author*




| | DKS 3795 (st.) | Gran 220 | Gran 310 | VN 63 | Gran 6 | KWS 381 (st.) | VN 6763 | Amarok 290 | Amarok 300 | Tesla | Gran 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.38 | 1.22 | 1.24 | 0.75 | 1.34 | 1.53 | 1.38 | 1.69 | 1.42 | 1.39 | 1.36 |
| | 1.62 | 1.22 | 1.19 | 1.10 | 1.70 | 1.46 | 1.61 | 2.02 | 2.13 | 1.72 | 1.59 |

***Figure 1.*** *Two-year average grain yield increase of maize under drip irrigation compared to sprinkler irrigation by hybrid and primary tillage method, t/ha, 2019-2020*

***Source:*** *compiled by the author*




| | DKS 3795 (st.) | Gran 220 | Gran 310 | VN 63 | Gran 6 | KWS 381 (st.) | VN 6763 | Amarok 290 | Amarok 300 | Tesla | Gran 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -0.01 | 0.24 | 0.39 | 1.01 | 0.87 | 0.09 | 0.44 | 0.19 | 0.29 | 0.66 | 0.89 |
| | 0.23 | 0.24 | 0.34 | 1.35 | 1.23 | 0.02 | 0.67 | 0.52 | 1.00 | 0.99 | 1.12 |

***Figure 2.*** *Two-year average grain yield increase of maize under deep non-inversion tillage compared to conventional plowing by hybrid and irrigation method, t/ha, 2019-2020*

***Source:*** *compiled by the author*

Yield increases in absolute terms were generally higher in 2019 compared to the following year, which can be attributed to extreme temperature conditions during the 2020 growing season. Among the FAO 200-300 maturity group, the highest two-year average yield increases under drip irrigation were recorded for the hybrids Gran 6 and DKC 3795 (st.), regardless of the type of primary tillage – both exceeding +1.3 t/ha (+11.1%). Other hybrids in this group also showed average yield increases above +1.0 t/ha under drip irrigation. Early-maturing hybrids Gran 220 and Gran 310 responded positively to drip irrigation, with yield increases above +1.2 t/ha. However, these were the lowest among all studied hybrids, due to their generally lower yield potential compared to the standard and other maturity groups.

The average two-year yield increase under drip irrigation with conventional plowing exceeded +0.75 t/ha across all hybrids, while with deep loosening it was more than +1.1 t/ha. Under plowing, the most effective response to drip irrigation was observed in Amarok 290 ($\bar{x}$ = +1.69 t/ha), Tesla ($\bar{x}$ = +1.39 t/ha), and the standard hybrid KWS 381 ($\bar{x}$ = +1.53 t/ha). Under deep non-inversion tillage, a yield increase greater than +1.50 t/ha under drip irrigation was recorded for the hybrids DKC 3795 (st.), Gran 6, VN 6763, Amarok 290, Amarok 300, Tesla, and Gran 1. The overall average yield increase of maize grain under drip irrigation (regardless of hybrid) compared to sprinkler irrigation was +1.34 t/ha under plowing and +1.58 t/ha under deep loosening.

Thus, the results of the experiment confirm findings from the literature regarding the superior effectiveness of drip irrigation over conventional sprinkler irrigation for grain maize production (Marchenko *et al.*, 2023), regardless of hybrid maturity group or primary tillage method. While the response of the studied maize hybrids to different tillage types was differentiated, a general trend of significantly higher grain yields under deep non-inversion tillage compared to conventional plowing was observed across all irrigation methods. This trend is illustrated in Figure 2.

The hybrids DKC 3795 (st.) and KWS 381 (st.), used as standards for their respective FAO maturity groups, showed no significant response to deep non-inversion tillage compared to conventional plowing, regardless of the irrigation method. This conclusion is supported by the results of the variance analysis (Table 1, Fig. 2). Short-season hybrids Gran 220 and Gran 310 demonstrated a consistent and significant ($\geq CI_{0.95}$) increase in grain yield under deep loosening across both irrigation methods, with yield gains of +0.24 t/ha (2.7%) and +0.39 t/ha (4.6%), respectively. A highly significant increase in grain yield ($>CI_{0.99}=0.60$) under deep non-inversion tillage was observed in VN 63 (+1.01 t/ha, 10.1%), Gran 6 (+0.87 t/ha, 8.1%), Tesla (+0.66 t/ha, 5.1%), and Gran 1 (+0.89 t/ha, 7.0%) under sprinkler irrigation. Under drip irrigation, the respective increases were +1.35 t/ha (12.6%), +1.23 t/ha (10.0%), +0.99 t/ha (6.9%), and +0.30 t/ha (7.9%) ($CI_{0.99}$ = 0.46). The most pronounced positive response to deep non-inversion tillage – exceeding +1.0 t/ha compared to plowing – was recorded under drip irrigation for hybrids VN 63, Gran 6, Amarok 300, Tesla, and Gran 1.

The average grain yield increase across all hybrids due to deep loosening, regardless of genotype, was statistically significant ($CI_{0.99}$ = 0.45): +0.46 t/ha under sprinkler irrigation and +0.70 t/ha under drip irrigation. These findings confirm the effectiveness of deep non-inversion tillage compared to conventional plowing, as also reported by other researchers such as Yu.M. Pashchenko (2009), O. Tomashuk (2019) and R.A. Vozhegova *et al*. (2022). Grain maize cultivation requires significant energy and economic inputs, especially in the Steppe zone, where additional investments in irrigation are essential. In this study, the highest average grain yields over two years were achieved by hybrids Gran 1 (15.21 t/ha) and Tesla (15.33 t/ha) under drip irrigation combined with deep non-inversion tillage. These results align with the findings of O. Averchev *et al*. (2020), who reported that Ukrainian-bred maize hybrids can produce yields of up to 14-15 t/ha under irrigation in southern Ukraine, although their response to irrigation technologies has not been sufficiently studied. Hybrids Gran 1 and Tesla consistently and significantly (>$CI_{0.99}$) outperformed the standard hybrid of their FAO group (320-370) in terms of grain yield, regardless of irrigation method or tillage system.

The full realisation of maize yield potential is possible through the integration of optimal technologies and growing conditions, including soil tillage methods, mineral nutrition, sowing time and technique, pest and disease control systems, and consistent moisture availability throughout the growing season (Marchenko *et al.*, 2020). In light of changing climatic and weather conditions over the past 12-15 years, the main limiting factor for grain maize cultivation in Ukraine has become the unfavorable soil water regime, as emphasised by M. Tkachenko & N. Borys (2018). Due to its large vegetative biomass, maize has a significantly higher total water demand than small grain cereals, although it utilizes available soil moisture more efficiently than most crops. The dry Steppe zone of Ukraine is characterised by high temperatures during the growing season and the accumulation of high sums of active temperatures (above 3,000°C), which allows for the successful cultivation of high-FAO hybrids with greater yield potential. However, limited rainfall (100-200 mm) and its uneven distribution – particularly during critical phases such as flowering and grain filling – present substantial challenges. Economically viable maize cultivation in such regions is only possible with artificial irrigation. In areas with insufficient and unstable moisture availability, irrigation enables sowing at optimal soil temperature conditions, regardless of natural topsoil moisture, which positively affects seedling emergence and crop uniformity. One of the major advantages of artificial irrigation is the possibility of applying pre-sowing moisture-charging irrigations when needed, ensuring consistently high yields of the main product.

Given that soil moisture is the primary limiting factor for crop development, and precipitation during the growing season is highly unpredictable, while irrigation is a controllable agronomic input, the conditions in the Steppe zone favor high-yield maize production primarily on artificially irrigated lands. Sprinkler irrigation is the traditional method used in southern Ukraine. It enables regulation of moisture in the topsoil from spring pre-sowing preparation to the crop's physiological maturity stage (Krutyakova *et al.*, 2021). However, the cost of production significantly increases due to the additional expenses associated with irrigation – specifically, the price and transport of water to the field. In cultivating any agricultural crop, including grain maize, it is essential to consider factors influencing production efficiency – particularly yield level and technological costs. S.M. Dolya (2024) emphasises that the intensification of mechanised tillage is one of the drivers of increased fossil energy use, enhanced soil erosion, loss of organic carbon, and broader climate change.

Additional water losses must also be considered: evaporation during water transport through open canals, evaporation during sprinkler irrigation, and further evaporation from inter-row spaces -all of which negatively impact the economic efficiency of grain yield. This issue can be addressed through the use of drip irrigation, a resource-efficient method of water delivery, as supported by the studies of N.M. Galchenko *et al*. (2022). Grain maize production remains one of the key directions in Ukraine's agricultural sector. The trends in maize production at both national and global levels demonstrate the relevance of further research into cultivation methods aimed at increasing grain yield. For example, Ukraine's total maize grain production increased from 21.03 million tons in 2012/13 to 41.79 million tons in the 2021/22 marketing years, with the crop accounting for up to 16.1% of the total sown area (Polishchuk & Khavhun, 2023).

Breeding efforts by research institutions are currently focused on developing new heat-and drought-tolerant parental lines and hybrids to ensure stable grain maize production. According to literature sources, maize yields in various regions of the world are as follows: approximately 12.1 t/ha in Chile, 11.73 t/ha in New Zealand and Spain, 10.68 t/ha in Greece, 10.53 t/ha in the United States, 10.42 t/ha in Austria, and 9.99 t/ha in Italy (Kernasiuk, 2021). In Ukraine, the average yield of maize varies from 5.5 to 7.8 t/ha, depending on annual weather conditions (State Statistic Service of Ukraine, 2022). Currently, various irrigation technologies are in use, including sprinkler machines, drip irrigation, subsoil irrigation, furrow irrigation, and basin (check) irrigation. According to the Israeli company Netafim (Corn on drip irrigation…, 2022), maize grown under drip irrigation emits 53% less carbon compared to flood irrigation and 39% less compared to sprinkler irrigation. This highlights a major environmental advantage of drip irrigation. The novelty of the present study lies in the investigation of the yield response of Ukrainian-bred maize hybrids of various maturity groups to different irrigation methods combined with contrasting primary soil tillage systems under the arid conditions of the Ukrainian Steppe.

## CONCLUSIONS

The experiment confirmed the high effectiveness and clear advantage of controlled drip irrigation over traditional sprinkler irrigation for all FAO maturity groups of the studied maize hybrids. Drip irrigation provided a statistically significant ($\geqslant CI_{0.95}$) grain yield increase ranging from 0.75 to 2.13 t/ha, equivalent to 7.5-18.3% compared to sprinkler irrigation. The use of deep non-inversion tillage as the primary soil cultivation method resulted in a significant grain yield increase compared to conventional plowing: an average of +0.46 t/ha under sprinkler irrigation and +0.70 t/ha under drip irrigation across the studied hybrids.

The highest grain yields in the experiment were achieved by the hybrids Gran 1 (FAO 370) and Tesla (FAO 350), with yields of 15.21 t/ha and 15.33 t/ha, respectively, under drip irrigation combined with deep loosening. These hybrids consistently and significantly ($>CI_{0.99}$) outperformed the standard across all treatment combinations. It is not advisable to cultivate maize hybrids with FAO values below 280 under irrigation in the Steppe region due to their insufficient yield potential compared to later-maturing hybrids. Based on yield performance under the given soil and climate conditions in southern Ukraine, the most suitable hybrids for irrigated crop rotations were Tesla (FAO 350) and Gran 1 (FAO 370), both exceeding 15 t/ha, as well as KWS 381 (FAO 350), which yielded more than 13 t/ha under drip irrigation.

The findings confirm the technical and economic feasibility of using drip irrigation and deep tillage as key elements of an efficient maize cultivation technology. A logical next step in optimising the system would be to investigate the effect of different seasonal irrigation rates on yield and economic efficiency. It is also recommended to expand research to include maize hybrids with FAO more than 400 under similar conditions.

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## CONFLICT OF INTEREST

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## Реакція гібридів кукурудзи на способи зрошення та основного обробітку ґрунту в Степу України

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**Анотація.** Метою досліду було встановити реакцію гібридів на краплинне зрошення порівняно з традиційним поливом методом дощування на фоні оранки (30-32 см) та глибокого розпушування (35-37 см), як основного обробітку ґрунту. У статті наведено результати вивчення ефективності краплинного зрошення та поливу дощуванням і вплив глибокого безвідвального розпушування ґрунту поряд з класичною оранкою на урожайність кукурудзи різних груп ФАО в Степу України. Дослідження проведено в зрошуваній сівозміні на чорноземах південних солонцюватих з вмістом гумусу 2,9-3,2 %, pH – 6,2. Попередник – соняшник. Норма виливу води за вегетацію 4 000 м$^3$. Об'єкти дослідження – 11 гібридів з ФАО 210-370. Низька варіація урожайності (CV = 12,7-13,4 %) вказує на однотипну реакцію вивчених гібридів при зміні умов вирощування. Урожайність кукурудзи істотно підвищується при краплинному зрошенні на +0,75…+2,13 т/га (+7,5…+18,3 %). Глибоке розпушування забезпечило істотну прибавку на +0,46 т/га при традиційному дощуванні та +0,70 т/га при поливі краплинним зрошуванням. Позитивна реакція на глибокий обробіток у гібридів ВН 63 (ФАО 280) – +1,0…+1,35 т/га, Гран 6 (ФАО 300) – +0,87…+1,23 т/га, Тесла (ФАО 350) – +0,66…+0,99 т/га, Гран 1 (ФАО 370) – +0,89…+1,12 т/га відповідно на дощуванні та краплинному зрошенні. Встановлена недоцільність вирощування в умовах Південного Степу гібридів з ФАО менше 280 через нижчу урожайность зерна. У групі ФАО 200-300 істотну прибавку урожайності забезпечили ВН 63 та Гран 6 – від +0,5 т/га до +2,5 т/га з урожайністю 10,93 т/га та 11,99 т/га відповідно. Суттєва прибавка урожайності в групі з ФАО 320-400 від +0,61 т/га до +2,08 т/га встановлена у гібридів Тесла та Гран 1 – середня урожайність відповідно 14,06 т/га та 13,92 т/га. Максимальний урожай зерна 15,57 т/га та 15,49 т/га забезпечили гібриди Тесла (ФАО 350) та Гран 1 (ФАО 370) при глибокому розпушуванні ґрунту на крапельному зрошенні, та істотно (>$НІР_{0,99}$) перевищували по урожайності стандарт. Аналіз проведеного дослідження вказує на високу ефективність застосування краплинного зрошення та глибокого розпушування ґрунту для підвищення урожайності кукурудзи в південній частині Степу України

**Ключові слова:** урожайність; краплинне зрошування; дощування; оранка; розпушування ґрунту