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Yield and energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems

Abstract. Over the past 15-20 years, Ukrainian agricultural production has shifted to growing more profitable, highly marketable, and drought-resistant crops, in particular, chickpeas and sunflower. Therewith, the technology of growing these crops is energy-consuming, especially in irrigation conditions. Therefore, it is relevant to examine the influence of microirrigation system designs on the energy parameters of chickpea and sunflower cultivation. The purpose of the study is to perform an energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems and the method of water supply. Research methods: short-term field experiments, analytical and statistical methods for processing experimental data. The scheme of experiments provided for laying irrigation pipelines in the horizontal and vertical planes, and implementing a pulse water supply mode (standard). Control is an option without irrigation. It is established that the method of laying pipelines (designs of microirrigation systems) substantially affects the productivity of crops. Higher yields were recorded at shorter distances between irrigation pipelines (0.7 and 1.0 m), regardless of the depth of laying. It is proved that the highest level of yield of chickpeas (4.28 t/ha) and sunflower (4.50 t/ha) was obtained by implementing a pulse water supply mode, but this increase was within the error of the experiment. The introduction of underground drip irrigation is more appropriate for the cultivation of chickpeas and sunflower according to the criterion of total energy costs for the technology. The analysis of energy efficiency by the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea and sunflower cultivation in both ground and ground drip irrigation (EEC=2.03-2.23 and 2.32-2.50, respectively). The most effective method was to grow these crops under a pulse water supply regime: the EEC was 2.44 for growing chickpeas and 2.61 for growing sunflower. The research materials are of practical value for farmers in managing energy consumption in chickpea and sunflower microirrigation technologies.

Keywords: drip irrigation, underground drip irrigation, pulse drip irrigation, irrigation pipelines, energy efficiency coefficient

INTRODUCTION

Climatic transformations and the high genetic potential of crop productivity led to an increase in actual irrigation standards in the Steppe zone to 4500-6000 m^3/ha, which is 2-2.5 times higher than the design parameters of irrigation systems (Shatkovsky & Zhuravlov, 2021). This practically makes it impossible to increase the irrigation area on a large scale, because the existing pumping equipment is used at maximum capacity. This problem is also relevant for the Forest-Steppe zone of Ukraine, where, in the absence of large state irrigation systems, access to potential irrigation sources is practically nonexistent. In addition, farmers use irrigation water extremely inefficiently – from 60 to 90% are losses on infiltration and physical evaporation from the surface of soil and plants. That is, only 10 to 40% of the volume of water intake for irrigation is received exclusively for the needs of plants – transpiration (Shatkovsky & Zhuravlov, 2021)

In this context, the "Irrigation and drainage strategy in Ukraine" (2019) defines that the development of irrigation should be based solely on a new, water- and energy-saving concept. It is known that microirrigation methods correspond to this as much as possible: drip

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irrigation with ground and underground placement of irrigation pipelines and pulse drip irrigation. The essence of the latter is the most synchronous compensation of moisture consumption by the plant for transpiration (Romashko *et al*., 2020, Shatkovskyi & Zhuravlov, 2021). However, the introduction of these irrigation methods requires substantial energy and material costs. Therefore, in a market economy, the energy analysis of the introduction of the latest agricultural technologies is important since it gives grounds to justify various options for growing agricultural crops from the standpoint of their energy saving. Thus, it was relevant to research the justification and energy assessment of agricultural technologies for growing chickpeas and sunflower, depending on the design of microirrigation methods.

The energy efficiency of agricultural technologies for growing both chickpeas and sunflower has been thoroughly investigated both in Ukraine and by foreign researchers. However, the analysed complex of papers concerned the influence on the energy parameters of such factors as fertiliser systems (Kyrychenko *et al*., 2014; Parlikokoshko & Burykina, 2021; Mazur *et al*., 2022), seed treatment (Mordovaniuk, 2020; Lohosha *et al*., 2020), growth regulators (Elhami *et al*., 2016; Unakıtan & Aydın, 2018), seeding schemes and dates (Krainiak, 2008; Oguz & Ogur, 2018; Pinkovsky & Tanchyk, 2019), plant protection products (Malysh *et al*., 2013; Korobko, 2019), tillage (Koocheki *et al*., 2011; Nabavi-Pelesaraei, 2012; Vozhehova *et al*., 2021,) etc. Therewith, under irrigation conditions, experiments were conducted only on sunflower culture. In particular, according to long-term data from the Institute of Irrigated Agriculture of the National Academy of Agrarian Sciences (Vozkhehova *et al*., 2021), higher energy efficiency was achieved when applying deep basic tillage with rotating topsoil. Researchers of the Institute of Agriculture of the National Academy of Agricultural Sciences (Kyrychenko *et al*., 2014), proved that the highest increase in gross energy – 30901 MJ/ha, was achieved when applying mineral fertilisers with doses of $N_{50}P_{30}K_{30}$ for cultivation and $N_{10}P_{10}K_{10}$ when sowing in rows. A comparison of energy efficiency and economic analysis of sunflower cultivation in Turkey was conducted based on a passive experiment – the survey method (Gökhan & Başak, 2018). Energy efficiency, energy productivity, specific energy, and net energy for sunflower cultivation were calculated as 3.77, 0.15 kg/MJ, 6.63 MJ/kg, and 28111 MJ/ha, respectively. In addition, Turkish researchers (Oguz & Ogur, 2018) calculated the energy value, productivity, and energy efficiency of resources used for growing sunflower seeds. It was identified that the energy efficiency (EEC) was 4.94, and the specific energy value was 5.06 MJ/kg.

Thus, a study on the influence of microirrigation system designs on the energy parameters of chickpea and sunflower cultivation in the southern region of Ukraine has not been conducted.

The purpose of the study was to perform an energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems and the method of water supply.

MATERIALS AND METHODS

Field research within the framework of the state enterprise experimental establishment Brylivske of Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences (Privitne village, Vinogradivska rural community of the Kherson district of the Kherson region, Dry Steppe subzone, 46°40´N. 33°12´E) during 2020-2022. The energy parameters were calculated depending on the following irrigation system designs: drip irrigation (DI) with ground-based irrigation pipeline laying (IP), underground drip irrigation (UDI) with IP laying to a depth of 30 cm. In addition, the design parameter was the distance between IP: for growing chickpeas 1.0 and 1.4 m, sunflower – 0.7 and 1.4 m. The reference option was underground drip irrigation with a pulse water supply mode (PUDI), and the conditional control was the option with natural moisture supply – without irrigation. The study was conducted according to generally accepted methods: placement of land plots – systematic, repetition – fourfold, the area of accounting plots – 32 m^2 (Ushkarenko *et al*., 2014, Romashchenko *et al*., 2014), sunflower hybrid of confectionery area of use – Ukrains'kyi F1, chickpea variety – Budzhak.

The soil of the experimental plot is liver-coloured light loamy, the density of the layer composition is 0-50 cm – 1.47 g/cm^3, the content of humus – 1.44%, alkaline hydrolysed nitrogen (Kornfield determination method) (DSTU 7863:2015, 2016) – 7.0 mg/100 g of soil, mobile compounds of phosphorus and potassium in the soil according to the Chirikov method (DSTU 4115:2002, 2003) – 32.3 mg/100 g and 9.3 mg/100 g of soil, respectively.

The amount of productive precipitation during the growing season of sunflower and chickpeas was different over the years of research. Thus, in 2020, only 68 mm fell, which is 35.5% of the climatic norm, during 2021 – 393.8 mm or 205.5%, which is also an abnormal phenomenon for the conditions of the Dry Steppe, and in 2022 – 167.6 mm, or 87.5% of the climatic norm. The level of pre-irrigation humidity in experiments is 80% of the lowest moisture capacity of 0-50 cm of the soil layer. Instrumental complexes were used to set irrigation dates: the Drill and Drop Sentek moisture meter probe and the iMetos soil moisture station with Echo Probe EC-5 sensors (Shatkovsky & Zhuravlov, 2016). Statistical analysis of the research results was performed using variance, correlation, and regression methods using the Statistica 6.0 programme.

Energy efficiency was calculated according to the method of energy assessment of crop cultivation technologies (Zasukha & Ponomarenko, 1998). The energy efficiency coefficient was determined by the formula (Medvedovsky & Ivanenko, 1988, Zasukha & Ponomarenko, 1998) without considering by-products:

$$K = \frac{Q_H}{Q_B} \quad (1)$$

where Q_A – energy accumulated by the economically valuable part of the crop, MJ/ha; Q_S – total energy spent on production, MJ/ha.

When calculating the energy accumulated by the economically valuable part of the crop, reference data on the energy value of dry organic matter were used: the calculations took the energy content in one kilogram of chickpeas – 36 MJ/kg and sunflower – 19.3 MJ/kg (Zasukha & Ponomarenko, 1998; Demchak *et al.*, 2015). Calculated specific energy consumption (Demchak *et al.*, 2015) for irrigation from the well amounted to 10.52 MJ/m^3. This considers the specific costs of electricity, the energy intensity of the drip and underground drip irrigation, and water systems.

RESULTS

The maximum yield of chickpea grain in the experiment (at the standard humidity of 14%) was obtained in the variant with the placement of irrigation pipelines at a distance of 1 m – 4.00-4.17 t/ha (Figure 1). The yield for placing IP at a distance of 1.4 m was substantially lower – 3.69-3.76 t/ha (0.31–0.41 t/ha) (HIP$_{0.5}$=0.285 t/ha).

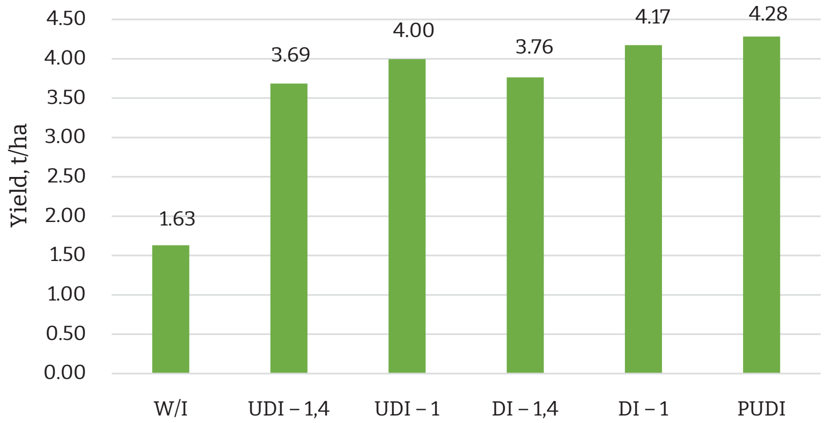

Figure 1. Chickpea yield depending on the schemes of laying irrigation pipelines of drip irrigation (HIP_{AB}=0.285 t/ha)

The average yield indicator for underground drip irrigation (3.85 t/ha) practically corresponded to the variant with the ground placement of IP (3.97 t/ha), and the excess of the latter (DI) of 0.12 t/ha was within the margin of error of the field experiment. Considering the average amount of productive precipitation during the three years of research (it was higher than the climatic norm), productivity at the control (without irrigation) was at the level of 1.63 t/ha, which also confirms the characteristic feature of chickpea crops as drought resistance. The yield of dry chickpea beans in the experiment (pulse water supply mode) was 4.28 t/ha. Thus, the established level of productivity growth was also within the margin of error of the field experiment (compared to the drip irrigation option), and substantially higher than the underground drip irrigation option.

In a parallel experiment, the highest yield of sunflower grain was obtained in the variant with the placement of irrigation pipelines at a distance of 0.7 m – 4.41 t/ha for drip irrigation and 4.09 t/ha for underground drip irrigation (Figure 2).

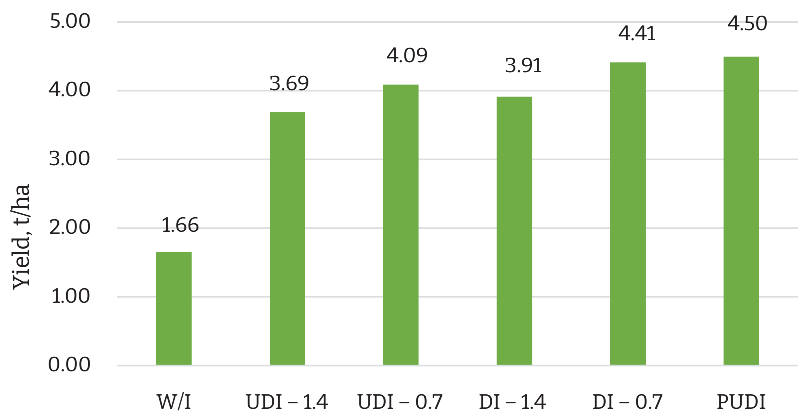

Figure 2. Sunflower yield depending on the schemes of laying irrigation pipelines of drip irrigation (HIP_{AB}=0.352 t/ha)

The seed yield for placing irrigation pipelines at a distance of 1.4 m was substantially lower – from 3.69 t/ha (DI) to 3.91 t/ha (UDI).

The average yield for underground drip irrigation (3.89 t/ha) was slightly lower compared to the option with ground-based irrigation pipelines (4.16 t/ha), but the excess of 0.27 t/ha was within the margin of error of the field experiment.

Considering the relatively sufficient availability of productive precipitation during the growing season of the years of the study (2020-2022), the yield of seeds under control (without irrigation) was at the level of 1.66 t/ha, which is almost 2.5 times lower compared to the irrigated conditions for growing sunflower.

The yield of sunflower seeds in the search experiment (pulse mode of water supply with the underground laying of pipelines) was a maximum of 4.50 t/ha. Thus, this increase (+0.09-0.41 t/ha compared to UDI) in seed yield was also within the margin of error of the field experiment.

Based on the productivity data of crops (main products), calculations of the energy assessment of the parameters of agricultural technologies for growing chickpeas and sunflower for various designs of microirrigation systems were conducted (Table 1).

Table 1. Energy assessment of chickpea and sunflower cultivation depending on the design of microirrigation systems

Factor A	Factor B	Energy accumulated on harvest, GJ/ha	Energy consumption for cultivation, GJ/ha	Energy efficiency ratio EEC
CHICKPEA				
DI	IP at a distance of 1.0 m	177.84	79.6	2.23
	IP at a distance of 1,4 m	157.68	77.6	2.03
UDI (-30 cm)	IP at a distance of 1.0 m	167.40	78.3	2.14
	IP at a distance of 1.4 m	155.52	76.5	2.03
Pulse UDI (standard, IP at a distance of 1.0 m)		181.80	74.4	2.44
Without irrigation (control)		72.80	38.8	1.88
SUNFLOWER				
DI	IP at a distance of 0,7 m	106.15	42.5	2.50
	IP at a distance of 1,4 m	94.18	39.0	2.41
UDI (-30 cm)	IP at a distance of 0.7 m	98.62	41.4	2.38
	IP at a distance of 1.4 m	88.78	38.3	2.32
Pulse UDI (standard, IP at a distance of 0.7 m)		107.50	41.2	2.61
Without irrigation (control)		41.88	21.0	1.99

Analysis of the table data shows that the introduction of microirrigation increased the energy intensity of chickpea cultivation technologies by almost 2 times – up to 74.4-79.6 GJ/ha, respectively. Without irrigation (control), energy costs for chickpea production were within 38.8 GJ/ha. The basic analysis of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea cultivation in both ground and underground irrigation conditions (EEC=2.03-2.23) and an average level of energy efficiency of the option without irrigation (EEC=1.88). The most effective cultivation of chickpeas was underground drip irrigation with a pulse water supply mode (standard), where the energy efficiency coefficient was 2.44.

The introduction of microirrigation has also increased the energy intensity of agricultural technologies for growing sunflower almost twice – up to 38.0-42.5 GJ/ha, respectively. Without irrigation (control), energy costs for growing sunflower hybrids were within 21.0 GJ/ha. The analysis of the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of growing sunflower hybrids in both underground and ground irrigation conditions (EEC=2.32-2.50) and the average level of energy efficiency of the control option without irrigation (EEC=1.99). The most effective method was the cultivation of sunflower hybrids with underground drip irrigation with a pulse water supply mode (standard version), where an energy efficiency coefficient of 2.61 was obtained.

The results of this study are original for the soil and climatic conditions of the Dry Steppe subzone of Ukraine. For the first time, an energy assessment of chickpea and sunflower cultivation using various designs of microirrigation systems was performed and their reliable impact on crop productivity was proved.

DISCUSSION

The results obtained on the productivity of chickpeas under various water supply conditions confirm the results of Indian researchers (Rao et al., 2019), although, they were obtained using mulching. However, researchers from the Central Queensland University and the Queensland Department of Agriculture and Fisheries (Bhattarai *et al.*, 2010) identified that chickpea yields in areas irrigated by aerial underground drip irrigation (oxygenation) were 27% higher than in drip irrigation with ground-based IP. The same researchers (Bhattarai *et al.*, 2008) proved that underground drip irrigation increases the efficiency of irrigation water use (IWUE) by minimising evaporation losses and maximising the use of seasonal precipitation by the soil profile. Similar parameters for increasing the yield of chickpea grain by drip irrigation (by 2.3-2.5 times) were obtained in the experiments of Indian researchers (Rai & Singh, 2019). Researchers of the Brazilian Agricultural Research Corporation have investigated the water demand and productivity of various chickpea varieties on irrigation in a more comprehensive manner (Silva *et al.*, 2021). In particular, they substantiate the coefficients of the culture by plant development phases (0.38-1.0) and water requirement parameters (4.1-5.6 mm/day). Lower yield parameters were obtained in the experiments of Serbian researchers (Stepanović *et al.*, 2019) subject to irrigation of chickpeas by sprinkling – 2.82-3.12 t/ha.

The results obtained confirm the experimental data of Spanish researchers (Soriano et al., 2004), where the productivity of early hybrids was 3.0 t/ha, and late hybrids – 2.4 t/ha. The effectiveness of drip irrigation of sunflower seeds for placing irrigation pipelines on the soil surface has also been proven by other researchers (Sesen et al., 2011, Kadasiddappa et al., 2017), however, in these studies, the method of irrigation by sprinkling was used as a control. In particular, in the study by Turkish researchers (Sezen *et al.*, 2011), drip irrigation productivity was 1.7 times higher and amounted to 3.82 t/ha, and in the one by Indian researchers (Kadasiddappa *et al.*, 2017) – 1.5 times and amounted to 3.36 t/ha.

In general, the highest productivity of sunflower grain was obtained by researchers from Lebanon (Karam *et al.*, 2007), who investigated the response of plants to insufficient and optimal irrigation. The average annual yield under optimal irrigation was 5.36 t/ha, which is 25.4% more than under scarce irrigation. In the context of Pakistan (Qureshi, A. et al., 2015), drip irrigation provided a 26% increase in sunflower grain yield (up to 3.24 t/ha), 56% savings in irrigation water, and the efficiency of water use was 3.2 times higher than drip irrigation. The influence of various irrigation systems and row spacing on growth processes and yield of sunflower hybrids was investigated by W. Simões *et al.*, (2020). The highest yield (3.96 t/ha) of the Helio 251 hybrid was obtained with drip irrigation systems and row spacing of 0.55 m, the Helio 360 hybrid achieved the highest yield (3.25 t/ha) with microirrigation and row spacing of 0.55 m and 0.45 m. On sprinkling, the Helio 360 hybrid had the highest yield with a row spacing of 0.45 m (3.02 t/ha).

CONCLUSIONS

Based on the results of experimental studies, it is proved that the designs of microirrigation systems, namely, the method of laying irrigation pipelines, substantially affect the yield and energy parameters of chickpea and sunflower cultivation technology. Primarily, the effectiveness of drip irrigation of these crops in the conditions of the steppe of dry Ukraine is generally confirmed. In addition, it was identified that the introduction of underground drip irrigation is more appropriate for these crops from the standpoint of energy efficiency, which is explained by their relative biological drought resistance. The pilot version with the underground installation of irrigation pipelines and pulse water supply mode provided the highest level of the yield of these crops – 4.28 t/ha of chickpea grain and 4.50 t/ha of sunflower grain.

The introduction of microirrigation technologies increased the energy consumption of agricultural technologies for growing chickpeas and sunflower almost twice – up to 74.4-79.6 GJ/ha and 38.0-42.5 GJ/ha, respectively. The analysis of energy efficiency by the value of the energy efficiency coefficient (EEC) indicates a high level of energy efficiency of chickpea and sunflower cultivation both in the conditions of ground and underground laying of drip irrigation pipelines (EEC=2.03-2.23 and 2.32-2.50 for chickpeas and sunflower, respectively). The most effective cultivation of these crops was under the pulse water supply mode, when the calculated energy efficiency coefficient amounted to 2.44 for growing chickpeas and 2.61 for growing sunflower.

The issue of introducing various microirrigation technologies for growing chickpeas and sunflowers requires further research. In particular, the environmental aspects of the impact of fertigation and irrigation water of different soil quality are currently unresolved.

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Урожайність та енергетична оцінка вирощування нуту і соняшнику залежно від конструкцій систем мікрозрошення

Анотація. За останні 15-20 років сільськогосподарське виробництво України переорієнтувалось на вирощування більш рентабельних, високоліквідних, а також посухостійких культур, зокрема – нуту і соняшнику. Одночасно, технології вирощування цих культур є енерговитратним, особливо – в умовах зрошення. Тому актуальним є дослідження щодо впливу конструкцій систем мікрозрошення на енергетичні параметри вирощування нуту і соняшнику. Мета наукової роботи – виконати енергетичну оцінку вирощування нуту і соняшнику залежно від конструкцій систем мікрозрошення та способу водоподачі. Методи дослідження: короткотермінові польові досліди, аналітичні і статистичні методи обробки експериментальних даних. Схема дослідів передбачала укладання поливних трубопроводів у горизонтальній та вертикальній площині, а також реалізацію імпульсного режиму водоподачі (еталон). Контроль – варіант без зрошення. Встановлено, що спосіб укладання трубопроводів (конструкції систем мікрозрошення) достовірно впливає на продуктивність культур. Вищу врожайність зафіксовано за менших відстаней між поливними трубопроводами (0,7 та 1,0 м) незалежно від глибини укладання. Доведено, що вищий рівень врожайності нуту (4,28 т/га) і соняшнику (4,50 т/га) отримано за реалізації імпульсного режиму водоподачі, проте таке збільшення було у межах похибки досліду. Впровадження підґрунтового краплинного зрошення є більш доцільним за вирощування нуту і соняшнику за критерієм сумарних енергетичних витрат на технологію. Аналіз енергоефективності за величиною коефіцієнта енергетичної ефективності (Кее), свідчить про високий рівень енергоефективності вирощування нуту і соняшнику як в умовах наземного, так і підґрунтового краплинного зрошення (Кее = 2,03-2,23 та 2,32-2,50 відповідно). Найбільш ефективним було вирощування цих культур за імпульсного режиму водоподачі: Кее дорівнював 2,44 за вирощування нуту та 2,61 за вирощування соняшнику. Матеріали дослідження становлять практичну цінність для фермерів у питанні управління енерговитратами у технологіях мікрозрошення нуту і соняшнику

Ключові слова: краплинне зрошення, підґрунтове краплинне зрошення, імпульсне краплинне зрошення, поливні трубопроводи, коефіцієнт енергетичної ефективності