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EFFECT OF SURFACE DRIP IRRIGATION AND CULTIVARS ON PHYSIOLOGICAL STATE AND PRODUCTIVITY OF FABA BEAN CROP

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ABSTRACT. Lack of water is one of the main abiotic factors that affect the change of plant production processes by imposing certain morphological, physiological and biochemical changes. The aim of the research conducted in 2019–2020 was to study the change in the productivity and yield of green beans of different cultivars of *Vicia faba* L. *var. Major* and the formation of a symbiotic system on surface drip irrigation. The results of the biometric analysis showed that the cultivation of faba beans under irrigation contributes to an increasing in plant height by 4.7–12.2%, the number of branches per plant increased by 17.3–30.0%, the leaf area of faba bean crops increased by 21.2–24.9%. The content of total chlorophyll increasing by 16.9–40.5%. Antioxidant enzymes activity decreased depending on the cultivar Catalase activity by 10.6–22.5%, Guaiacol peroxidase – 19.4–25.9%, Superoxide dismutase – 19.3–24.4%. The yield of green faba beans (*Vicia faba* L.) increased by 31.3–39.2%. Growing faba beans on irrigation helped to reduce the protein content by 1.4–2.1 %, but to reduce the dry matter content by 1.3–2.0%, which was significant in both indicators. In general, drip irrigation contributed to the improved development of bean-rhizobial symbiosis of faba bean plants. The mass of the nodules on the drip irrigation increased by 0.3 g plant^{-1} regardless of the cultivar, and their number is 1.5–9.0 pcs plant^{-1}. The presented results give an idea of the functioning of the legume agrocenosis and the impact of irrigation on the main quality indicators of the product. Further research is to study the regimes (rates, timing, and multiplicity) of irrigation.

Introduction

One of the most important problems of agriculture today is the shortage of vegetable protein, equivalent to animal protein. Beans are an important source of biological nitrogen in agriculture, the importance of which has increased especially in a difficult environmental situation with an insufficient supply of mineral nitrogen fertilizers. The share of biological nitrogen in the nitrogen balance is still very small and is about 5%, and when creating favourable conditions for symbiosis, it can increase up to 30% (Stolyarov, 2005).

Given the growing cost of man-made resources and environmental tensions to ensure the sustainable functioning of agroecosystems, alternative approaches to the development of agrotechnologies based on the concept of biologization of agriculture and providing it with resource-saving and sustainable development. Based on this, the selection of cultivars of beans and their cultivation on drip irrigation is an urgent problem of vegetable growing and agricultural production in general (Stolyarov, 2005).

In the modern world, with the high nutritional value of bean seeds, their nutritional value increases. Green beans are rich in B vitamins, which play an important role in preventing ageing and multiple sclerosis. The grains contain 1.0 % of fibre, 0.7 % of ash and 80.0% of water. In terms of calories, beans are 3–4 times higher than potatoes and 6 times higher than corn (Bouchenak, Lamri-Senhadji, 2013; Yamawaki *et al*., 2014; Lizarazo *et al*., 2015; Ali, 2016; Rosa *et al*., 2018; El-Naggar *et al*., 2019).

Currently, beans are not paid attention to, probably due to the presence of vicin and convicine, which limit their consumption. These anti-food factors can cause acute hemolysis in subjects with glucose-6-phosphate dehydrogenase deficiency (Cappellini, Fiorelli, 2008). At the same time, beans show interesting characteristics due to the presence of some nutraceutical compounds, such as levo-dihydroxy phenylalanine (L-dopa). This compound is used to treat diseases such as Parkinson's, hypertension, renal failure and liver cirrhosis (Korczyn *et al*., 2008).

Today, when growing vegetables, the optimization of the irrigation regime as a factor is of paramount importance. It determines the efficiency of technology and crop quality, total costs, water and energy needs (Molden *et al*., 2010; Gagan *et al*., 2021). Experience of advanced farms and data from research institutions show that good management practices and optimal irrigation regime contribute to the formation of high and stable yields of vegetable crops (Azzeddine *et al*., 2016; 2019). It is well known that irrigation costs and plant productivity vary depending on irrigation methods. Therefore, drip irrigation is promising in the cultivation of vegetable crops (Borodychev, Martynova, 2011; Etemadi *et al*., 2019; Fu *et al*., 2021). Drip irrigation is generally more effective than compared with other types of irrigation in terms of crop yields and water savings.

Beans are usually grown without irrigation, but in unstable climates, drip irrigation becomes a necessity and can significantly improve the efficiency of cultivation technology (Alghamdi *et al*., 2015; Guoju *et al*., 2016). The greatest water demand for beans covers the growth stages from flowering to full harvest (BBCH 60–89), June–July (Dudek *et al*., 2018; Karkanis *et al*., 2018).

Under scarce water in semi-arid areas, irrigation water management aims to provide sufficient water to replenish depleted soil water in time to avoid physiological water stress in growing plants, using modern irrigation technologies such as a drip irrigation system (Saleh *et al*., 2012).

Topak *et al*. (2009) indicate that the highest yield of *Phaseolus vulgaris* was obtained in areas irrigated by drip irrigation with full irrigation (565 mm). The highest level of water efficiency was obtained by drip irrigation.

Lysimetric studies of Tarantino and Rubino (1989), calculated the seasonal water requirement for the maximum yield of beans – 235 L m^{2-1}. While El Noemani *et al*. (2010), recommended using 371 L m^{2-1} for the maximum yield of green bean pods.

Several studies have shown that the effect of the water regime on green beans (Abd El-Mawgowd, 2006; Sezen *et al*., 2008; El-Noemani *et al.*, 2010; Abd El-Aal, 2011). But the results of these studies are limited to the area (zone) of research and are mainly conducted using a single variety, therefore these results may give a false idea of the impact of irrigation in other soil and climatic conditions. Sezen *et al*. (2008) found a direct relationship between watering rate and bean yield.

Irrigation reduces pod abortion and is expected to have a significant impact on final yield. The amount and distribution of rainfall during the season greatly affect the rainfed faba bean yield. This is particularly important in water-scarce areas, where the water saved as a result of this practice can be used to irrigate additional land, thus, allowing farmers to achieve higher levels of production (Attila *et al*., 2017).

The purpose of this research is to identify varietal and physiological characteristics of the formation of a high level of the yield of green beans under drip irrigation and the formation of the nodulation apparatus of plants in the Forest-Steppe of Ukraine. For the first time in the conditions of the Forest-Steppe of Ukraine the experimental data connected with the formation of a commodity crop of green beans of a faba bean on drop irrigation are received.

The novelty of the study is a comprehensive study of production processes of faba beans, as previously published data by other authors do not give a complete picture of the impact of irrigation on physiological responses of faba bean plants, changes in nutritional value (the content of protein and dry matter), the concentration of antinutrient composition and formation of nodulation apparatus.

Material and methods

The experiment of the influence of drip irrigation of faba bean (*Vicia faba* L.) cultivars was carried out in 2019–2020 at the Department of Vegetable Growing of Uman National University of Horticulture (Right-Bank Forest Steppe of Ukraine) by national methods (Bondarenko, Yakovenko, 2001). The soil was black, puddle, heavy loam with a well-developed humus horizon (about 2.9% of humus) (Krupsky, Polupan, 2018), (Table 1), in the deep of 40–45 cm. Soil pH was determined in water (soil to water ratio 1:1). The electrical conductivity (ECe) of the soil suspension was measured using the conductivity meter. The P and K were determined by the ammonium bicarbonate-diethylenetriaminepentaacetic acid (ABDTPA) method (Ryan *et al*., 2001).

Table 1. Chemical properties of soil (x ± SD)

Parameter	Value
Organic carbon %	2.2 ± 0.12
Acidity (pH)	6.1 ± 0.10
ECe, µS/cm	24 ± 0.45
Extractable P (ABDTPA), mg kg^{-1}	102 ± 3.33
Extractable K (ABDTPA), mg kg^{-1}	123 ± 2.00
NO_3N, mg kg^{-1}	64 ± 1.53

The scheme of the two-factor experiment included four cultivars of faba beans (factor A), which were grown without irrigation and drip irrigation (factor B), maintaining soil moisture at 80% by applying surface drip irrigation to the technical maturity of beans (El-Noemani *et al*., 2010). Irrigation started from June, 2 to 10, July 2019 and May, 20 to July 25, 2020.

The experiment scheme included the following variants:

Factor A – method of cultivation:

- without irrigation (A_1);
- surface drip irrigation (A_2).

Factor B – cultivars of faba bean:

- 'Karadag' (B_1) – medium-ripe faba bean cultivar of universal purpose with a growing season to technical maturity of 83–90 days. Resistant to disease, drought; suitable for mechanized harvesting. Formed from 22 to 27 beans, each with three to five dark purple seeds at technical maturity;
- 'Biloruski' (B_2) – medium ripe from germination to technical maturity 70–85 days. Pods are straight, smooth, green in technical maturity, with 3–5 large carmine-red seeds, when ripe – red-brown, relatively cold-resistant, unpretentious to growing conditions, characterized by the excellent quality of immature and ripe seeds.
- 'Ukrainski Slobidski' (B_3) – medium–ripe variety of universal purpose with a growing season to technical maturity of 85–90 days. Resistant to disease, drought. Suitable for mechanized harvesting. The plant forms from 24 to 29 beans. Seeds oval, light brown;
- 'Vindzorski' (B_4) – medium-ripe hybrid from germination to technical maturity of 76–89 days. Bush plant. In technical maturity, the beans are characterized by a dark green colour.

Scheme of the variants:

- A_1B_1 – 'Karadag' without irrigation;
- A_1B_2 – 'Biloruski' without irrigation;
- A_1B_3 – 'Ukrainski Slobidski' without irrigation;
- A_1B_4 – 'Vindzorski' without irrigation;
- A_2B_1 – 'Karadag' surface drip irrigation;
- A_2B_2 – 'Biloruski' surface drip irrigation;
- A_2B_3 – 'Ukrainski Slobidski' surface drip irrigation;
- A_2B_4 – 'Vindzorski' surface drip irrigation.

The cultivar 'Karadag' was used as a reference as this cultivar is currently cultivated as a food crop.

The experimental design was a randomized complete block design with four replicates. The area for the sampling – 100 m² (Bondarenko, Yakovenko, 2001). Planting was carried out by the scheme of 60 × 10 cm (166 000 plants ha^{-1}) of April 5, 2019, and April 10, 2020. Early-maturing varieties of faba beans were used for research. Harvesting took place at the technical ripeness of the beans (BBCH 81). The growing period was 82 ± 2 DAP (the day after planting).

The leaf surface area of plants was determined in the phase of technical maturity of beans by the method of "cuttings" (Nichiporovich, 1961). At the experimental site, 10 plants were selected, all leaves were plucked from them and weighed. Then with the help of a cork drill took from these leaves 20 cuts and weighed them. The total leaf surface in the sample was determined by the formula:

$$S = \frac{M \times s \times N}{m}, \quad (1)$$

where S is the total area of leaves in the sample; M – the mass of leaves in the sample, g; s – the area of one cut (1 cm^2); N – number of cuts, pcs.; m – a mass of cuts, g.

By calculating the total leaf area in the sample, we determined the leaf area per plant and, multiplying this indicator by the density of plants per 1 ha, we obtained the area of the leaf apparatus of plants expressed in m^2 ha^{-1} (Grytsaenko *et al*., 2003).

Chlorophylls *a* and *b* content was determined according to the method reported by Albanese *et al*., (2007). Briefly, 2 g of sample was homogenized in 10 mL of acetone/water (80:20 v/v) and then centrifuged at 4000 r. The absorbance of the extract was measured at 646, 663 nm using a spectrophotometer T60U (PG Instruments, UK).

Activity measurements of antioxidant enzymes. Enzyme activities were determined, during the harvest. A one g of plant tissue from control and treated plants was homogenized on ice in 4 ml extraction buffer (50 Mm^{-1} phosphate buffer pH 7.0, containing 1 mM EDTA, 1 mM phenylmethylsulphonyl fluoride and 1% polyvinylpolypyrrolidone). The homogenate was centrifuged for 25 min at 15,000 × g^{-1} and 4 °C. The supernatant was used for enzyme activity assays. The means ± SD were calculated from the data of at least 3 independent measurements. SOD (Superoxide dismutase) activity was determined spectrophotometrically by measuring the ability of the enzyme to inhibit the photochemical reduction of nitro blue tetrazolium (NBT) in the presence of riboflavin in light (Dhindsa *et al*., 1981). One unit (U^{-1}) of SOD was the amount that causes 50% inhibition of NBT reduction in light. The enzyme activity was expressed in terms of specific activity (U mg $protein^{-1}$). CAT (Catalase) activity was determined by the decomposition of H_2O_2 which, in turn, was measured by the decrease in absorbance at 240 nm (Upadhyaya et al., 1985). One U^{-1} equals the amount of H_2O_2 (in μmol^{-1}) decomposed in 1 min^{-1}. POD (Guaiacol peroxidase) activity was determined by monitoring the increase in absorbance at 470 nm during the oxidation of guaiacol (Upadhyaya *et al*., 1985). The amount of enzyme-producing 1 µmol min^{-1} of oxidized guaiacol was defined as 1 U^{-1}.

To calculate the number and risobial formations selected soil monoliths 25 × 25 × 30 cm. After washing the roots of each repetition left 5 plants, separated from the roots of the nodules, counted their average number per plant, dried (Grytsaenko *et al*., 2003).

Green bean weight and yield per plot were weighed in a technical maturity stage.

Dry matter of green beans (%). The average dry matter weight (g) of the green bean after curing were measured by drying 10 randomly sampled beans in an oven with a forced hot air circulation at 70 °C until a constant weight was obtained. The per cent of bean dry matter was calculated by taking the ratio of the dry weight to the fresh weight of the sampled beans and multiplying it by 100.

The crude proteins content (N × 6.25) of the seeds was determined by Kjeldahl nitrogen, according to the AOAC method 955.04 (AOAC, 1991).

Vicine and convicine assays. Analyses of samples from faba bean cultivars were performed by the Natural Resources Institute of Finland, according to the method of Gutierrez *et al*. (2006). Briefly, samples (1 g) were extracted with ultrapure water (30 mL) in a hot-water bath (90 °C) for 3.5 h, with shaking every 30 min. The samples were then cooled in a water bath and centrifuged to remove solids. Concentrated HCl (100 µL) was added to the supernatant (10 mL), followed by an additional centrifugation step (10 min, 2500g) Samples were filtered through a 0.45 µm Acrodisc GHP membrane filter (Pall Corporation, Port Washington, NY, USA) before analysis by HPLC (Agilent 1100 with a diode array detector, HPLC-DAD; Agilent) on an Atlantis T-3 (2.1 ×150 mm, 3 µm) column (Waters Corp., Milford, MA, USA), followed by elution with a gradient of 50 mmol L^{-1} phosphate buffer and methanol at 0.2 mL min^{-1}. Detection of vicine (Sigma-Aldrich, St. Louis, MO, USA) and convicine was conducted at 280 nm, and for identification purposes, the spectrum from 190 nm to 450 nm was recorded. Quantification of convicine was achieved using the calibration curve for vicine.

The weather conditions in the years of research. According to the Uman meteorological station, hydrometeorological conditions in 2019 were characterized by slightly larger precipitation compared to long-term averages. The amount of precipitation for this period in 2020 was much higher than in 2019. Most of them fell in June, which allowed the plants to form better leaf mass The amount of added irrigation in 2020 is higher than in 2019 because the air temperature was higher and the evaporation of moisture was faster (Figure 1, Table 2).

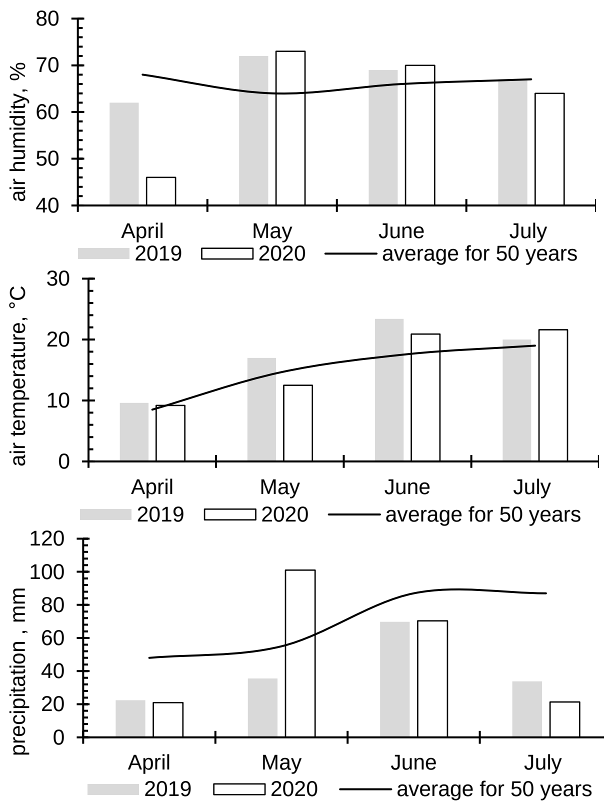

Figure 1. Climate chart for the study period (2019–2020)

Table 2. Moisture content indicators and the total irrigation rates throughout high water needs in faba beans from June to July and dynamics of stock of productive moisture (mm) during the growing season (data of the Meteorological Station "Uman")

Year	Drought level	Absolute precipitation, mm	Evapotranspiration ratio, mm	Total irrigation rate, mm
Average (1970–2020)	wet	174	81.0	–
2019 (June–July)	mild dry	103.6	92.6	120
2020 (June–July)	mild dry	91.8	97.7	140

Dynamics of stock of productive moisture (mm) in the root zone (in the soil layer 0–30 cm)

Year	Month			
	April	May	June	July
2019	32.40	40.05	19.70	11.50
2020	30.0	71.50	25.50	10.0

The ratio of precipitation to potential evapotranspiration (ET), calculated based on Grabarczyk's (1992) formula:

$$ET = (d + \frac{1}{3}\,t), \quad (2)$$

where d – mean vapour pressure deficit in hPa; t – mean air temperature in °C.

Irrigation water requirements

The amount of irrigation water for green beans was applied by flowmeter after it was calculated according to the following equation:

$$IW = \left[\frac{ETo \times Kc \times Kr \times I}{Ea} + LR\right] \times 4.2, \quad (3)$$

where IW – irrigation water applied m^3; ET_O – reference evapotranspiration (mm day^{-1}); Kc – crop coefficient; Kr – reduction factor (Keller, Karmeli, 1975); I – irrigation interval, day; Ea = irrigation efficiency, 80%; LR – leaching requirement – 20% of the total water amount delivered to the treatment.

Statistical analysis. Statistical processing of the obtained results was performed with the calculation of the arithmetic mean (x) standard deviation (SD), calculated using Microsoft Excel 2016 and Statistica 10. The obtained data were compared using analysis of variance.

Results

The results of the biometric analysis showed that the cultivation of faba beans under irrigation contributes to an increase in plant height by 4.7–12.2% relative to the options without irrigation. When growing beans under irrigation, the difference increased to 14.8 cm; 13.0 cm and 19.2 cm, in accordance. On average, in two years the number of branches per plant per cultivation under irrigation increased by 17.3–30.0 %, or 0.7–1.0 $plant^{-1}$. The leaf area of faba bean crops increased by the drip irrigation by 21.2–24.9%.

The 'Ukrainski Slobidski' and 'Biloruski' formed a leaf area smaller than the control by 1.0 and 1.7 thousand m^2 ha^{-1} without irrigation (Table 3).

The concentration of total chlorophyll was the highest in the 'Ukrainski Slobidski', which was 8.1% higher than the standard cultivar 'Karadag' without irrigation and 12.9% on irrigation. Drip irrigation on average contributed to an increase in the concentration of total chlorophyll by 16.9–40.5%, in the 'Ukrainski Slobidski' and 'Windzorski' more significantly increases the concentration of chlorophyll *b* (Table 4).

The results of studies of the activity of antioxidant enzymes show that their activity during the cultivation of beans under irrigation is significantly reduced in all cultivars relative to similar options when grown without irrigation Catalase activity decreased depending on the cultivar by 10.6–22.5%, Guaiacol peroxidase – 19.4–25.9%, Superoxide dismutase – 19.3–24.4%. The decrease in the activity of antioxidant enzymes indicates the drought resistance of this culture and the significance of this decrease in the level of drought resistance of the cultivar (Table 5).

Table 3. Effect of irrigation and cultivars on plant growth and leaf area of the faba beans (2019–2020) (x ± SD)

Growing conditions	Cultivar	Plant height, cm	Number of branches	Leaf area, thousand, m^2 ha^{-1}
Without irrigation (natural conditions)*	'Karadag' st	63.46 ± 2.12	3.10 ± 0.14	27.26 ± 1.47
	'Ukrainski Slobidski'	75.20 ± 2.47*	3.20 ± 0.14	26.29 ± 1.75
	'Biloruski'	73.45 ± 2.12*	3.50 ± 0.00*	25.58 ± 1.98
	'Windzorski'	76.30 ± 2.33*	4.05 ± 0.07*	27.53 ± 1.48
Surface drip irrigation (soil moisture 80%)	'Karadag' st	66.46 ± 2.12*	3.85 ± 0.21*	33.38 ± 1.55*
	'Ukrainski Slobidski'	81.25 ± 5.23*	3.90 ± 0.14*	31.88 ± 0.71*
	'Biloruski'	79.45 ± 6.36*	4.55 ± 0.07*	31.43 ± 0.64*
	'Windzorski'	85.65 ± 4.66*	4.75 ± 0.35*	34.38 ± 1.70*
LSD_{05}	A	1.29	0.07	0.50
	B	1.92	0.10	0.79
	AB	2.71	0.17	1.31
	CV%	9.8	15.3	11.5

st – standard; values are means (n = 2) ± standard deviation; * shows significance at the $P \le 0.05$ probability levels.

Table 4. Effect of irrigation and cultivars on leaf's chlorophyll content of the faba bean (2019–2020) (x ± SD)

Growing conditions	Cultivar	Chlorophyll a, µg g^{-1} FW	Chlorophyll b, µg g^{-1} FW	Total chlorophyll, µg g^{-1} FW
Without irrigation (natural conditions)*	'Karadag' st	8.16 ± 1.18	4.67 ± 0.18	12.83 ± 1.35
	'Ukrainski Slobidski'	9.31 ± 0.39*	4.55 ± 0.06	13.86 ± 0.46*
	'Biloruski'	7.27 ± 0.60	4.11 ± 0.13	11.38 ± 0.47
	'Windzorski'	8.77 ± 0.46*	4.61 ± 0.01	13.37 ± 0.44
Surface drip irrigation (soil moisture 80%)	'Karadag' st	10.04 ± 1.20*	5.46 ± 0.20	15.50 ± 1.40*
	'Ukrainski Slobidski'	11.23 ± 1.64*	6.26 ± 0.05*	17.49 ± 1.69*
	'Biloruski'	10.47 ± 1.45*	5.51 ± 0.26	15.98 ± 1.71*
	'Windzorski'	10.15 ± 1.35*	5.49 ± 0.18	15.64 ± 1.53*
LSD_{01}	A	0.25	0.10	0.40
	B	0.39	0.16	0.62
	AB	0.56	0.88	0.88
	CV%	13.9	13.9	13.7

st – standard; values are means (n = 2) ± standard deviation; * show significance at the $P \le 0.01$ probability levels.

Table 5. Effect of irrigation and cultivars on leaf's antioxidant enzyme activity of the faba bean (2019–2020) (x ± SD)

Growing conditions	Cultivar	Catalase, U mg^{-1} protein	Guaiacol peroxidase, U mg^{-1} protein	Superoxide dismutase, U mg^{-1} protein
Without irrigation (natural conditions)*	'Karadag' st	186.8 ± 16.0	18.3 ± 1.8	18.0 ± 3.0
	'Ukrainski Slobidski'	198.3 ± 18.5*	22.5 ± 2.1*	21.3 ± 2.6*
	'Biloruski'	175.3 ± 19.5	14.4 ± 3.1	15.0 ± 3.0
	'Windzorski'	216.3 ± 25.5*	24.4 ± 1.8*	24.2 ± 3.8*
Surface drip irrigation (soil moisture 80%)	'Karadag' st	144.9 ± 19.0	14.1 ± 2.0	14.0 ± 3.0
	'Ukrainski Slobidski'	177.4 ± 13.5*	16.7 ± 1.3*	16.1 ± 3.9*
	'Biloruski'	139.4 ± 30.5	11.3 ± 2.7	12.1 ± 3.4
	'Windzorski'	192.9 ± 15.0*	19.6 ± 2.4*	18.5 ± 3.5*
LSD_{01}	A	3.54	0.39	0.36
	B	5.60	0.62	0.57
	AB	7.91	0.88	0.81
	CV%	17.8	26.7	28.6

st – standard; values are means (n = 2) ± standard deviation; * show significance at the $P \le 0.01$ probability levels.

The number of beans (pods) increased on average in two years on the cultivars with drip irrigation by 47.8% in the 'Biloruski', by 50% – in the 'Karadag' and 'Ukrainski Slobidski', in the 'Windzorski' – by 62.5% compared to the option without irrigation, which was significant. The inter-varietal difference was significant in all variants. Thus, for growing without irrigation, the number of beans in the 'Ukrainski Slobidski' and 'Windzorski' was less by 1 pcs $plant^{-1}$ relative to the standard. In the 'Biloruski', this figure was lower than the standard by 1.5 pcs. Under the conditions of drip irrigation, the difference between the options increased. Thus, in the 'Ukrainski Slobidski' noted a smaller number of beans compared to the standard by 1.5 pcs plant^{-1}, in the 'Biloruski' – a decrease against the standard cultivar 'Karadag' by 2.5 pcs, the 'Windzorski' formed the 2.5 number (Table 6).

Weight and yield of green beans. Drip irrigation contributed to a significant increase in the mass of green beans on the plant by 35.9–41.9 g.

Crop yield is the most important indicator of the effectiveness of cultivation technology. Under drip irrigation, the commodity yield increased by 3.5–4.2 t ha^{-1}, or 31.3–39.2%.

The results show that the most accumulating protein in the 'Ukrainski Slobidski' (12.3% without irrigation; 10.9% under irrigation) and 'Windzorski' (13.4% without irrigation; 11.8% under irrigation). The protein content under drip irrigation decreased by 1.4–1.5% relative to similar variants without irrigation. As the water intake causes hydrolysis and catabolism of proteins, releasing free amino acids and ammonia, as well as proline.

Growing beans on drip irrigation significantly reduced the dry matter content by 1.2–2.0%. The 'Biloruski' was characterized by a lower dry matter content compared to the 'Karadag' – 0.8 without irrigation and 0.3% higher on irrigation. The 'Ukrainski Slobidski' had a higher dry matter content by 0.3% and 0.5%, in accordance, according to the method of cultivation. The 'Windzorski' was dominated by the 'Karadag' by 0.7% and 1.5%, in accordance, according to the method of cultivation (Table 7).

Table 6. Effect of irrigation and cultivars on the number of pods and seeds pod^{-1} of faba bean (2019–2020) (x ± SD)

Growing conditions	Cultivar		Pods per plant	Seeds per pods
Without irrigation (natural conditions)*	'Karadag' st		13.02 ± 1.41	2.30 ± 0.14
	'Ukrainski Slobidski'		12.05 ± 0.50	2.45 ± 0.21*
	'Biloruski'		11.50 ± 0.71	2.50 ± 0.0*
	'Windzorski'		12.03 ± 0.45	2.30 ± 0.14
Surface drip irrigation (soil moisture 80%)	'Karadag' st		19.50 ± 0.74*	2.80 ± 0.28*
	'Ukrainski slobidski'		18.04 ± 0.55*	3.00 ± 0.0*
	'Biloruski'		17.00 ± 1.46*	3.85 ± 0.21*
	'Windzorski'		19.50 ± 0.87*	3.75 ± 0.35*
	LSD_{05}	A	0.22	0.06
		B	0.35	0.09
		AB	0.50	0.12
		CV%	23.0	21.7

st – standard; values are means (n = 2) ± standard deviation; * show significance at the P≤ 0.05 probability levels.

Table 7. Effect of irrigation and cultivars on weight and yield of green beans, protein and dry matter content in green beans (2019–2020) (x ± SD)

Growing conditions	Cultivar	Weight of green beans, g plant^{-1}	Yield, t ha^{-1}	Protein content %	Dry matter content %
Without irrigation (natural conditions)*	'Karadag' st	92.0 ± 10.00	11.0 ± 1.20	11.6 ± 0.85	13.0 ± 1.17
	'Ukrainski Slobidski'	93.6 ± 9.13	11.2 ± 1.10	12.3 ± 0.71*	13.3 ± 1.13
	'Biloruski'	90.1 ± 5.86	10.8 ± 0.70	10.9 ± 0.92	12.6 ± 0.70
	'Windzorski'	95.4 ± 6.33	11.5 ± 0.76*	13.4 ± 0.23*	13.7 ± 0.44*
Surface drip irrigation (soil moisture 80%)	'Karadag' st	127.9 ± 10.14	14.6 ± 1.16	10.2 ± 0.28	11.0 ± 0.42
	'Ukrainski slobidski'	135.1 ± 11.56*	15.4 ± 1.32*	10.9 ± 0.14*	11.5 ± 0.42*
	'Biloruski'	132.0 ± 12.78*	15.0 ± 1.46	9.4 ± 0.28	11.3 ± 0.42
	'Windzorski'	131.9 ± 7.91*	15.0 ± 0.90	11.8 ± 0.49*	12.5 ± 0.69*
	LSD_{05} A	1.80	0.20	0.19	0.16
	B	2.85	0.33	0.30	0.25
	AB	4.02	0.46	0.42	0.36
	CV%	1.80	16.0	16.5	7.7

st – standard; values are means (n = 2) ± standard deviation; * show significance at the P≤ 0.05 probability levels.

The results of studies have shown that the content of vicin and convicin is significantly reduced under irrigation. The concentration of vicin decreases by 28.6–39.1%, the concentration of convicin – 25.2–46.4% relative to the options without irrigation (Table 8). Mayer *et al*. (2021) report the dependence of these indicators on the genotype.

Studies of the formation of the nodulation apparatus showed that the cultivation of beans under irrigation contributed to a significant increase in the mass of nitrogen-fixing nodules (rhizobia) from 34.2% in the 'Ukrainski Slobidski' to 114.9% in the 'Biloruski'. At the same time, the variability of these traits (CV) was significant (41.6% by weight and 48.8% by the number of nodules), which indicates that the bean-rhizobial system is the most sensitive component of the phytocenosis (Table 9).

For cultivation without irrigation, by weight of tubers, the standard prevailed most significantly to the 'Ukrainski Slobidski' (+34.8%), the difference in the 'Windzorski' (+19.1%) was slightly lower. The 'Biloruski' formed 66.7% fewer rhizobia than the 'Karadag'. The same trend was maintained for growing under irrigation, but the difference between the options was reduced. Thus, the 'Ukrainski Slobidski' and the 'Windzorski' formed rhizobia larger by weight by 21.4% and 13.3% compared to the standard cultivar 'Karadag', the 'Biloruski' had 51.9% less by weight rhizobia. Drip irrigation contributed to a significant increase in the number of rhizobia on the plant. Thus, the 'Karadag' increased their number relative to the option without irrigation by 5.7%, the 'Ukrainski Slobidski' by 16.4%, the 'Biloruski' by 16.3%, and the 'Windzorski' by 46.7%.

When grown without irrigation, the 'Ukrainski Slobidski' and 'Biloruski' formed more by 28.5 and 8.7 $plant^{-1}$ nodules relative to the 'Karadag' and the cultivar of Windzorski by 13.0% less. During cultivation under irrigation, the 'Ukrainski Slobidski' and 'Biloruski' formed more by 36.0 and 13.0 $plant^{-1}$. nodules relative to the 'Karadag', and the 'Windzorski' by 8.2%. That is, the reaction of plants of the 'Karadag' was more positive for the growth of rhizobia, which helped to reduce the difference between the options.

Table 8. Effect of irrigation and cultivars on concentracion of antinutrient composition in green beans (2019–2020) (x ± SD)

Growing conditions	Cultivar	Vicine, ug g^{-1}	Convicine, ug g^{-1}
Without irrigation (natural conditions)*	'Karadag' st	5233 ± 8	1422 ± 58
	'Ukrainski Slobidski'	6705 ± 67*	2127 ± 59*
	'Biloruski'	4480 ± 244	971 ± 26
	'Windzorski'	7012 ± 155*	2705 ± 59*
Surface drip irrigation (soil moisture 80%)	'Karadag' st	3361 ± 112	1064 ± 13
	'Ukrainski slobidski'	4086 ± 58*	1207 ± 33*
	'Biloruski'	3105 ± 100	520 ± 8
	'Windzorski'	5008 ± 135*	1588 ± 2*
	LSD_{01} A	113.34	22.90
	LSD_{01} B	179.20	36.21
	LSD_{01} AB	253.42	51.21
	CV%	29.3	47.7

st – standard; values are means (n = 2) ± standard deviation; * show significance at the P≤ 0.01 probability levels

Table 9. Effect of irrigation and cultivars on development of the nodulation apparatus of faba beans (2019–2020) (x ± SD)

Growing conditions	Cultivar	Mass of nodules, g $plant^{-1}$	Number of nodules $plant^{-1}$
Without irrigation (natural conditions)*	'Karadag' st	0.70 ±0.08	26.5 ±2.12
	'Ukrainski Slobidski'	0.95 ± 0.14*	55.0 ± 2.83*
	'Biloruski'	0.23 ± 0.05	35.2 ± 1.06*
	'Windzorski'	0.84 ± 0.08*	13.5 ± 0.71
Surface drip irrigation (soil moisture 80%)	'Karadag' st	1.05 ± 0.07	28.0 ± 1.4
	'Ukrainski slobidski'	1.27 ± 0.18*	64.0 ± 5.65*
	'Biloruski'	0.50 ± 0.13	41.0 ± 1.41*
	'Windzorski'	1.19 ± 0.16*	19.8 ± 1.70
	LSD_{01} A	0.011	0.74
	LSD_{01} B	0.018	1.17
	LSD_{01} AB	0.026	1.66
	CV%	41.6	48.8

st – standard; values are means (n = 2) ± standard deviation; * show significance at the P≤ 0.01 probability levels

Discussion

The importance of the obtained results lies in the comprehensive disclosure of physiological processes, processes of growth and development of plants, crop formation and the relationship between them.

The results are shown in Table 3, Similar results are reported by Al-Suhaibani (2009), bean plants with a higher level of moisture formed more leaves on the plant and, accordingly, a larger area of leaves of the plant. Plants grown in conditions of water deficiency had a smaller leaf area (Alderfasi, Alghamdi, 2010)

The results are shown in Tables 4 and 5 intertwined with the results Erdem *et al*. (2006). Reporting that optimal soil moisture leads to improved various physiological processes, better nutrient uptake, higher rates of photosynthesis, which can affect more leaf area and area and higher yields. Similar results were reported by Abd El-Mawgoud (2006), Siddiqui *et al*. (2015). A correlation analysis showed a strong relationship between the leaf index and yield (r = 0.93; P = 0.0009; R^2 = 0.86). Moreover, there was a good correlation between chlorophyll content and yield (r = 0.96, P = 0.002, R^2 = 0.92) (data not shown).

The results are shown in Table 6, similar to results were obtained by Ashenafi and Mekuria (2015), which reported a significant inter-varietal difference in the number of beans per plant. Accordingly, Mulualem *et al*. (2012), Awol *et al*. (2016), Cerqueira *et al*. (2018) and Souana *et al*. (2020) indicated that the number of beans on a plant-primarily depends on the cultivar. Detected close correlation between the number of grains in the pod and yield (r = 0.83; P = 0.0115; R^2 = 0.68) (data not shown). Therefore, when selecting cultivars or their selection, preference should be given to cultivars with an increased number of grains.

The present study concluded that 80% of ET was quite enough to achieve maximum productivity for green faba beans. The results of our experiment are similar to those previously reported by El-Noemani *et al*. (2010), Liu *et al*. (2021). They noted that increasing the irrigation amount up to 100% of ET prompted the highest growth, although the maximum pod yield was achieved by 80% of ET. Under stress conditions, water deficit had a significant impact on plant growth, leading to a decline in growth, leaf area development, and photosynthetic capacity (Bayuelo-Jimenez *et al*., 2003). Previous studies revealed that the reduction in bean productivity (number of pods per plant and seed biomass) due to heat stress was associated with reduced leaf water content (Amer *et al*., 2012; Attila *et al*., 2017).

The lowest protein content was obtained by irrigation. These findings may be because protein is considered a good indicator of plant resistance to water deficiency, as the water intake causes hydrolysis and catabolism of proteins, releasing free amino acids and ammonia, as well as proline (Fayed *et al*., 2018; Mayer *et al*., 2021). There are also close correlations between protein content and antinutrient components: protein-vicine – r = 0.96; P = 0.0001; R^2 = 0.91; protein-convicine – r = 0.96; P = 0.0001; R^2 = 0.93 (data not shown). There were also no studies on the influence of elements of technology, particular drip irrigation on the concentration of antinutrient components, there was only one study of varietal characteristics of the accumulation of such substances (Khazaei *et al.*, 2019). Our research has established a positive effect of this factor.

Moreover, from an agronomical point of view, including faba bean in crop rotation systems improves soil, since this crop can fix atmospheric N2 to amounts that may exceed 200 kg N ha^{-1}, and increases soil organic matter. El Idrissi *et al*. (2020), claim that small rhizobia may not accumulate nitrogen at all. In our studies, the mass and number of nodules increased significantly on drip irrigation, which increased the accumulation of biological nitrogen.

Conclusion

Conclusively, at similar experimental conditions, it could be concluded that the irrigation of faba bean plants was effective the proper for enhancing yield and improved green pod quality.

Studies have shown a positive effect of irrigation on reducing the concentration of antinutrient compositions. Are identified genotypes with relatively high accumulation of antinutrient compositions ('Karadag' and 'Biloruski') that need to be included in the selection process. Selection and irrigation will allow the widespread use of faba beans as a valuable high-protein source.

The presented results, based on the data of a field experiment with surface drip irrigation of beans grown in central Ukraine, showed that the yield of green beans due to irrigation increased on average for all cultivars by 34.9%.

Growing beans on drip irrigation contributed to a significant increase in the number of nitrogen-fixing nodules on the plant by 34.2–114.9% and their weight by 5.7–46.7%, which increased the concentration of biological nitrogen in the soil. Growing beans on drip irrigation contribute to a significant improvement in the formation of the bean-rhizobial system, which has a positive effect on the concentration of biological nitrogen in the soil.

Our methodology can be used for assessing the response of different genotypes of faba bean to soil water deficit. The identified tolerant cultivars can be utilized as a source for water stress tolerance in faba bean breeding.

The results presented in this paper are of great importance because they can be used to model the economic consequences as well as to plan the development of irrigation systems in a given area.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

OU, SP, AY, VY – study conception and design;
VL, VY, OL, VK – acquisition, analysis and interpretation of data;
OU, SP, VL, AY, VY – revision and approval of the final manuscript.

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