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THE RESPONSE OF RUNNER BEAN CROP TO IRRIGATION AND FERTILIZATION

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ABSTRACT

Currently there is a growing interest both in obtaining large agricultural yields in order to provide food for a growing population as well as in increasing the sustainability of production systems by improving the health of the soil. The overall objective of this study was to evaluate the effect of organic versus chemical fertilization versus irrigation on runner bean crop and soil health. A bi-factorial field experiment was organized in a split plot design with three replicates during two years (2019 and 2020). The first factor, irrigation, had two graduations: irrigated with 3000 $m^3 \cdot ha^{-1}$ (Ir) and non-irrigated (Non-Ir). The second factor, fertilization, had four graduations: biosolids (1200 $kg \cdot ha^{-1}$) (B), chemical (360 $kg \cdot ha^{-1}$) (Ch), microorganism (80 $kg \cdot ha^{-1}$) (M) and unfertilized (Unfert). The results showed that, regarding the physiological state of the plants, both the photosynthesis and the chlorophyll content were higher at Ir x M (5.31 µmol CO_2 m^{-2} s^{-2} and 45.23 SPAD units, respectively). The yield of dried beans ranged between 1476-4811 $kg \cdot ha^{-1}$ in 2019 and 1498-4727 $kg \cdot ha^{-1}$ in 2020 and was highest for Ir x Ch. Soil health status estimated by determining the dehydrogenase activity in the soil, has been improved for irrigated (Ir) and fertilized (B, M, Ch) variants.

Keywords: *Phaseolus coccineus* L., irrigation system, differentiated fertilization, physiological indicators, dehydrogenase activity.

INTRODUCTION

Runner bean crop (*Phaseolus coccineus* L.) is the second most important species of the *Phaseolus* genus, after the common bean (*Phaseolus vulgaris* L.) (Piecyk et al., 2013). However, when compared to common beans, runner bean is not as popular worldwide (Łabuda, 2010; Mihalache et al., 2018).

In Romania, the species is widespread, being mostly cultivated on small areas, especially on family farms, being appreciated for its food and sometimes for ornamental value in small garden (Munteanu, 1985; Paplinski, 2014; Galea et al., 2018). The species is grown as an annual plant, in pure culture or intercropping, for its mature or immature seeds (Munteanu, 2005; Popa et al. 2008; Mihalache et al., 2015, Schwember et al., 2017). In UK and other countries there are runner bean cultivars that can be cultivated for pods (Rodiño et al., 2007), however these cultivars are not grown in Romania (Teliban et al., 2014, 2015; Avasilcăi et al., 2017). The seeds can be stored very well in dry conditions or preserved; used in the preparation of various dishes, being an important source of fiber, minerals and vitamins, being very rich in protein and having a high energy value (Łabuda, 2010; Wołosiak et al., 2018; Yang et al., 2020).

Lately, the species enjoys an increased attention from the Iaşi University of Life Sciences's researchers, who developed two doctoral theses (Popa, 2010; Hamburdă, 2015),

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and numerous scientific papers highlighting the agrobiology of the species and the cultivation technology (Munteanu et al., 2007a, 2007b; Popa et al., 2008; Popa and Munteanu, 2009; Munteanu et al., 2013; Hamburdă et al., 2016). The research regarding the irrigation and fertilization were performed in one direction and quite limited, for this reason, the present study included both technological parameters in an integrated way. Obtaining high yields has been a desire of the modern agriculture (Bărbieru, 2021), but lately there is an increasing attention on soil protection and its pollution avoidance (Samuel and Ciobanu, 2018; Stoleru et al., 2019). For this reason, it is necessary to study different fertilization regimes that meet both the health requirements of the soil and those of the plant (Mărin et al., 2021).

The effect of different fertilizers on the soil health can be highlighted by different methods. One of these is to evaluate the activity of soil microorganisms based on specific indicators, for example, dehydrogenase activity (Samuel et al., 2021). Dehydrogenase activity produced by the soil microbiota represents an efficient indicator for soil health status (Bireescu et al., 2010).

Dehydrogenase is an oxidoreductase found in living microorganisms in the soil, and plays an important role in the decomposition of organic matter. Dehydrogenase is an intracellular enzyme and provides information only about the biologically viable, active microbial cells in the soil. For this reason, dehydrogenase activity is considered an indicator of the microbiological REDOX system and an efficient indicator of the soil health (Bireescu et al., 2010; Furtak and Gajda, 2017; Bireescu et al., 2018; Małachowska-Jutsz and Matyja, 2019).

In general, the edaphic microbiota has a special importance in regulating the dynamics of the transformation of plant residues and the bioaccessibility of nutrients, in directing the flows of substances in forms accessible to plants, in maintaining the soil structure and in establishing interrelations with the roots of the plants in the edaphic rhizosphere (Wolińska and Stępniewska, 2013; Wolińska et al., 2016). The enzymatic activity catalyzes the indispensable reactions of the edaphic vital processes, the circuit of nutrients in nature, the decomposition of organic residues, the formation of humus and of the soil structure, while also representing a qualitative indicator for soil fertility (Gianfreda and Ruggiero, 2006; Dincă et al., 2013).

In this way, the plant biomass is directly influenced by its physiological state. From a physiological stand point, the intensity of the photosynthesis is the process that influences the most the rate of biomass accumulation (Agapie et al., 2020). The intensity of the photosynthesis is limited by the level of the nutrients in the soil, and it can be stimulated by the addition of fertilizers. Furthermore, the fertilizers accessibility for plants is dependent of the water content in the soil, which in case of limitation it can be supplemented by irrigation (Brandão et al., 2013).

Accordingly, the goal of this paper is to find the best technical solutions for optimizing the culture of runner bean by testing different types of fertilizers under irrigation and non-irrigation conditions.

MATERIAL AND METHODS

Experimental design

The field study was conducted at the experimental farm of Iaşi University of Life Sciences, Romania (http://www.uaiasi.ro/, N = 47°11′76″ E = 27°33′71″) during two cropping seasons, in 2019 and 2020. The experience was established on anthropic cambic chernozem soil, with the following characteristics: 32% clay, 4.5% sand; pH 7.2; 2.86% organic matter; 2.8 $g \cdot kg^{-1}$ N, 32 $mg \cdot kg^{-1}$ P, 218 $mg \cdot kg^{-1}$ K, 4.1 $g \cdot kg^{-1}$ $CaCO_3$; C/N 5.91. The weather conditions during the experimental period are presented in Table 1.

Biological material was represented by a local population of runner bean. This local population was collected from the Suceava area and has an indefinite growth, with great vigor, with 3-5 branches. The color of the foliage is dark green, the flowers are red, and the seeds are purple with a black pattern. Size of the pod (L / l) = 10 / 1.9 cm, with 2 to 4 seeds in a pod (17 mm long and 12 mm wide), TKW = 1196 g.

The runner bean crop was established by direct sowing in the field, spaced 50 cm along the rows (three seeds/nest) and 100 cm between the rows with a density of 20000 nests·ha^{-1}. A split plot design with three replicates was arranged for treatment distribution in the field, the experimental factors investigated being represented by the irrigation regime - irrigated with 3000 m^3·ha^{-1} (Ir) and non-irrigated (Non-Ir) and fertilization type - fertilization with biosolids (B), chemical (Ch), microorganisms (M) and unfertilized (Unfert). The control of the experiment was the non-irrigated x unfertilized variant.

Table 1. Monthly average value of the main meteorological factors of the experimental period

Month	Average temperature (°C)		Rainfall (mm)		Atmospheric humidity (%)		Sunlight duration (hours)	
	2019	2020	2019	2020	2019	2020	2019	2020
May	16.6	14.4	74.9	130.5	77	67	198.4	178.2
June	22.7	21.3	8.4	99.0	29	71	276.0	235.7
July	22.0	22.1	3.8	7.9	67	61	282.8	187.4
August	22.1	23.6	35.1	8.8	67	54	285.5	289.6
September	16.9	19.5	51.0	24.2	66	60	239.2	264.1
October	11.4	14.1	24.7	75.4	74	83	146.3	129.5

The fertilization treatments were:

1. Biosolids (B) applied at a rate of 1200 kg·ha^{-1}. The biosolids were obtained from the municipal waste water treatment plant (Iaşi, Romania); they were platform dried for 2 years. Physico-chemical composition of the biosolids was: pH 6.96, 6280 µS cm^{-1} EC, 26.6% OM, 4.83% total N, 2.43% P_2O_5, 0.51% K_2O.

2. Cristaland® (Ch) is a solid chemical fertilizer, applied at a rate of 360 kg·ha^{-1}. The composition of this fertilizer was: 20% of total N of which nitric N-5.6%, ammoniacal N-3.9%, and ureic N-10.5%; 20% P_2O_5; 20% K_2O, enriched with B-0.012%, Fe-0.02%, Mn-0.01%, and Zn-0.003%.

3. Micoseeds MB® (M) is a powder fertilizer based on microorganisms and was applied at 80 kg·ha^{-1}. It contains predominantly spores of arbuscular mycorrhizal fungi (AMF), and is based on *Glomus* spp. and enriched with *Beauveria* sp., *Metarhizium* sp., and *Trichoderma* sp.

4. Control treatment (Unfert), without the application of fertilizers.

Fertilization with biosolids accounted for about 80% of the rate associated with chemical fertilization, taking into account the higher efficiency of nutrient utilization obtained through organic fertilization. The application of microorganisms served to evaluate the beneficial potential of microorganisms to favor the nutrient absorption of plants in the absence of fertilization. All the fertilizers were applied in two stages: the first one as the starter fertilization and the second one after three weeks from the emergence of the crop, by local administration at the nest.

Physiological measurements

Assimilatory pigments content was measured with a non-destructive portable SPAD 502, Minolta, Japan, that measures the optical absorbance of chlorophyll; the readings were expressed as SPAD units. Measurements were performed on three leaves (lower, middle, and upper portions of the plant) from nine plants in each treatment.

Photosynthetic activity *A* (µmol CO_2 m^{-2} s^{-1}) was measured with a portable device LCi, ADC Bioscientific, UK. Measurements were performed during the light regime, from 09:00 to 14:00. A total of 36 measurements were obtained per treatment.

Dehydrogenase activity

Dehydrogenase activity (DA) (mg TPF/100 g dry soil) was determined by incubation at 28°C and 24 h with 2,3,5-triphenyltetrazolium chloride (TTC), according to Casida et al. (1964) modified by Kiss and Boaru (1965) and Bireescu et al. (2018).

Statistical analyses

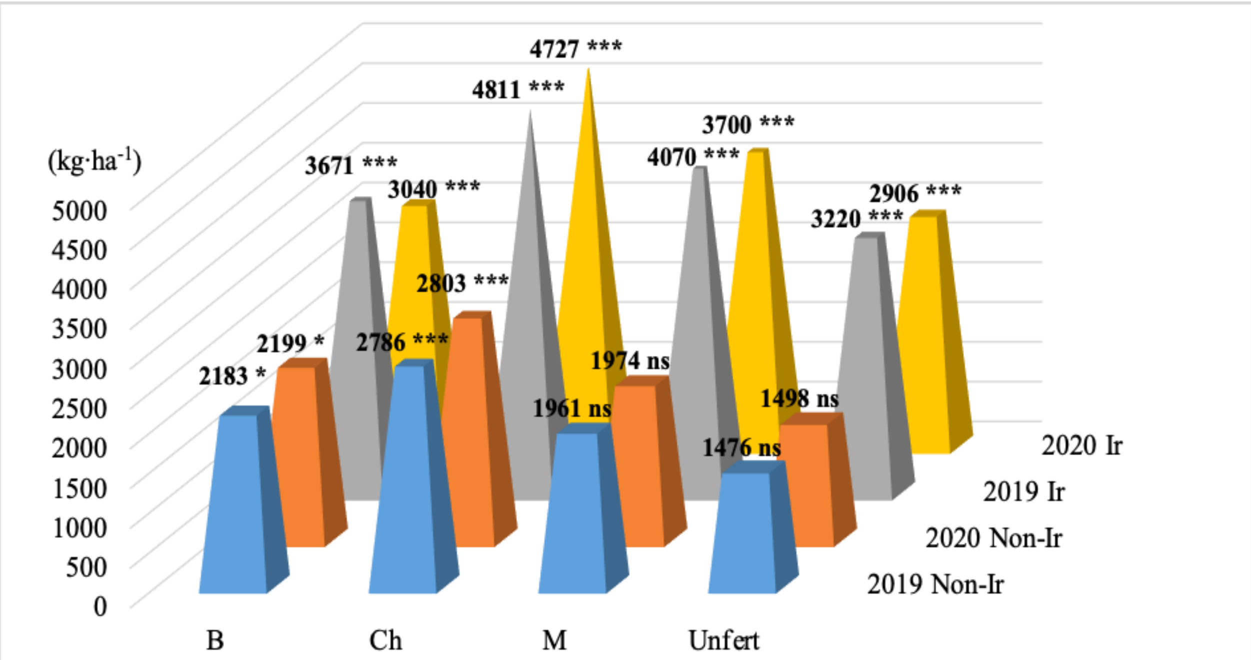
In order to determine the runner bean yield, the harvesting was performed in a single stage, the production results being processed by the method of limit differences. For the other parameters analyzed, the data were statistically processed by ANOVA and the mean separation was performed through Tukey's test at 0.05 probability level. The results were reported as means ± standard deviation (Gomez and Gomez, 1984). The variables regarding the determinations in our research were not significantly affected by the research year and, therefore, the results discussions were done by taking into account the average data of the two years.

RESULTS AND DISCUSSION

1. Runner bean yield

Runner bean is an economically important crop due to its high protein content that is found in the seeds. In this case, the seeds represent the economic yield, and therefore efforts are made to find better cultivation methods, that include irrigation and fertilization. Assuring a proper nutrition by fertilization is important, as nutrients, and especially nitrogen are used in the primary production pathway that led to the formation of proteins, flowers, seeds etc. (Matev et al., 2022).

The yield data obtained during the two years of experimentation are shown in Figure 1. The highest average yield was highlighted in the combination of factors Ir x Ch (4769 kg·ha^{-1}), while the lowest in the Non-Ir x Unfert variant (1487 kg·ha^{-1}). The yield values for 2019 were between 1476 kg·ha^{-1} obtained in the Non-Ir x Unfert variant and 4811 kg·ha^{-1} registered in the irrigated version x chemical fertilization. In 2020, the yield values were between 1498 kg·ha^{-1} (Non-Ir x Unfert) and 4727 kg·ha^{-1} (Ir x Ch). The yields obtained in the present study for irrigated variants were in accordance with those reported by Popa (2010), and those obtained in the case of non-irrigated variants were similar to those reported by Hamburdă (2015).



Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization; n.s.: no statistically significant difference; *: significant difference; ***: very significant difference.

Figure 1. The yield obtained in the experimental field (2019-2020)

The calculated F values for the irrigation regime and fertilization type (Table 2) were higher than their theoretical values (Fc = 137.52 > Ft = 18.51 and Fc = 30.87 > Ft = 3.49, respectively) resulting that the yield significantly varied depending on the irrigation regime and the type of fertilization. However, among the two factors taken into consideration, the irrigation regime had a higher influence on the yield as compared to the fertilization type. The first factor considered in the study, the irrigation regime (Table 2), had a major influence on the production of runner beans, the irrigation of the crop resulting in production increases of 78.57%, this increase being considered distinctly significant compared to the control (Non-Ir variant). Therefore, this factor represents an important technological parameter with a particularly important positive impact on the production of dried seeds in the runner bean crop.

Regarding the second factor taken into study - the fertilization regime (Table 2), all three types of fertilization provided positive production differences at a distinct and very significant level compared to the control-Unfert variant. Very significant differences were registered for the chemically fertilized variant (Ch), the production increase being of 1506.5 kg·ha^{-1} (66.21%), while distinctly significant differences were achieved by the variants to which microorganisms (M) were applied - 650.7 kg·ha^{-1} (28.60%) and variants fertilized with biosolids (B) - 498.0 kg·ha^{-1} (21.89%). From the obtained data, it turns out that this factor also had a positive impact on production, and can be considered a key element in the success of the runner bean crop.

Table 2. The influence of irrigation and fertilization on runner bean yield

Treatment	Yield			Significance of differences
	kg·ha^{-1}	% compared to C	differences compared to C	
Irrigation regime				
Ir	3768.3	178.57	1658.0	**
Non-Ir	2110.3	100	0	C
Fc = 137.52; Ft = 18.51; LSD 5% = 608.0 kg·ha^{-1}; LSD 1% = 1404.0 kg·ha^{-1}; LSD 0.1% = 4468.0 kg·ha^{-1}				
Fertilization type				
B	2773.5	121.89	498.0	**
Ch	3782.0	166.21	1506.5	***
M	2926.2	128.60	650.7	**
Unfert	2275.5	100	0	C
Fc = 30.87; Ft = 3.49; LSD 5% = 347.8 kg·ha^{-1}; LSD 1% = 488.1 kg·ha^{-1}; LSD 0.1% = 689.2 kg·ha^{-1}				

Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization; C: Control; LSD: Least Significant Difference; Fc: calculated F value; Ft: F theoretical value.

Regarding the results of the combination of the two factors (Irrigation x Fertilization) the interaction between them is not significant, meaning that the effect of fertilizers was not influenced by the irrigation regime. Therefore, the irrigation factor is dominant, having a higher influence on the yield than the fertilization factor (Table 3).

The combination of irrigation x fertilization factors (Table 3) generated positive yield differences at very significant level for five variants, the average yields obtained during the two years of study being 4769.3 kg·ha^{-1} - Ir x Ch fertilization, 3884.7 kg·ha^{-1} - Ir x M, 3356.0 kg·ha^{-1} - Ir x B, 3063.3 kg·ha^{-1} - Ir x Unfert and 2794.7 kg·ha^{-1} - Ir x Ch fertilization. Positive differences at the significant distinct level were recorded in the non-irrigated variant (Non-Ir) x Biosolids fertilization (B) - 2191.0 kg·ha^{-1}, while applying microorganisms on non-irrigated soil generated insignificant positive differences - 1967.7 kg·ha^{-1} compared with the control, represented by the non-irrigated (Non-Ir) x unfertilized variant (Unfert) - 1487.7 kg·ha^{-1}.

Table 3. The influence of interaction between irrigation and fertilization on runner bean yield

Interaction between irrigation x fertilization	Yield			Significance of differences
	$kg \cdot ha^{-1}$	% compared to C	differences compared to C	
Ir x B	3356.0	225.58	1868.3	***
Irigat x Ch	4769.3	320.58	3281.6	***
Ir x M	3884.7	261.12	2397.0	***
Ir x Unfert	3063.3	205.91	1575.6	***
Non-Ir x B	2191.0	147.27	703.3	**
Non-Ir x Ch	2794.7	187.85	1307.0	***
Non-Ir x M	1967.7	132.26	480.0	-
Non-Ir x Unfert	1487.7	100	0	C
Fc = 2.73; Ft = 3.49; LSD 5% = 491.8 $kg \cdot ha^{-1}$; LSD 1% = 690.3 $kg \cdot ha^{-1}$; LSD 0.1% = 974.6 $kg \cdot ha^{-1}$				

Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization; C: Control; LSD: Least Significant Difference; Fc: calculated F value; Ft: F theoretical value.

It is well known that the chemical fertilizers have a high effect on yield in vegetable crops, due to the increased nitrogen content in the form accessible to plants. However, there is a tendency to use biological fertilizers, even in conventional agriculture, and organic and microbiological fertilizers give good production and quality results as added value (Amalfitano et al., 2018; Caruso et al., 2019).

On the other side, the biosolids fertilizers contain high amount of organic matter and nutrients that slowly decompose in time. Another positive effect of the use of biosolids fertilizers is related to the improvement of the physico-chemical properties of the soil such as water holding capacity, aeration, decrease density, etc. Positive effects of biosolids were also obtained for other crops such as basil (Burducea et al., 2018, 2019).

Furthermore, many of the nutrients that are used by plants in the biosynthesis of the chlorophyll (N, P, K, Mg, Fe, Mn, etc.) are found in biosolids, however concerns regarding the presence of high content of heavy metals are reported in the literature. The presence of the heavy metals in the biosolids varies from one waste water treatment plant to another and depends on the dimension of the locality and industrial activities. The concentration of the heavy metals in biosolids used in this study was below the maximum admissible values imposed by the legislation in force for the use in agriculture.

According to the data obtained in the two years of study, the two factors taken into consideration - irrigation and fertilization - had a high impact on the production, these being important parameters in obtaining high yields of *Phaseolus coccineus* L. crop. By comparison, from the five variants with very significant positive differences, the first four were the irrigated variants, which mean that the application of irrigation to the culture of runner bean is a condition before fertilization. The non-irrigated but fertilized variants also brought significant increases in production the chemical fertilization on non-irrigated soil bringing an increase of 87.85%, which is considered very significant, compared to the control.

However, applied fertilization did not outweigh the irrigation effect. So, in the absence of irrigation, the plants of this species cannot maximize the supply of nutrients, which means that irrigation is paramount to the success of this crop and then fertilization.

2. Physiological results in this study

The analyzed physiological parameters, the content in chlorophyll pigments and the rate of photosynthesis, according to the experimental factors studied - irrigation and fertilization, are presented in Table 4. From the data presented in the table, it can be observed that the irrigation regime did not significantly influence the physiological parameters analyzed, while the applied fertilization determined significant positive differences compared to the unfertilized variant.

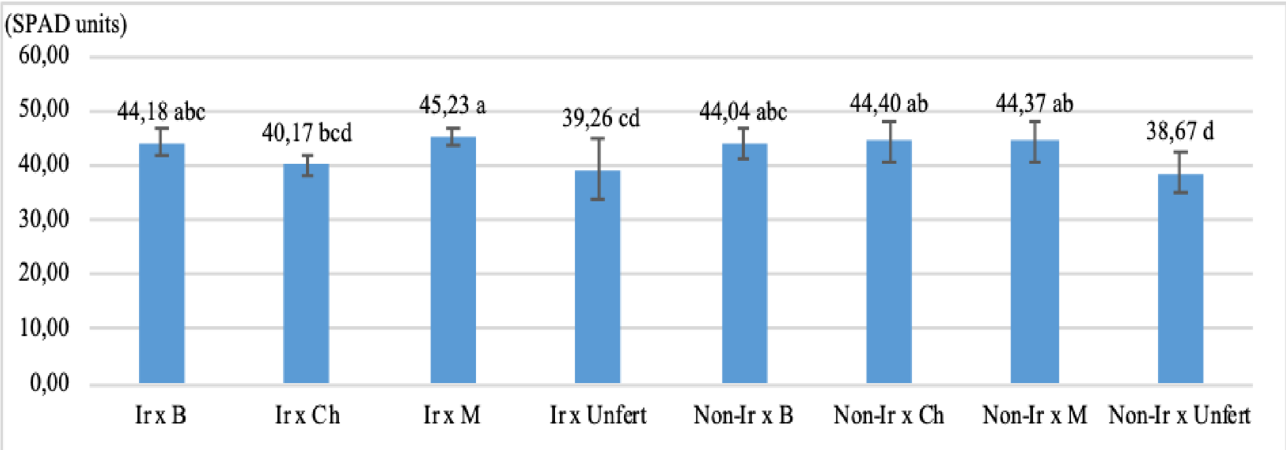
Table 4. Chlorophyll content and the photosynthetic activity of runner bean leaves as affected by irrigation and fertilization

Treatment	SPAD (unit SPAD)			Photosynthesis (μmol CO_2 m^{-2} s^{-1})		
	2019	2020	Average 2019-2020	2019	2020	Average 2019-2020
Irrigation regim						
Ir	42.12 ± 1.66	42.40 ± 1.26	42.26 ± 0.26	4.59 ± 0.63	3.86 ± 0.36	4.23 ± 0.29
Non-Ir	43.36 ± 0.18	42.37 ± 0.55	42.87 ± 0.36	4.02 ± 0.41	3.29 ± 0.36	3.65 ± 0.18
Significance	ns	ns	ns	ns	ns	ns
Fertilization type						
B	44.48 ± 0.96 a	43.83 ± 0.33 ns	44.15 ± 0.57 ab	4.51 ± 0.69 a	3.43 ± 0.34 b	3.97 ± 0.20 b
Ch	43.78 ± 0.65 a	40.54 ± 1.86 ns	42.16 ± 0.60 b	4.72 ± 0.17 a	3.27 ± 0.20 b	4.00 ± 0.19 b
M	45.45 ± 2.17 a	44.14 ± 0.85 ns	44.80 ± 1.28 a	5.39 ± 0.57 a	5.06 ± 0.47 a	5.22 ± 0.18 a
Unfert	37.25 ± 3.93 b	41.03 ± 2.16 ns	39.14 ± 1.11 c	2.59 ± 0.73 b	2.55 ± 0.44 b	2.57 ± 0.16 c

Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization.
Within each column, n.s. no statistically significant difference at $p \leq 0.05$, values associated to different letters are significantly different according to Tukey's test at $p<0.05$.

Application of both irrigation and fertilization treatments positively influenced the content of assimilatory pigments (SPAD units) in leaves of runner bean plants (Figure 2). The highest increase of chlorophyll content was obtained under irrigated (Ir) x microorganisms (M) treatment (17.0%) followed by the non-irrigated (Non-Ir) x chemical (Ch) treatment (14.8%) and non-irrigated (Non-Ir) x microorganisms (M) (14.7%), compared with control variant (non-irrigated x unfertilized). Similar increases were also obtained under irrigated (Ir) x Biosolids (B) and non-irrigated (Non-Ir) x Biosolids (B) (14.3% and 13.9%, respectively). Although the chlorophyll content also increased under the variants irrigated (Ir) x chemical (Ch) and irrigated (Ir) x unfertilized (Unfert), the differences were statistically insignificant.

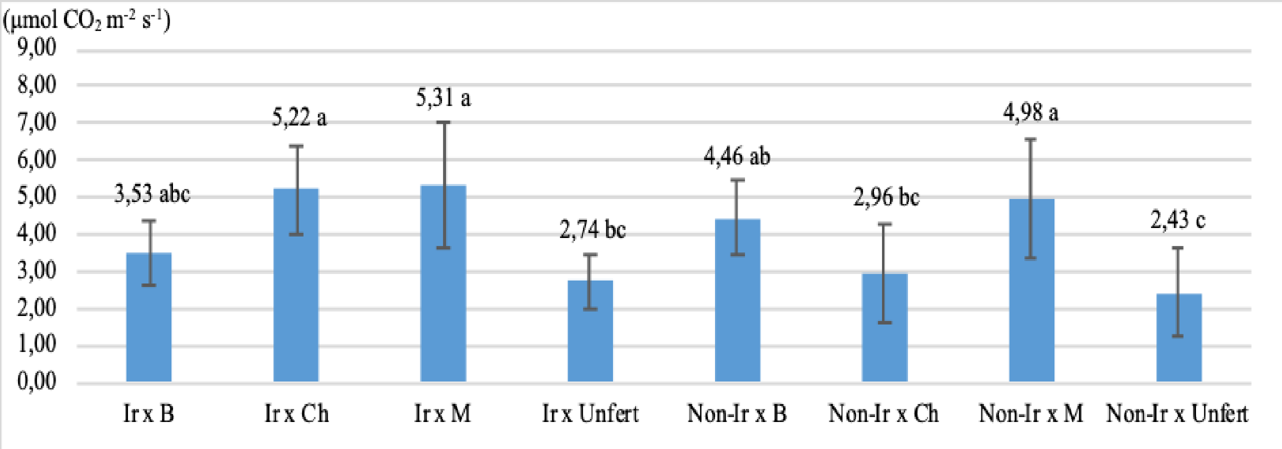
Measuring the chlorophyll content in the plant leaves is a good method to prove the nitrogen availability in the soil, as well as to estimate the plant physiological state, due to the fact that an important amount of nitrogen is stored in leaves (in chlorophyll and RuBisCo) (Ciorolanu et al., 2017; Mohamed et al., 2021).



Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization.
Values associated to different letters are significantly different according to Tukey's test at $p \leq 0.05$.

Figure 2. Chlorophyll content in runner bean leaves as affected by the interaction between irrigation and fertilization

The photosynthetic rate of runner bean plants varied under the applied treatments (Figure 3). The CO_2 assimilation was increased under all the treatments compared to the non-irrigated (Non-Ir) x non-fertilized (Unfert) (control) variant. Significant differences were found for: irrigated (Ir) x microorganisms (M) (118.0%), irrigated (Ir) x chemical (Ch) (114.4%), non-irrigated (Non-Ir) x microorganisms (M) (104.5%), non-irrigated (Non-Ir) x biosolids (B) (83.2%). The other variants, although they registered some increases of the photosynthesis rate, eg. irrigated (Ir) x biosolids (B) (44.8%), non-irrigated (Non-Ir) x chemical (Ch) (21.5%) and irrigated (Ir) x unfertilized (Unfert) (12.4%), were insignificant compared to the control variant.



Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization.
Values associated to different letters are significantly different according to Tukey's test at $p \leq 0.05$.

Figure 3. The photosynthetic activity of runner bean leaves as affected by the interaction between irrigation and fertilization

In according to our results, Ştefan et al. (2013), obtained high values of photosynthesis in runner bean plant as a result of inoculation with microorganisms. The results obtained for the physiological parameters (chlorophyll and photosynthesis) support the beneficial effects of the microbiological fertilization on the production, under irrigation conditions (3884.7 kg·ha^{-1}).

3. Dehydrogenase activity

Dehydrogenase activity in soil was measured for 2 depths: 0-20 cm and 20-40 cm. As shown in Table 5, the highest values of dehydrogenase activity were obtained at 0-20 cm depth, irrespective of the treatment applied, irrigation or fertilization, due to, both, the abundance of the soil microbes on this depth and the quantity and quality of the soil organic matter that have accumulated under the different treatments (Giacometti et al., 2013; Tan et al., 2014). The values of dehydrogenase activity fall below 20 cm (20-40 cm) with average values of 35.97% for the irrigation regime and 34.61% for the fertilization regime, as a result of the weaker watering of the soil below 20 cm and its deepening. Regarding the irrigation regime, the irrigated variants (Ir) registered a significantly higher activity of dehydrogenase activity compared to the non-irrigated (Non-Ir) variants, both on the 0-20 cm depth and on the 20-40 cm depth. The applied fertilization influenced the activity of dehydrogenase differently. For the 0-20 cm depth, the highest values were recorded in the case of chemically fertilized variants (Ch) [30.97 mg TPF·(100 g dry soil)$^{-1}$] followed by biosolids fertilized variants (B) [26.75 mg TPF·(100 g dry soil)$^{-1}$] and those to which microorganisms (M) were applied [26.41 mg TPF·(100 g dry soil)$^{-1}$], these having significant values compared to the unfertilized version-Control [23.56 mg TPF·(100 g dry soil)$^{-1}$]. For the depth of 20-40 cm, the highest value was recorded by the chemically fertilized variants (Ch)

[22.57 mg TPF·(100 g dry soil)$^{-1}$], followed by the variants fertilized with microorganisms (M) and biosolids (B) [18.39 mg TPF·(100 g dry soil)$^{-1}$, respectively 16.08 mg TPF·(100 g dry soil)$^{-1}$], the values recorded as significant compared to the control of the experience-unfertilized variant [13.88 mg TPF·(100 g dry soil)$^{-1}$]. Moderate doses of chemical fertilizers had a greater positive influence over variants fertilized with biosolids or microorganisms due to their faster solubilization.

Table 5. Dehydrogenase activity of soil of runner bean, expressed as mg TPF•(100 g dry soil)$^{-1}$ as affected by irrigation and fertilization

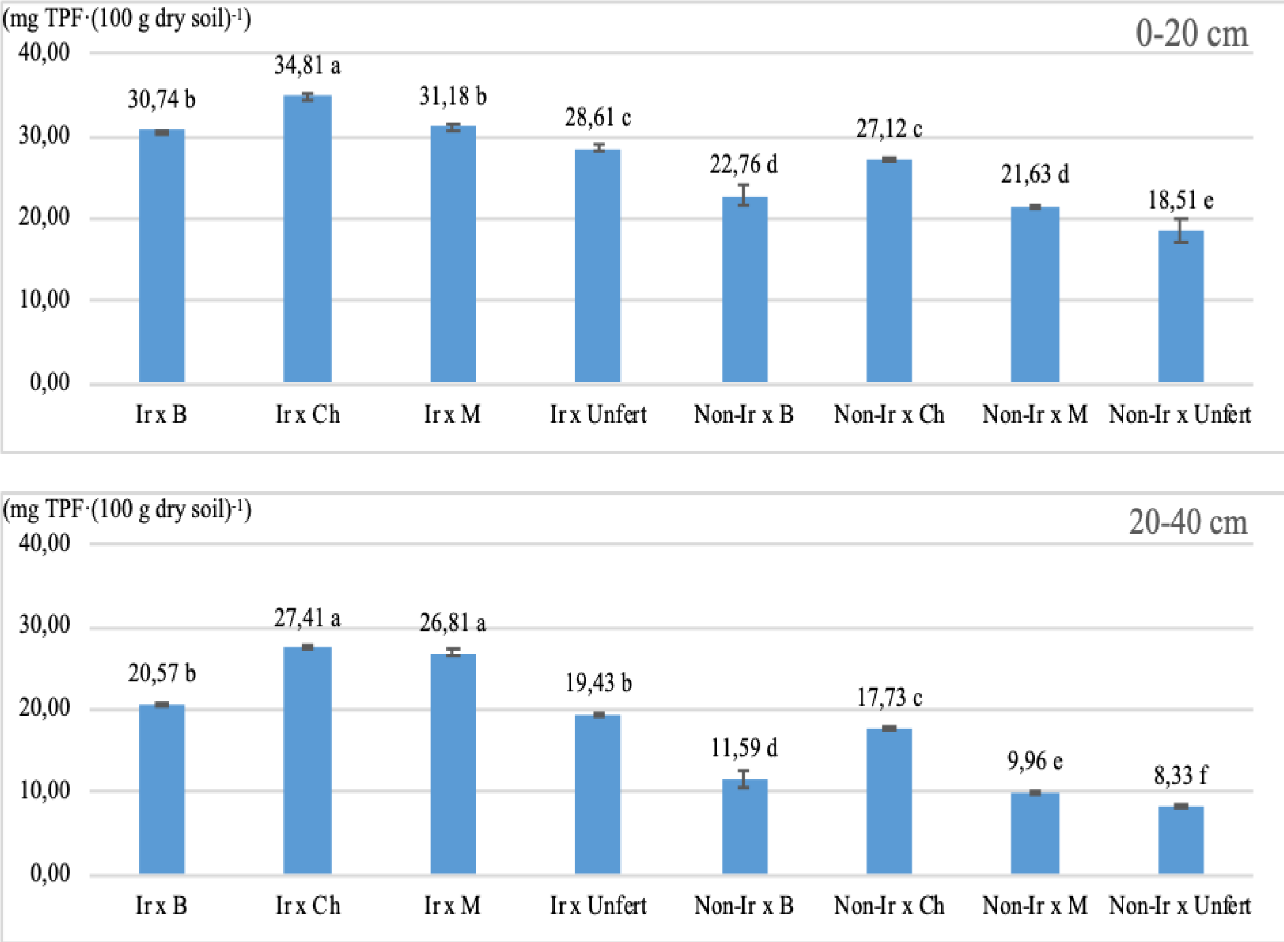
Treatment	0-20 cm			20-40 cm		
	2019	2020	Average 2019-2020	2019	2020	Average 2019-2020
Irrigation regime						
Ir	32.28 ± 0.30	30.40 ± 0.14	31.34 ± 0.21	24.58 ± 0.26	22.53 ± 0.28	23.56 ± 0.17
Non-Ir	20.89 ± 0.49	24.12 ± 0.52	22.50 ± 0.08	11.26 ± 0.35	12.55 ± 0.47	11.91 ± 0.34
Significance	*	*	*	*	*	*
Fertilization type						
B	25.94 ± 0.52 b	27.57 ± 0.83 b	26.75 ± 0.62 b	15.76 ± 0.24 c	16.41 ± 0.99 c	16.08 ± 0.60 c
Ch	30.00 ± 0.57 a	31.93 ± 0.34 a	30.97 ± 0.26 a	22.65 ± 0.47 a	22.50 ± 0.27 a	22.57 ± 0.16 a
M	26.56 ± 0.12 b	26.26 ± 0.44 b	26.41 ± 0.22 b	18.81 ± 0.03 b	17.97 ± 0.20 b	18.39 ± 0.11 b
Unfert	23.84 ± 0.55 c	23.28 ± 0.97 c	23.56 ± 0.69 c	14.47 ± 0.25 d	13.30 ± 0.22 d	13.88 ± 0.23 d

Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization.
Within each column, * significant difference at $p \leq 0.05$; values associated to different letters are significantly different according to Tukey's test at $p \leq 0.05$

Fertilization can stimulate dehydrogenase activity, as demonstrated in lupine (Niewiadomska et al., 2020). Similar to our results, Bielińska et al. (2013) report that chemical fertilization increased soil dehydrogenase activity. Sánchez-Navarro et al. (2020) achieved higher dehydrogenase activity in broccoli and melons grown in organic system compared to conventional ones.

Irrigation had a positive impact on the microbiological activity of the soil, especially on the 0-20 cm depth, correlated with the fertilization variants (Figure 4). Chemical fertilization provided the largest differences compared to the other fertilization variants, both irrigated and non-irrigated, for both depths (Figure 4). The effect of applying the biosolids on the two depths is significantly greater compared to the unfertilized variants, but significantly slower, as a result of the gradual decomposition of their components, compared to the action of the chemical fertilizers that have entered into action faster.

The application of microorganisms to irrigated variants resulted in higher values of dehydrogenase activity compared to the application of biosolids on irrigated soil [31.18 mg TPF·(100 g dry soil)$^{-1}$ versus 30.74 mg TPF·(100 g dry soil)$^{-1}$], but on the non-irrigated variant the applied microorganisms had quite a small influence [21.63 mg TPF·(100 g dry soil)$^{-1}$], the values recorded being below the values registered by the variants fertilized with biosolids [22.76 mg TPF·(100 g dry soil)$^{-1}$] but higher than those of the non-irrigated and unfertilized variants [18.51 mg TPF·(100 g dry soil)$^{-1}$].



Ir: Irrigation; Non-Ir: Non-irrigation; B: Biosolids; Ch: Chemical; M: Microorganisms; Unfert: Unfertilization.
Values associated to different letters are significantly different according to Tukey's test at $p \leq 0.05$.

Figure 4. Dehydrogenase activity of soil of runner bean as affected by the interaction between irrigation and fertilization

The better results obtained for the dehydrogenase activity in the irrigated soil treated with microorganisms as compared with the non-irrigated soil, could be due to the better condition for growth and development of microorganisms, which stimulated their multiplication and therefore the accumulation of dehydrogenase in the soil.

Regarding the activity of dehydrogenase in higher depths (20-40 cm), it was observed that on irrigated (Ir) soil, the chemical (Ch) and microorganism (M) fertilizations gave the best results as compared to the fertilization with biosolids (B), significant difference being registered. This difference might be the result of the added microorganisms which could enrich the native microbial community of the soil and thus the dehydrogenase activity. In the non-irrigated (Non-Ir) soil it was seen a decrease of the dehydrogenase activity, the highest results being recorded by the chemical fertilization (Ch), followed by biosolid fertilization (B) and microorganism fertilization (M), between which significant differences were recorded. These results confirm the fact that in irrigated soils, the conditions needed for the microorganisms to grow and develop and thus produce dehydro-genase, are better than in non-irrigated soils.

The highest content of assimilating pigments (45.23 SPAD units) is correlated in the present study with the highest photosynthetic rate (5.31 μmol CO_2 m^{-2} s^{-1}) recorded for variant Ir x M, while the dehydrogenase activity of the soil for the same treatment occupied the second place [31.18 mg TPF·(100 g dry soil)$^{-1}$ in the 0-20 cm layer and 26.81 mg TPF·(100 g dry soil)$^{-1}$ in the 20-40 cm layer] after irrigated x chemical treatments. Moreover, the analysis of the correlation between dehydrogenase activity and yield showed a strongly positive correlation, both at the soil horizon 0-20 cm (0.97 for irrigation and 0.90 for fertilization), and at 20-40 cm (0.98 for irrigation and 0.94 at fertilization). The availability of the nutrients depends on the water content in the soil that allows the dilution of nutrients and formation of ions and development of the beneficial microorganisms (e.g. AMF). From a practical point of view, the results demonstrate the importance of irrigating runner bean crops, having a more pronounced influence on production than fertilization. These results demonstrate the starting hypothesis of the experiment that irrigation improves the mineral nutrition and physiology of runner bean. Variation in chlorophyll content among plants cultivated under different fertilizers may be related to the type of fertilizer and thus different mechanisms of interaction between plants and fertilizer may be revealed. For instance, AMF are known to increase the P availability to plants as well as a better protection against abiotic stresses.

CONCLUSIONS

Runner bean grown in the open field responded favorably in terms of yield both to the application of irrigation and fertilization. However, the irrigation factor proved to be a major condition for the success of runner bean crop, regardless of the fertilization regime.

Data about dehydrogenase activity of the soil confirm its minimum activity in the absence of water, these being strongly correlated with the obtained yields.

The use of biosolids in the runner bean fertilization turned to be a sustainable choice, as well as a way to recycle them, while the microorganisms' application was more efficient under irrigation conditions.

Overall, both irrigation and chemical fertilization resulted in high production, and the combination of these two factors led to the synergy phenomenon, generating the best production results.

Taking into account the current climate changes, the results of this study show that for the hill and plain area in northeastern Romania, runner bean, a species native to cold and humid climates, should be cultivated under irrigation conditions, but not ignoring, the need for fertilization to increase production.

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