Research Article

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Evaluation of vegetable–faba bean (*Vicia faba* L.) intercropping under Latvian agro-ecological conditions

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Abstract

BACKGROUND: Monoculture is used mostly in conventional agriculture, where a single crop is cultivated on the same land for a period of at least 12 months. In an organic and integrated growing approach, more attention is paid to plant–environment interactions and, as a result, diverse growing systems applying intercropping, catch crops, and green manure are being implemented. Thus, field experiments for evaluation of vegetable/faba bean full intercropping efficiency, in terms of vegetable and faba bean yield and protein content, were set up during two consecutive growing seasons (2014 and 2015).

RESULTS: Data obtained showed that the most efficient intercropping variants were cabbage/faba bean (cabbage yield 1.27–2.91 kg m^{-2}, immature faba bean pods 0.20–0.43 kg m^{-2}) and carrot/faba bean (carrot yield 1.67–2.28 kg m^{-2}, immature faba bean pods 0.10–0.52 kg m^{-2}), whilst onion and faba bean intercrop is not recommended for vegetable growing since it induces a very low onion yield (0.66–1.09 kg m^{-2}), although the highest immature faba bean pod yield was found in the onion/faba bean intercropping scheme (up to 0.56 kg m^{-2}).

CONCLUSION: Vegetable/faba bean intercropping can be used in practical horticulture for carrot and cabbage growing in order to ensure sustainable farming and environmentally friendly horticultural production.

Keywords: horticultural crops; legumes; dehydrogenase activity; hydrothermal coefficient, soil biological activity

INTRODUCTION

Monoculture is used mostly in conventional agricultural systems in developed countries, where crops are cultivated on the same land during at least a 12-month period.[1] In contrast to conventional agriculture, when organic and integrated growing systems are implemented, more attention is paid to plant–environment interactions and specific growing approaches (intercropping, catch crops, and application of green manures, among others).[2] Hence, during the last decades diverse cropping systems have been assayed in Europe in order to identify the most appropriate agronomical and environmental performances of particular systems.[3]

Intercropping is an agricultural system focused on growing two or more crops on a particular field within the same year. Within this system, to date three categories has been described, depending on the extent of the physical association between the crops: full (complete association between crops), relay (partial time association between crops), and sequential intercropping, also named as multiple cropping (development of involved crops on the same land, in the same year, but not simultaneously).[4] The main advantages of intercropping are the reduction of the risk of total crop failure, the diversification of the production, and a lower incidence of pests and diseases, as well as increasing soil fertility, contributing to more sustainable agriculture, and avoiding the application of inorganic fertilisers.[5]

A sustainable cropping system maintains resources, such as soil and water, while providing proper economic features to agro-food production and ensuring that resources are conserved, recycled or renewed.[6] This contributes to preserving agricultural resources and prevents environmental damage.[7] Despite these advantages, conventional farms with large land areas are less reliant on using intercropping approaches, which are currently applied in small farms unable to control production stability without the capacity of applying other inputs such as water and inorganic fertilisers because of their high cost.[8]

Over the last few years intercropping has been increasing its relevance (especially in organic farming) as a valuable technique to enhance cropping efficiency and environmental performances, including the improvement of soil properties. In this sense, one of the main profits of intercropping with legumes is based on

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their contribution to the plant– soil system features by biological nitrogen (N) fixation.[9] However, the extent in which legume crops can substitute the use of mineral N fertilisers remains poorly explored.[10] To date, it has been reported that legume nitrogen fixation contributes to the biological activity in soils and soil fertility, displaying up to five times higher efficiency than other management alternatives, such as the application into soils of vegetable residues.[11] Nonetheless, some potential risks of nitrogen losses from the plant–soil system have been associated with nitrate leaching or emissions of N_2O to the atmosphere.[9]

In order to shed some light on the mutual interaction of intercropped species, and on the advantages of intercropping, the influence of this management practice on the yield and economic returns has been recently evaluated.[12,13] These studies have allowed to stress intercrop systems on their capacity to improve the efficiency of irrigation and solar radiation, while enhancing pollination, grain yield, and total protein content.[14–18]

The aim of this study was to evaluate the efficiency of using faba bean as intercrop with onion, carrot, and cabbage growing in a full intercropping system during two consecutive seasons, 2014 and 2015. It is assumed that faba bean will positively influence the neighbouring vegetable crop growing in terms of yield and biological activity of soil, by reducing mineral N application, simultaneously providing faba bean yield from the same plot. The data obtained will contribute positively to the design of more sustainable agricultural technologies by involving legume crops.

MATERIAL AND METHODS

Climatic conditions

Intercrop field trials were carried out at the Pure Horticultural Research Centre (PHRC) located 90 km to the west from Riga, Latvia (57° 037′ N, 22° 921′ E, 57 m altitude) during two consecutive seasons, 2014 and 2015. Mean precipitation of each growing season was 21.0 mm (0.0–55.9 mm) and 11.0 mm (0.2–47.3 mm), respectively. The average temperature during the 2014 and 2015 seasons was 13.9 °C (3.9–22.7 °C) and 13.3 °C (4.0–19.3 °C), respectively (Fig. 1). The soil type was a sandy loam, pH_{KCl} 6.2, P_2O_5 290 mg kg^{-1}, K_2O 127.6 mg kg^{-1}, and organic matter 31 g kg^{-1}.

Experimental design

The growing seasons (2014 and 2015) started on 6 April and 8 April, respectively, when stable average air temperature was above +5 °C. At this stage, two local faba bean (*Vicia faba* L.) genotypes (‘VF_001’ and ‘VF_002’) were sown in full intercropping schemes with vegetable crops: (1) cabbage (*Brassica oleracea* var. capitata L.) ‘Jaguar’ F1, (2) carrot (*Daucus carrota* L.) ‘Nevis’ F1, and (3) onion (*Allium cepa* var. cepa L.) ‘Centurion’ F1. Carrot (seed) and onion (sets) crops were established on 5 May 2014 and 8 May 2015, respectively. Seedlings of cabbage were planted later, on 19 May, in both years.

Two control variants were established in the trial: C1 (no faba beans and vegetables cultivated without N fertilisation) and C2 (no faba beans and vegetables cultivated by applying mineral fertilisers at 70 g m^{-2} of $Ca(NO_3)_2$, twice during the growing period). No irrigation was applied.

In control treatments, onions and carrots were set on three-row beds on a plane surface (0.30 m between rows within beds, and 1.20 m between centres of beds) where carrots were sown at 0.03 m distance between plants in row, onion sets were planted 0.05 m apart in row, whilst cabbage was planted on a 0.60 × 0.50 m spacing. Onion density was 66 plants m^{-2}, carrot density was 100 plants m^{-2} and cabbage density was 3.3 plants m^{-2}.

Faba beans were interspersed between two vegetable rows in intercropping treatment by replacing the middle row of onion and carrot with beans (so reducing planting density to 44 and 66 plants m^{-2} for onion and carrot, correspondingly). In cabbage intercropping a row of beans was inserted between two rows of cabbage keeping the same cabbage density as in controls. Planting distance for faba beans in intercropped treatment was 0.14 m between plants within row (making the density 7 plants m^{-2}), within plots accounting for 10 m^2 size. The experiments were organised in a randomised complete block with four replications ($n = 4$).

In onion and carrot intercropped variants (except cabbage, which was grown in two rows in all treatments, intercropping and both controls), the yield of vegetable was analysed in two categories: (1) yield of harvested vegetable from the intercropped plot expressed in kg m^{-2}, and (2) yield recalculated as for a monocrop when vegetable plants were grown as the sole crop (in the above-mentioned control variants density) by multiplying the obtained yield from intercropped variants by 1.5, so ‘adding’ a potential yield of one missing row. This approach provides comparable yield results relative to control variants. Similarly, both yield categories (yield of harvested vegetable from the intercropped plot expressed in kg m^{-2} and yield recalculated as monocrop) were used for faba bean yield assessment. For faba bean, yield recalculation when the crop was grown as a monocrop (estimated yield) was calculated by doubling the yield obtained from intercropped plots since, in the case of a sole crop for faba bean, two rows instead of one would be grown (making the plant density 14 plants m^{-2}).

Cumulative vegetable yield was calculated for all treatments for both seasons (2014 and 2015), in order to obtain a more objective interpretation of the vegetable yield modifications obtained by applying intercropping with faba bean.[19]

Immature faba bean pods were harvested from half of each plot when ready to eat as fresh vegetables. The remaining half of the plot was harvested when seeds were mature (in September, both seasons). Mature bean seeds where weighed after drying and cleaning. Vegetables were harvested according to marketable maturity (onion, 18 and 24 August, and carrot and cabbage, 2 and 7 October, in the 2014 and 2015 seasons, respectively). Marketable and total yields, as well as the weight of 10 vegetables were measured from each plot.

Determination of the hydrothermal coefficient

For the description of the growing conditions, the hydrothermal coefficient (HTC) was assessed as the ratio between precipitation to 1/10 of the sum of active temperatures, indicating the balance between moisture and temperature during the vegetation period.[20] Thus, this parameter provides rational information on the correlation between the amount of precipitation in the period, when average day temperature exceeds +10 °C, and sum of temperature in degrees in the same period. The HTC was calculated by applying the formula described by Selyaninov:[22] $HTC = \sum x / \sum t \times 10$, where $\sum x$ is the sum of the precipitation and $\sum t$ is the sum of the temperatures in the period, when the temperature has been above 10 °C.[21–24]

Protein content determinations

Faba bean samples were analysed on protein content in the four replications ($n = 4$) using the procedure described by the

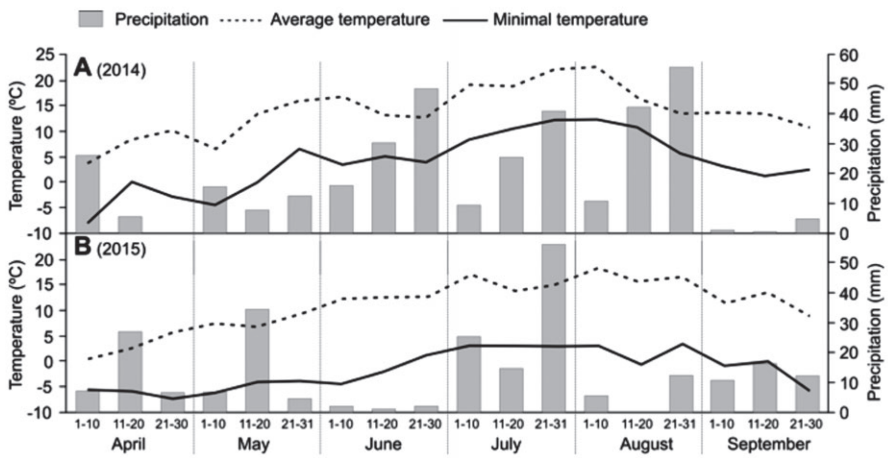

Figure 1. Meteorological data for the 2014 (A) and 2015 (B) growing season.

Association of Official Analytical Chemists (AOAC protocol #954.01; Kjeldahl's method),[25] and by near infrared spectroscopy by using an XDS Rapid Analyzer (FOSS, Hillerod, Denmark), where the average sample of all replications was analysed for each variant.[26]

Assessment of dehydrogenase activity in soils

During the growth period soil samples ($n = 4$) were collected every 14 days (10 times per season in each plot) to measure dehydrogenase activity (DHA), as an indicator of soil microbial activity and ecological changes in the soil,[21] as given by previously described methodology.[27] Briefly, soil samples (1 g) were exposed to 0.20 mL of $4\,g\,L^{-1}$ 2-*p*-iodophenyl-3-*p*-nitrophenyl-5-phenyltetrazolium chloride (INT) and 0.05 mL of $10\,g\,L^{-1}$ glucose solution in 1.00 mL of distilled water for at least 6 h at 28 °C, protected from light. The formed iodonitrotetrazolium formazan (INTF) was extracted by adding 10.00 mL of methanol and shaking for exactly 60 s. The formation of INTF was determined spectrophotometrically at a wavelength of 485 nm. The DHA activity ($\mu g\,g^{-1}\,h^{-1}$), as measured by the amount of INTF, was calculated according to the formula: DHA activity $= [(-3 \times {A_{485}}^2 + 4 \times A_{485}) \times 86\,400]/[(60 \times h) + m]$, where A_{485} is the spectrophotometer reading, h is the incubation time in full hours, and m is the incubation minutes over full hours.

Statistical analysis

Data shown are the mean values ($n = 4$). All data were subjected to analyses of variance (ANOVA) using STATISTICA (Dell Software, Round Rock, TX, USA) and the level of significance was set at $P < 0.05$.

RESULTS AND DISCUSSION

The intercrop trials performed in 2014 and 2015 provided relevant information on the influence of faba bean on the yield of vegetable crops and soil properties. Similar tendencies were observed for yield and quality parameters, independently of the season effect, which means a negligible impact of the agro-climatic conditions.

Influence of vegetable crops on faba bean yield in the full intercropping system

The evaluation of the influence of intercropping with onion, carrot, and cabbage of both 'VF_001' and 'VF_002' faba bean genotypes throughout two consecutive seasons (2014 and 2015) was done for immature pods and mature seeds yield. Concerning the yield of mature seeds, in 2014, differences between intercrop variants were not significant either between genotypes or between onion, carrot, or cabbage intercropping variants considered for each separate faba bean genotype. The intercropping assays developed with 'VF_001' provided yields of 0.09, 0.07 and 0.07 $kg\,m^{-2}$ of mature grain, on average, when intercropped with onion, carrot and cabbage, respectively (Table 1). On the other hand, for 'VF_002' mature grain yields of 0.08, 0.07 and 0.06 $kg\,m^{-2}$ were obtained, on average, for onion, carrot, and cabbage intercropping variants, respectively. When recalculated as monocrop, no significant differences were observed between the intercrop variants developed for each separate faba bean genotype. Thus, the average mature grains yields were 0.08 and 0.07 $kg\,m^{-2}$, on average, for 'VF_001' and 'VF_002', respectively (Table 1). In 2015, observations were similar to 2014 with no significant differences neither between faba bean genotypes ('VF_001' and 'VF_002') nor between vegetables intercropped (onion, carrot, and cabbage) regarding mature seeds yield.

The yields from the field trials developed in the present work were rather low in comparison with the average yield in the region, which ranges from 0.30 to 0.49 $kg\,m^{-2}$.[24,28,29] Such low yield is not a result of the cropping variants assayed, but due to the unfavourable and critical weather conditions – low precipitation events during the seed growth period – at the beginning of August for both seasons. Concerning the yield of immature pods in the 2014 season, in onion and carrot intercropping variants, 'VF_001' provided yields (0.56 and 0.30 $kg\,m^{-2}$, respectively) significantly higher than 'VF_002' (two-fold and three-fold, respectively). Concerning the cabbage variant no significantly different yield of immature pods between faba bean genotypes was found (Table 1). Unlike 2014, in 2015, in onion and carrot intercropping variants both bean genotypes displayed a similar performance, with a yield of 0.48 and 0.51 kg of immature pods m^{-2}, on average, respectively. However, in 2015 the cabbage intercropping variant developed with the genotype 'VF_002' presented almost two-fold higher yield than the genotype 'VF_001' (0.43 and 0.21 $kg\,m^{-2}$, respectively) (Table 1).

When recalculated as monocrop, in 2014, the immature pods yield ranged from 0.2 to 1.12 $kg\,m^{-2}$ (Table 1). In this season, the highest value corresponded to the faba bean genotype 'VF_001' in all intercropping alternatives, whilst the combination of this genotype with onion provided the best yield (1.12 $kg\,m^{-2}$, on average).

Table 1. Yield parameters (kg m^{-2}) and protein content (g kg^{-1} DM) for faba bean in the intercrop with onion, carrot, and cabbage under Latvian agro-ecological conditions in two consecutive seasons (2014 and 2015).

	Yield of immature pods		Yield of immature pods (calculated as monocrop)		Yield of mature grains		Yield of mature grains (calculated as monocrop)		Protein content in mature grains (faba bean) (g kg^{-1} DM)	
Intercrop	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
VF_1/onion	0.56b	0.46a	1.12	0.92	0.07a	0.10a	0.14	0.20	318	333
VF_2/onion	0.28a	0.50a	0.56	1.0	0.05a	0.10a	0.10	0.20	308	311
VF_1/carrot	0.30b	0.49a	0.60	0.99	0.05a	0.09a	0.10	0.19	303	336
VF_2/carrot	0.10a	0.52a	0.20	1.4	0.04a	0.09a	0.09	0.19	295	314
VF_1/cabbage	0.25a	0.21a	0.50	0.42	0.07a	0.07a	0.14	0.15	303	333
VF_2/cabbage	0.20a	0.43b	0.40	0.86	0.04a	0.08a	0.08	0.15	295	309
LSD ($p < 0.05$) (vegetables)	0.10	0.10								
LSD ($p < 0.05$) (beans)	0.08	0.08								
P-value (vegetables)	***	***	N.a.	N.a.	N.s.	N.s.	N.a.	N.a.	N.s.	N.s.
P-value (bean)	*	*	N.a.	N.a.	N.s.	N.s.	N.a.	N.a.	N.s.	N.s.

Values are mean (n = 4). Means in the same column followed by different lower-case letters are significantly different according to Tukey's multiple range test at $p < 0.05$. (*) and $p < 0.001$ (***). N.s. = Not significant differences. N.a. = not applicable.

The lowest immature pod yield corresponded to intercrop variant faba bean 'VF_002'/carrot (0.20 kg m^{-2}, on average) in 2014. The faba bean/cabbage variant provided an immature pods yield of 0.50 and 0.40 kg m^{-2}, on average, for the genotypes 'VF_001' and 'VF_002', respectively (Table 1). The statistical analysis of the immature pods production in cabbage intercrop variants showed no significant differences, whereas the faba bean genotype 'VF_001', in the onion and carrot variant, provided significantly higher values (1.12 and 0.60 kg m^{-2}, respectively) when recalculated as monocrop. The comparison of the three intercrop variants developed in the present work, revealed a higher immature pod yield in the onion/faba bean variant (1.12 kg m^{-2} if recalculated as monocrop), which gave almost two-fold higher values than in the carrot and cabbage intercropping (0.55 kg m^{-2}, on average).

The results of 2014 season were quite different from 2015; in this season, the faba bean genotype 'VF_002' presented a higher immature pods yield in all intercrops variants in comparison to 'VF_001', and also exhibited an increase relative to the data observed in 2014 in the three intercrop alternatives (with onion, carrot, and cabbage).

Overall the immature pods yields were a 25.8% (on average) lower than those reported in the literature, which are between 0.39 and 1.55 kg m^{-2}.[30,31] The differences between the two faba bean genotypes ('VF_001' and 'VF_002'), concerning the immature pods and mature seeds yield in 2014 and 2015, revealed that 'VF_001' is better adapted to the changing climatic conditions than 'VF_002', which must be taken into consideration when selecting the cultivar according to the agro-environmental conditions of the geographical area (northern Europe).

Influence of faba bean on vegetables yield in the full intercropping system

Regarding the influence of growing faba bean in intercropping with vegetables, on the performance of onion, carrot, and cabbage there was a significant influence in both the 2014 and 2015 seasons. Thus, the 2014 onion yield, when grown with both faba bean genotypes, was almost a half of the yield obtained in fertilised and unfertilised controls (0.89 kg m^{-2}, on average, in the onion crop grown with both faba bean genotypes, 1.79 kg m^{-2} in the fertilised control variant, and 2.08 kg m^{-2} in the unfertilised control variant) (Table 2). This is in agreement with previous works on intercrop variant where onion had the lowest negative influence on the faba bean yield, compared to wheat as neighbouring crop.[32] Even recalculated as monocrop, onion yield in both intercropped variants was significantly lower in comparison to both fertilised and unfertilised controls.

The carrot/faba bean intercrop variant was found as the best combination as it gave marketable yield of both faba bean and carrots according to standard productions. Carrot yield was significantly different between the variants set up with and without faba bean ($P = 0.007$). In addition, both 'VF_001' and 'VF_002' faba bean genotypes exerted different influences on carrot yield, the highest values being 1.69 and 2.28 kg m^{-2}, respectively (Table 2). Thus, in the intercropping variant with the genotype 'VF_002', carrot yield did not differ significantly from the control variant developed without N fertilisation (C1) (2.68 kg m^{-2}), whilst when recalculating carrot yield as monocrop, it was observed that the 'VF_002' intercropping variant provided even higher yield than the unfertilised control (3.01 kg m^{-2}).

Regarding the cabbage crop variants, in 2014, the highest cabbage yield (relative to marketable products) was obtained in the variant developed without N fertilisation (1.69 kg m^{-2}), which was very similar to that corresponding to the intercropping plots established with 'VF_001' (1.63 kg m^{-2}) (Table 2). In the control variant developed with the application of N fertilisation, the yield was almost negligible (0.34 kg m^{-2}) because of the weak development of cabbage heads. This might be due to the negative influence of a nitrogen fertilisers on the soil microbial community as well as on the nutrients availability imbalance.[33,34] Moreover, to some extent, the combined effect of the improper level of mineral nutrients with the lower precipitation events recorded during 2014 could have a negative influence on the formation of cabbage heads. During the 2015 season, the climate conditions were even more severe than in 2014, regarding precipitation deficiency during the vegetation period (Fig. 1) caused a critical injury to the most sensitive crops. Under such conditions, intercropping had a crucial impact causing a decrease of onion yield, which was found in the average value 0.75 kg m^{-2} recalculated as monocrop

Table 2. Yield parameters (kg m^{-2}) for vegetables in the intercrop trials performed at PHRC (Latvia) in 2014 and 2015.

Crops		Marketable yield of vegetables			Yield of vegetables (calculated as monocrop)		
Faba bean genotype	Vegetable	2014	2015	Cumulative	2014	2015	Cumulative
'VF_1'	Onion	1.09[a] ab	0.71 a	1.80	1.63	1.06	2.69
'VF_2'	Onion	0.66 a	0.79 a	1.45	0.99	1.03	2.02
-	C1 onion[Y]	2.08 b	1.15 ab	3.23	2.08*	1.15	3.23
-	C2 onion	1.79 b	1.16 b	2.95	1.79	1.16	2.95
LSD ($p < 0.05$)		1.07	0.44	N.a.	N.s.	N.s.	N.a.
'VF_1'	Carrot	1.69 a	1.75 a	3.44	2.52	2.63	5.15
'VF_2'	Carrot	2.28 ba	1.67 a	3.95	3.41	2.50	5.91
-	C1 carrot	2.68 b	3.01 a	5.69	2.68	3.01	5.69
-	C2 carrot	3.64 c	2.43 a	6.07	3.64	2.43	6.07
LSD ($p < 0.05$)		0.96	N.s.	N.a.	N.s.	N.s.	N.a.
VF_1/cabbage	Cabbage	1.63 cb	2.91 a	4.54	-	-	-
VF_2/cabbage	Cabbage	1.27 b	2.35 a	3.62	-	-	-
C1 cabbage	C1 cabbage	1.69 c	2.22 a	3.91	-	-	-
C2 cabbage	C2 cabbage	0.34 a	2.35 a	2.69	-	-	-
LSD ($p < 0.05$)		0.40	N.s.	N.a.	N.a.	N.a.	N.a.

[a] Values are mean (n = 4). Means in the same column followed by different lower-case letters are significantly different according to Tukey's multiple range test at $p < 0.05$. N.a. = Not available, N.s. = Not significnat. [Y] C1 = Unfertilized control, C2 = Fertilized control.
*For C1 and C2 yield is not recalculated, as it is already harvested from sole crop plot

in intercropping variants developed with faba bean, 1.15 kg m^{-2} under the unfertilised control variant (C1), and 1.16 kg m^{-2} in the fertilised control variant (C2).

Results from 2014 and 2015 clearly indicated that onion suffers detrimental effects when grown with faba beans in full intercrop. In our trial the negative effect of faba bean on the onion yield was further demonstrated by evaluating the cumulative yield of both years. In this sense, according to Mead and Willey, the influence of intercropping on plants' performance and yield is better expressed in long-term periods, when seasonal peculiarities are taken into consideration.[19] Hence, cumulative yield data confirmed results of separate years for onion suffering from faba bean intercropping. This fact could be due to the shallow root system characteristic of onions, which competes (with a disadvantage) with the dense root system of faba bean for water and nutrients. Since almost 65% of the faba bean root system is located at a depth of 0.15 m,[30] and its water demand is high,[9] the competing ability of faba bean is quite strong for onion.[35] The sensitiveness of onion to water deficiency has been already reported by Kalbartcyk *et al.*, under Polish agro-climatic conditions, which supports the relatively low yield of onions in faba bean intercropping.[36]

Carrot yield in the intercropped variants established in 2015 was 1.75 and 1.65 kg m^{-2} for 'VF_001' and 'VF_002', respectively, which is not under the average yield. Even if recalculated as monocrop, the yields (2.63 and 2.50 kg m^{-2}, respectively) are lower than the average carrot yield in the region (2.83 – 7.0 kg m^{-2}).[37] Also control (fertilised and unfertilised) variants provided lower yields relative to the regional records (3.01 and 2.43 kg m^{-2}, respectively), without significant difference between both variants ($P = 0.05$). In addition, significant differences were not found between controls and intercrop variants. Cumulative yield for 2 years also demonstrated a neutral influence of faba bean intercropping on the carrot yield. These results could be due to the similar vigour of the carrot and faba bean root systems and the similar root growth rate described in both species during the vegetation period, which might ensure equal competition ability for water and nutrients.[35] Furthermore, as faba bean nodules decomposition starts at the second half of summer, when rhizodeposition of nitrogen occurs, carrot plants can take up and use this mineral nutrient for yield production.[38] Thus, faba bean/carrot intercropping contributes to a sustainable agricultural management, supporting carrot and faba bean yield simultaneously from the same area, diversifying the agricultural production, ensuring an extra income, and improving soil properties.[39]

Regarding intercropping with cabbage, it should be noted that this is a leafy vegetable featured by a similar root system (in terms of vigour and depth) as carrots.[35] However, cabbage is featured by a higher nutrients demand during the whole vegetation period. In 2015, cabbage yield was higher than in 2014, whilst again, no significantly different yields were found between intercrop variants with faba bean relative to fertilised and unfertilised controls. A very low marketable yield was noticed in both years in comparison with the average yield in the region (6.33 – 7.06 kg m^{-2}).[40] Taking into account that cabbage yield was quite different between both trial years, cumulative yield was expected to shed some light on the influence of faba bean intercrop on the cabbage yield. This parameter certainly contributed to state the positive influence of intercropping on the cabbage yield in the 2-year period under consideration. Thus, even though the results obtained indicated that faba bean crop has neutral or positive influence on cabbage yield, further investigations on cabbage/faba bean intercropping are required to demonstrate the efficiency of this variant.

Influence of the full intercropping on the protein content in the faba bean grains

Regarding protein content in the faba bean seeds, in 2014 and 2015, a significant influence of the faba bean genotype and growing conditions (influenced by the particular climatic features

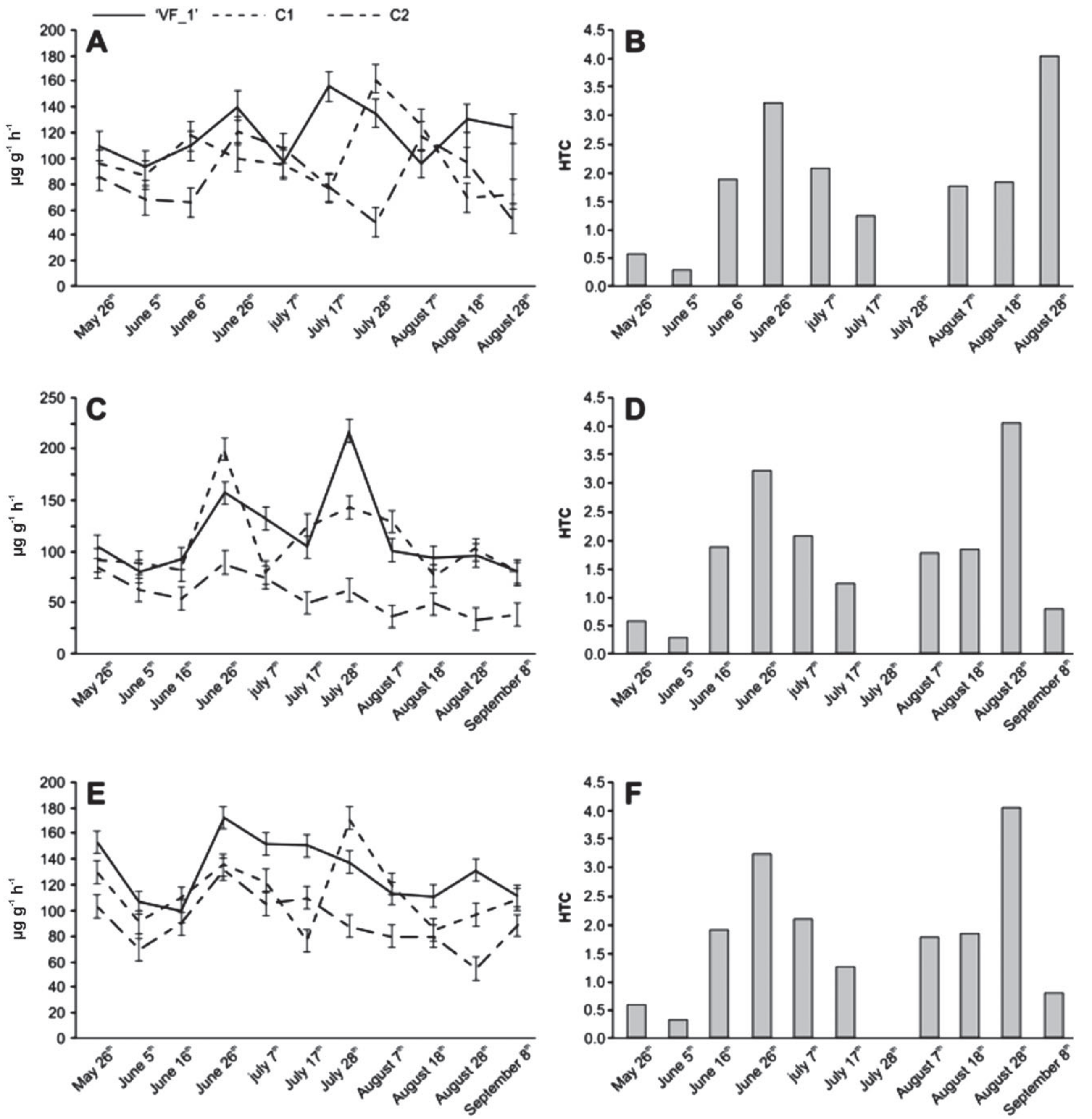

Figure 2. Dehydrogenase activity (DHA) in soil and hydrothermal coefficient (HTC) in onion/faba bean (A and B), carrot/faba bean (C and D), and cabbage/faba bean (E and F) intercrops developed in 2014.

of each season) was found, whilst the intercrop variant remained a less relevant factor with no significant influence.[24]

In 2014, the genotype 'VF_001' presented the highest protein content with an average value of 308 g kg^{-1}, without significant differences between intercropping variants ($P > 0.05$) (Table 1), whilst the genotype 'VF_002' had a slightly lower protein content (299 g kg^{-1}, on average, for all variants). On the other hand, in the year 2015, the genotype 'VF_001' had 334 g kg^{-1}, on average, in all intercropping variants, with slightly (no significant) differences between variants (333–336 g kg^{-1}). In 2015, a feature of the genotype 'VF_002' was a lower protein content relative to 'VF_001' (309 g kg^{-1}). It was shown that the protein content in faba bean is not significantly influenced by the neighbouring vegetable crop, whereas this is determined by the genotype and particular climatic conditions. Similar observations have been mentioned also by Lizarazo *et al.*, who reported average protein concentrations ranging from 280 to 370 g kg^{-1}, which highlights that the faba bean genotype and the climatic conditions are the most relevant factors influencing the protein content in this legume.[24,41]

Influence of faba bean intercropping on soil biological activity

Apart from the evaluation of yield and quality parameters, results on the biological activity in soil, monitored by assessing DHA, showed higher values in intercropping and control variants without N fertilisers for all crops (Fig. 2 and Fig. 3). The values on DHA

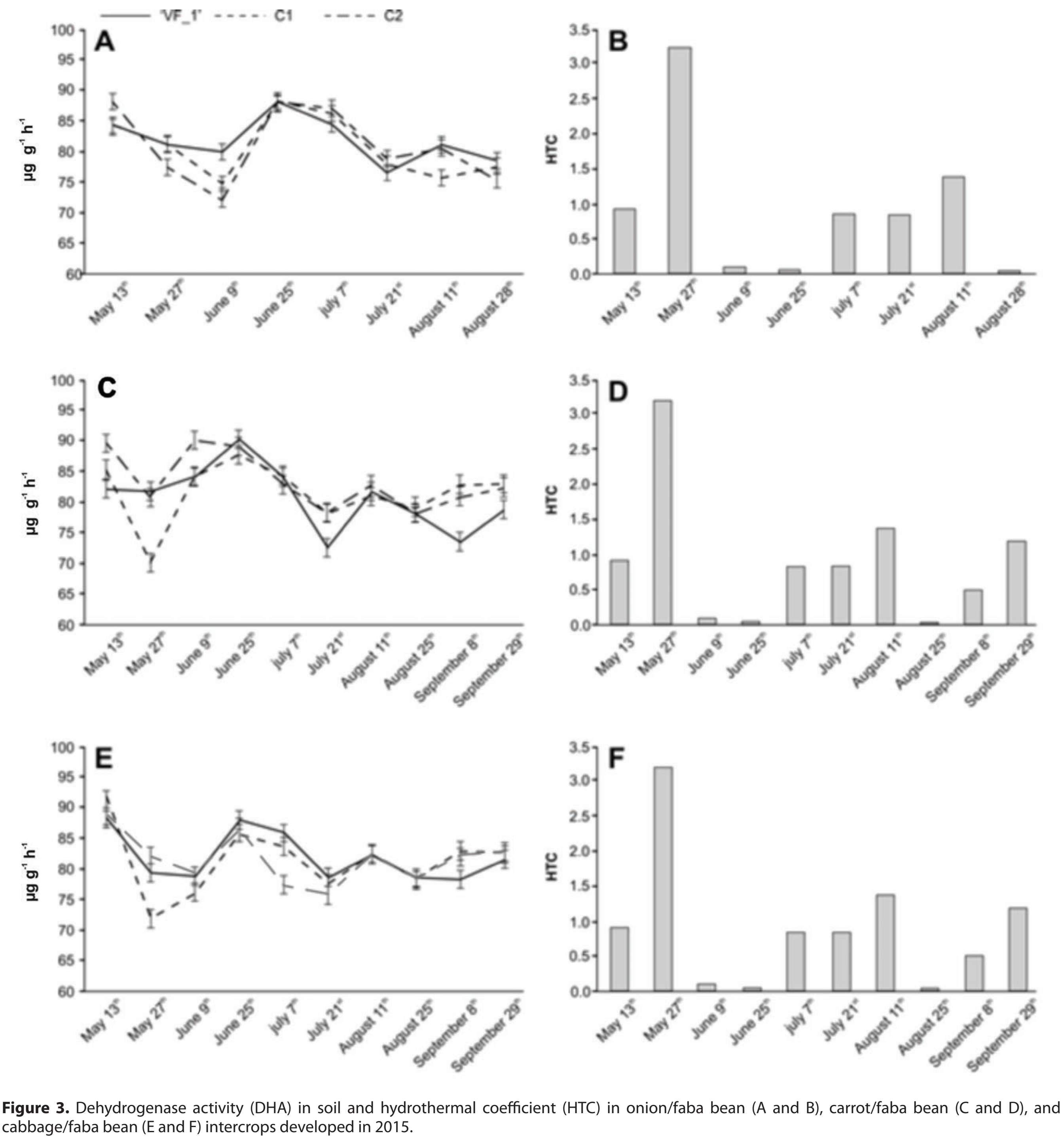

Figure 3. Dehydrogenase activity (DHA) in soil and hydrothermal coefficient (HTC) in onion/faba bean (A and B), carrot/faba bean (C and D), and cabbage/faba bean (E and F) intercrops developed in 2015.

were in agreement with the findings reported in the literature on the negative influence of mineral N fertilisers on the soil microorganisms and ecology.[31,32] Hence, in 2014, the assessment of DHA informed on significantly higher values in the plots with faba bean intercropping (121 $\mu L\,L^{-1}\,h^{-1}$, on average) relative to fertilised and unfertilised variants (77 and 107 $\mu L\,L^{-1}\,h^{-1}$, on average, respectively) ($P < 0.05$). In 2015, DHA did not fluctuate significantly with respect to 2014 results. Thus, as a general trend, a weak (no significant) increase of the DHA activity was observed in the faba bean intercrop variant (by 1.0–2.0%, depending on vegetable crop). This change could be a consequence of the climatic influence on DHA, which was supported by the evaluation of the DHA dynamics during the vegetation period in relation to hydrothermal coefficient (HTC), calculated for the period between soil sampling dates (Fig. 2 and Fig. 3).

The differences between DHA activities in both growing seasons showed that the biological processes occurring in the soils are closely related to temperature and moisture, which are very sensitively influenced by climate conditions during the vegetation period, as well as by soil properties. So, the vegetation period of 2015 was characterised by critical lack of precipitation, having only 58.0% from the rainfall recorded in 2014 and 70.0% from long-term precipitation data. This influenced negatively soil moisture conditions, causing severe competition between plants and microorganisms, and the subsequent decrease of the DHA values. These findings are supported by Kumar *et al.*, who have indicated the significance of soil moisture, temperature, aeration, and mineral content on the DHA activity.[27] Further, more detailed long-term investigations on DHA in vegetable/faba bean intercropping are needed in order to gain a further understanding on the influence of different cropping systems on the soil biological activity.

CONCLUSIONS

From the overall results obtained through the two consecutive seasons (2014 and 2015) concerning immature pods and mature bean yield and on faba bean crops interactions with vegetables (onion, carrot, and cabbage), it was concluded that carrot and onion are the best neighbouring horticultural crops for the immature bean pods harvest in the full intercropping system. However, not all intercrop variants can be encouraged regarding both legume and vegetable productions. In this regard, it is necessary to stress that, although faba bean/onion variant appeared as the best option concerning faba bean yield, this is not recommended concerning onion production due to the competition for moisture and nutrients, especially under unfavourable conditions (high temperature and low precipitation). On the other hand, the results obtained on the other combination highlighted faba bean/carrot as a promising intercrop variant, which leads to us to describe both cultures as equal competitors that share available soil resources.

Concerning the positive influence of faba bean on soil features, and its contribution to reducing the application of nitrogen fertilisers, full intercropping constitutes an interesting approach that merits further implementation. Thus, cabbage efficiently uses available nitrogen in the soil, which is released by decomposition of faba bean nodules and plant residues and, hence, this full intercrop variant exerts a positive influence on cabbage yield, although this fact needs to be further explored to gain a full understanding.

Apart from the effect of intercrop on faba bean and vegetable yield, the contribution to the protein content of faba bean seeds seems not to be significantly influenced by the neighbouring vegetable, whilst this seems to be more critically determined by genotype and growing conditions.

Soil biological activity does not have a steady trend through the growing season, being closely related to environmental factors and, to a lesser extent, with plant growth habit. Nonetheless, faba bean has a positive influence on biological activity of soil.

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