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The Complex Effect of Different Tillage Systems on Faba Bean Agrocenosis

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Abstract: Interactions of different factors in differently tilled faba bean agrosystem is still insufficiently studied and evaluated. For these reasons we studied the results of long-term field experiment, which was carried out in the Research Station of Vytautas Magnus University, Agriculture Academy (Lithuania). The aim of this study is comprehensively evaluating the effect of the deep and shallow ploughing, deep cultivation-chiseling, shallow cultivation-disking, and no-tillage systems for faba bean cultivation on the much-interacted factors, relations between them and strength of impact by the integrated evaluation method using complex evaluation index (CEI). Calculations showed that the influence of the no-tillage system was the greatest on the faba bean agrosystem than other system used. Shallow cultivation was more efficient than deep and shallow ploughing and deep cultivation systems. In the deep ploughing system, there were calculated more minimal, i.e., close to 1 as the CEI value, which showed DP ineffectiveness.

Keywords: *Vicia* faba; tillage systems; complex evaluation; CEI

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1. Introduction

Faba bean is a valuable protein crop used for human food and animal fodder; they are also an important crop rotation plant [1]. Growing faba beans, the soil does not lose fertility because the amount of nitrogen in the soil increases. These crops also protect against the spread of pests, diseases and weeds [2].

Lithuania is a favorable country for growing faba beans [3]. According to the Statistics Lithuania [4], Lithuania in 2021 was the tenth in the world in terms of the amount of faba beans received because faba beans are more tolerant of low temperatures during germination and vegetation than other legumes [5]. Today the area of faba bean cultivated in Europe ranks second in terms of popularity. The EU greening program calls for increasing the biodiversity of farms in Europe. For this reason, since 2015 more and more legumes are grown [4]. The most important agronomic feature of faba beans – to form a symbiosis with *Rhizobium* bacteria in the soil [6]. Crops also increase the yield and/or protein content of the crops sown after them, because part of the nitrogen obtained during symbiosis is not used, it enters the soil with plant residues [7]. It is considered that faba beans leave about 45 kg ha^{-1} of nitrogen in Lithuanian soils.

It is proven that crops suffer from excessive density and looseness of the soil [8]. Therefore, tillage and its intensity affect soil properties such as: physical, chemical and mechanical. Also, the development of faba bean cultivation, production and quality depends on different tillage [9]. Tillage intensity (from deep plowing) can be reduced by methods such as shallow tillage, strip tillage or direct seeding [10]. Results showed that deep plowing has been found to increase the number of microorganisms in the soil, then shallow plowing up to 10 cm. Deep plowing creates a regime of air, water and nutrition in thicker soil layers that is favorable for plants and is maintained longer during drought. Deeply plowed soils have fewer weeds, plant roots can penetrate deeper, better air aeration [11]. Conservation tillage creates a soil environment that is suitable for growing crops, leaving plant

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residues, and reducing tillage intensity [12]. No tillage system reduces environmental pollution, wind and water erosion, consumes less energy than the simplest method of tillage, and monitors sustainable development [13,14].

Lithuanian and foreign scientists do not have an exact and comprehensive answer to the question of how faba bean cultivation can be affected by different tillage methods because sustainable farming depends on many indicators. Indicators that determine the impact of tillage on faba beans should be combined into an evaluation system, but it is very difficult to decide which indicator has a greater influence on physical, biological, productivity and weediness in faba bean cultivation, and which indicator has a lower impact. This problem would be solved by a complex evaluation system.

The aim of this study is comprehensively evaluating the effect of different tillage systems for faba bean cultivation on the much-interacted factors, relations between them and strength of impact.

2. Materials and Methods

2.1. Site Description

A stationary field experiment has been performed since 1988 at the Experimental Station (54º52′ N, 23º49′ E) of Vytautas Magnus University, Lithuania. Data from 2016–2018 was taken. The soil at the experimental site is a silty loam (45.6% sand, 41.7% silt, 12.7% clay) Planosol (*Endohypogleyic-Eutric – Ple-gln-w*). The pH_{KCL} of the soil was 6.4–7.7, the amount of available phosphorus varied from 194 to 384 mg kg^{-1} and potassium – from 85 to 206 mg kg^{-1}. The elements variation depended on the long-term (since 1988) soil tillage practices.

Lithuania is in the zone of surplus moisture content, 600–650 mm per year or 350 mm per vegetative period. The vegetative period lasts about 150–180 days. In 2016 vegetative season, air temperature was like the long-term average (long-term data since 1974) but in June-September was more humid than long-term conditions (Tables 1 and 2). 2017 season was colder with average humidity, and 2018 was warmer and much arid.

Table 1. The average air temperature (° C) during faba bean vegetative period. Kaunas Meteorological Station.

Month/Year	2016	2017	2018	Long-Term Average
April	7.4	5.6	10.2	6.9
May	15.7	12.9	17.2	13.2
June	17.2	15.4	17.5	16.1
July	17.9	16.8	20.1	18.7
August	16.9	17.5	19.2	17.3
September	-	13.4	-	12.6

Table 2. Precipitation rate (mm) during faba bean vegetative period. Kaunas Meteorological Station.

Month/Year	2016	2017	2018	Long-Term Average
April	41.2	73.7	64.8	41.3
May	36.4	10.2	17.6	61.7
June	83.9	80.2	57.6	76.9
July	162.9	79.6	137.5	96.6
August	114.9	55.0	66.2	88.9
September	-	87.1	-	60.0

2.2. Experimental Design and Agricultural Practice

Five primary tillage systems were investigated: 1. Deep mouldboard ploughing (DP, as control treatment); 2. Shallow mouldboard ploughing (SP); 3. Deep cultivation-chiselling (DC); 4. Shallow cultivation-disking (SC); 5. No-tillage (direct sowing) (NT) (Table 3).

Table 3. Description of tillage practice (according to Romaneckas et al. [15]).

Tillage system	Stubble tillage	Primary tillage	Implement	Depth of tillage cm	Pre-crop residue cover %
Deep ploughing	Yes	Inversion	Mouldboard plough	22–25	0–3
Shallow ploughing	Yes	Inversion	Mouldboard plough	12–15	2–4
Deep cultivation	Yes	Non-inversion	Chisel cultivator	25–30	40–51
Shallow cultivation	Yes, twice	Non-inversion	Disc harrow	10–12	40–50
No-tillage	No	No	None	0	47–87

The pre-crop of faba bean was winter wheat. The experiment was arranged with four replications for each tillage treatment, and a randomized complete block design (RCBD) was used. The total number of plots was 20. The *brutto* size of plot was 14x9 m, *netto* was 70 m^2 (10 x 7 m).

After pre-crop winter wheat harvesting, experimental plots (except NT) were tilled with a Väderstad Carrier 300-disc harrow (Väderstad AB, Väderstad, Sweden). Soil was ploughed with plough Gamega PP-3–43 (Gamega Ltd., Garliava, Lithuania). The soil was chiseled with the KRG-3.6 (Gamega Ltd., Garliava, Lithuania) ridge cultivator. SC plots were additionally disked with a Väderstad Carrier 300 disk harrow. In spring, faba bean seedbed was done with a Laumetris KLG-3.6 cultivator (Laumetris Ltd., Keleriškės village, Kėdainiai reg., Lithuania) (except NT). Faba bean was sowed with Väderstad Rapid 300C Super XL sowing machine and fertilised locally (complex fertilizer 7:16:32, 300 kg ha^{-1}). The sowing rate was 200–220 kg of seed per ha (40–45 seeds per m^2). Sowing depth was 5–6 cm, distance between the rows was 25 cm. Variety "Fuego" was sown (Norddeutsche Pflanzenzucht Hans–Georg Lembke KG, Germany). Pests (aphids) and diseases (*Botrytis cinerea*, B. *fabae*) were chemically controlled at the beginning of crop flowering (BBCH 60–63), weeds – just after sowing once.

2.3. Methods and Analysis

2.3.1. Soil Structure and Its Stability

The samples were taken using a shovel before spring tillage and after bean harvest from at least five spots per plot. The analyzed layers were 0–15 and 15–25 cm. Sample means were drawn. A Retsch sieving machine (Retsch Lab Equipment, VERDER Group, The Netherlands) and a set of sieves were used to determine soil structure. It is arranged according to the mesh size as follows: 10.0 mm, 7.1 mm, 5.6 mm, 4.0 mm, 2.0 mm, 1.0 mm, 0.5 mm, and 0.25 mm [15,16].

Soil agrochemical properties. Soil chemical composition was determined by sampling in at least 10–15 spots per experimental plot. A sample mean was drawn, and laboratory analyses were used to determine the levels of the main macronutrients (N, P, K, Mg) and soil pH. Methods of analysis: pH_{KCl} – ISO 10390 (potentiometry); available phosphorus (P) and potassium (K) – AL method (P – spectrometry, K – atomic emission spectrometry); available magnesium (Mg) – LVP D–13:2016, 2nd edition; and N_{total} – ISO 11261 (Kjeldahl). The analyses were carried out at the certified Agrochemical Research Laboratory of the Lithuanian Research Centre for Agriculture and Forestry in Kaunas [17].

Covering soil with crop residues. Distribution of the residues of previous winter wheat crop on the soil surface before and after sowing was determined by visual inspection. The visual method used a 10 m long metal tape, which was stretched perpendicular to the sowing direction at two points diagonally across the sowing rows in each plot. The points of contact with plant residues were set at 10 cm intervals (100 spots). A total of 200 points per plot or 4000 spots per experiment [15,17].

CO_2 concentration and emissions. The flux and concentration of CO_2 emissions above the soil surface was determined by the closed–chamber method using a portable infrared analyzer LiCor–6400. The IRGA technique was used. A portable soil respirator system LI–8100A with camera 8100–103 was used. A 20 cm diameter ring was hammered into each experimental plot in spring and 3 measurements were taken. The measurements were taken 3 times: at the beginning, in the middle and at the end of the plant growing season [17].

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Soil temperature, moisture content. Performed at least 5 locations in each experimental plot. The basis of the HH2 Moisture Meter (Delta-T-Devices) is used - WET sensor. The WET sensor directly measures soil moisture and temperature. It is used for accurate soil and artificial substrate testing up to 10 cm deep.

Soil enzymatic activity. The samples were taken annually after the bean harvest, together with soil structure samples, and were dried in the laboratory at 20–22 °C. The analyzed layer was 0–15 cm deep. The activity of soil enzyme saccharase was analyzed according to Hofmann and Seegerer [18] method modified by A. I. Chunderova [15,19].

Numbers and mass of earthworms. Determined after bean harvest. Earthworm abundance was determined at three spots in the 0.25 m^2 experimental plot. The study is based on the use of formalin solution. A 0.5 x 0.5 m metal frame was driven into the ground and used for studying. A 0.55% formalin solution (at least 10 l) was prepared and poured onto the soil area separated by the frame. After absorption of the solution, earthworms appearing on the soil surface were collected, counted and weighed [15].

Crop germination and density. At the beginning of growth, 10 spots of the experimental plot in a 1 m continuous row were assessed on day 3 and day 10 from the start of germination. At the end of the growing season, crop density was evaluated by determining the productivity of bean agrocenosis [20].

Photosynthetically active radiation (PAR). Determined at the beginning of bean flowering (BBCH 60–63). Photosynthetically active radiation (PAR) was measured with a radiometer HD 9021 RAD/PAR (PAR E m^{-2}, 400–700 nm wavelength). PAR was measured at different crop layers: on the soil surface, at $^1/_2$ bean crop height and above the crop (background). The measurements were taken from at least 5 spots in the experimental plot. The indicator is expressed as a percentage of the background irradiation [20].

Indicators of crop development. Determined at the beginning of bean flowering (BBCH 60–63). 10 bean plants were cut in each experimental plot for the study. The height of each plant was measured and weighed to determine its green biomass. The biomass samples were dried in a thermostat at 105 °C to constant weight. The dry biomass of the plants was thus determined. The assimilation area of bean leaves (cm^2) was measured with a leaf area measuring device Win Dias (Delta–T Devices Ltd., UK). The leaf chlorophyll index was also measured with a chlorophyll content meter CCM–200 plus (OPTI–SCIENCES) [21].

Crop weediness. It was determined by assessing the weed species composition, the number of weeds at the beginning and at the end of the growing season and the dry matter at the end of the bean growing season. The crop weediness was determined in at least 10 spots of the experimental plot within the 0.06 m^2 area. Weed seedlings (pcs m^{-2}) were counted at the beginning of the growing season and the number of weeds (pcs m^{-2}) and dry matter (g m^{-2}) were determined at the end of the growing season. The weeds were uprooted, dried to air–dry weight, and a botanical analysis of the species composition was carried out [16,22].

Crop biometric, productivity and quality parameters. The samples for these parameters were taken from at least five spots in the experimental plot, in a longitudinal row of 0.5 m. A sample mean was drawn. A total of 20 samples were to be analyzed. The average height of the faba bean plant, the green and dry biomass of the sample, the average crop density, number of pods per plant, the bean seed yield (at 15 % moisture content), the 1000–seed weight and the average number of seeds per pod were determined. The protein content of faba bean seeds was determined at the Agrochemical Research Laboratory of LRCAF Method Directive 72/199/EEC [15,16].

2.3.2. Statistical Analysis

Correlation and regression analyses of the data were carried out using STAT and SIGMA PLOT.

A comprehensive evaluation of the faba bean agroecosystem was carried out based on the methodologies of G. Lohmann [23] and K. U. Heyland [24]. The following studies and mathematical calculations were carried out: 1) the values of the different indicators were determined; 2) calculate the values of the various indicators expressed in different units of measurement to convert the values into a single scale. A score of 1 corresponds to the worst or minimum value, and 9 – to the best or optimum value. For all other values of the same indicator, the scores are calculated according to the following formula:

$$VB_i=(X_i-X_{min}) \times (X_{max}-X_{min})^{-1}\times 8+1 \quad \text{(Formula 1)}$$

where: VB_i is the score for a value of a given indicator, X_i is the expression for a given value, X_{max} is the maximum value for a given indicator, X_{min} is the minimum value for a given indicator; (3) the indicators converted to scores are shown in grid diagrams with a radius from 1 to 9; (4) the scale also shows the average value of the individual indicators – the score threshold – which is equal to 5 points, and which distinguishes between the high and the low scores. The effectiveness of the measure will be indicated by the area bounded by the scores of all its indicators; 5) the calculation of the complex evaluation index (CEI), which consists of the average of the evaluation scores, the standard deviation of the evaluation scores and the standard deviation of the average of the evaluation scores below the evaluation threshold [25].

3. Results and Discussion

The correlational regression analysis revealed the most important (endogenous) factors in differently tilled faba bean cultivation: soil structural stability, CO_2 emission, faba bean crop density at the beginning of vegetative season, faba bean canopy fresh biomass, yield of faba bean seeds, weed density and air-dried biomass. In the study, we conducted an integrated assessment of the impact on them, we conducted an integrated assessment based on them.

3.1. Soil Aggregate Stability to Water

Soil performs several functions at the same time, and soil-forming factors, physical, chemical and biological properties of soil determine the degree of functionality of each function [26,27]. Long-term intensive ploughing reduces soil aggregate stability [28], increases soil bulk density [29,30] and deteriorates soil biological properties [31,32].

It is very difficult to decide which indicator has a greater impact on the crop agroecosystem, and which one has a lesser impact. Therefore, a comprehensive assessment of soil quality is needed to describe the soil's ability to function by integrating soil chemical, physical and bio-logical components, which are highly sensitive to the management decisions of land users [33].

In our experiment, the stability of the structure of the surface layer of the soil, both at the beginning and at the end of the vegetative season, was mostly determined by the differences in the amount of precrop (winter wheat) residues before tillage in spring (r = 0.897 and 0.906; $p<0.05$). A relationship between earthworm biomass (r = 0.902; $p<0.05$) and structure stability was also established [15]. Other indices included in Figure 1 had less influence.

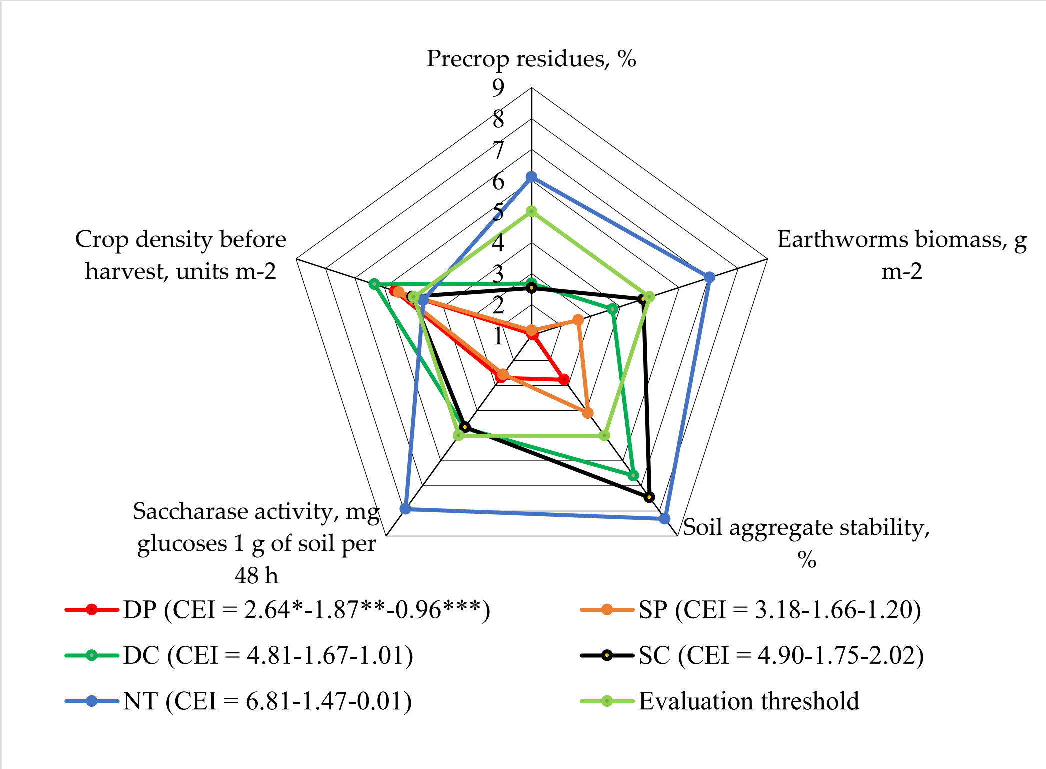

Figure 1. Complex assessment of the impact of tillage systems in the case of soil aggregate stability, 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the EP below the evaluation threshold.

In 2016-2018, when assessing the stability of the soil structure in the 0-15 cm soil layer, the deep tillage (DP), shallow tillage (SC) and direct seeding (NT) systems were superior to others, their results rose above the 5-point evaluation threshold (Figure 1). The same results were found by Sinkevičius [34]. He states that the highest score for soil aggregates stability was found in the no-till and no-catch crop technology. In our experiment, the no-tillage system had an influence on the precrop cover, earthworm biomass and saccharase activity scores to rise more than the evaluation limit (5 points). Crop density scores below the assessment threshold were determined using the NT system.

The calculated complex evaluation indicators (CEI), consisting of the average of all evaluation scores (EP), standard deviation and EP not exceeding the evaluation limit, standard deviation, and areas limited by evaluation scores. That shows that direct sowing (NT) in the faba bean cultivation has a positive impact on the agroecosystem, and there is greater than other tillage systems.

3.2. CO_2 Emission

Another important endogenous factor acting in faba bean cultivation was CO_2 gas emission. As much as 57% of all greenhouse gases are attributed to CO_2. About 20% of the total amount of CO_2 is released into the atmosphere by soils, so soils have a considerable influence on the CO_2 emission balance [35]. Currently in the world 12-15%, or 5.1-6.1 Gt $CO_{2\text{-eq.}}$ m^{-1} of greenhouse gases is generated in agriculture (9% in the EU).

In our experiment, it was found that the CO_2 emission in faba bean cultivation mostly varied during the June-August and was more correlated with soil temperature ($r = 0.8$; $p>0.05$) and soil moisture content ($r = 0.6$; $p>0.05$) [17].

When evaluating the release of CO_2 emissions from the soil in different applied tillage systems, it was found that only NT was rated lower than 5 points (Fig. 2). The highest evaluation score was

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determined in the DP. Rudinckienė [25] claims that CO_2 emission scores from the soil, when growing multifunctional crops and applying different technologies, were determined to be higher than the assessment limit. In our experiment, for soil temperature (0-15 cm soil layer) and precrop residues cover, the evaluation scores rose above the evaluation threshold only in NT system. For all tillage technologies, after determining the soil moisture (0-15 cm in the soil layer, in the middle of the vegetation), the evaluation scores were evenly distributed. All assessment scores are set above the assessment threshold. After determining the photosynthetic active radiation (PAR) on the soil surface, the scores for the application of all tillage systems were found to be lower than the evaluation limit. In the upper (0-15 cm) soil layer, total nitrogen assessment scores rose above the assessment limit only with SP, SC and NT systems.

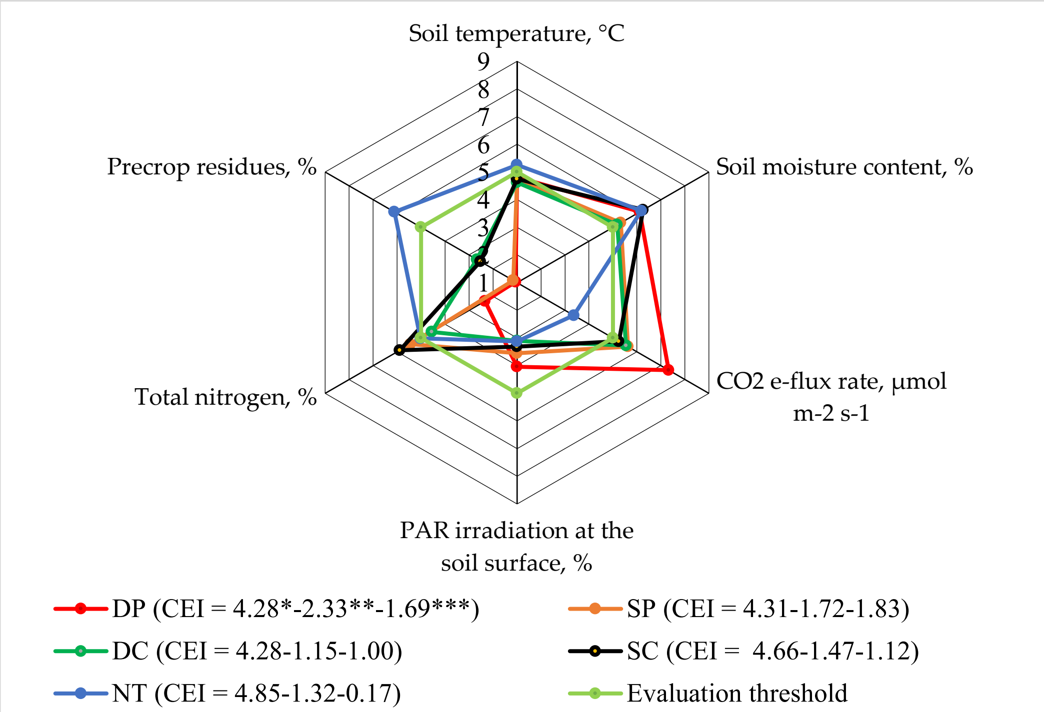

Figure 2. Complex assessment of the impact of tillage systems in the case of CO_2 respiration from the soil, 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

The calculated indicators of the complex evaluation and the areas limited by the evaluation points showed that the impact of the direct seeding (NT) technology on the agroecosystem was the highest compared to the other technologies used.

3.3. Faba Bean Crop Density at the Beginning of Vegetative Season

Tillage is the most common agricultural practice that creates a suitable environment for seed germination by promoting soil warming and water evaporation [36] and controlling weed infestation.

The correlation-regression analysis showed that the faba bean crop density at the beginning of the growing season is one of the endogenous factors depending on the faba bean agrocenosis. We performed an integrated evaluation to find out the interactions between faba bean crop density at the beginning of the growing season and other research factors. The density of the bean crop was calculated on the 10th day from the beginning of faba bean germination (Figure 3). The density of the crop largely depended on the amount of precrop residues on the soil surface. This influence was

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particularly significant in 2017 not only at the beginning of faba bean vegetative period (r = -0.819, *p*>0.05), but also during harvesting (r = -0.824, *p*>0.05) [20].

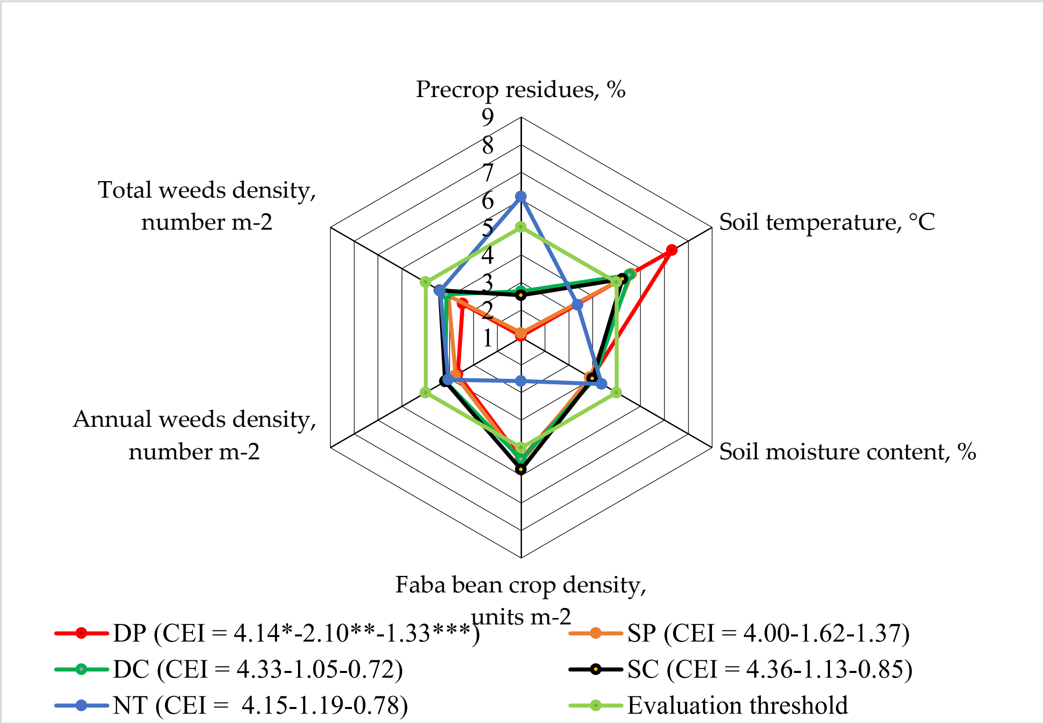

Figure 3. Complex assessment of the impact of tillage systems in the case of faba bean crop density, 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

Faba bean crop density and soil temperature (at the beginning of vegetation in the 0-15 cm soil layer scores lower than the evaluation limit were determined only when applying direct sowing (NT) (Figure 3). When evaluating soil moisture in the 0-15 cm soil layer at the beginning of vegetation, the number of annual and the total weeds at the beginning of vegetation the evaluation scores did not increase more than the evaluation limit when applying different tillage systems. The highest score of precrop cover after sowing was determined by applying NT system.

The calculated indicators of the complex evaluation and the areas limited by the evaluation scores showed that the impact of NT on the agroecosystem was the greatest.

3.4. Faba Bean Canopy Fresh Biomass

Among the different soil tillage methods, the average fresh biomass of the faba bean canopy was mostly not significantly different, so the evaluation scores of all applied different systems did not reach the evaluation limit when studying the fresh biomass of the crop, crop height, leaf chlorophyll index and photosynthetically active radiation (PAR) on the soil surface (Figure 4). Only NT did not increase faba bean crop density at the beginning of vegetative period above the evaluation limit (5 points) scores. The scores of leaf assimilation area above the evaluation limit rose the highest with NT (Figure 4).

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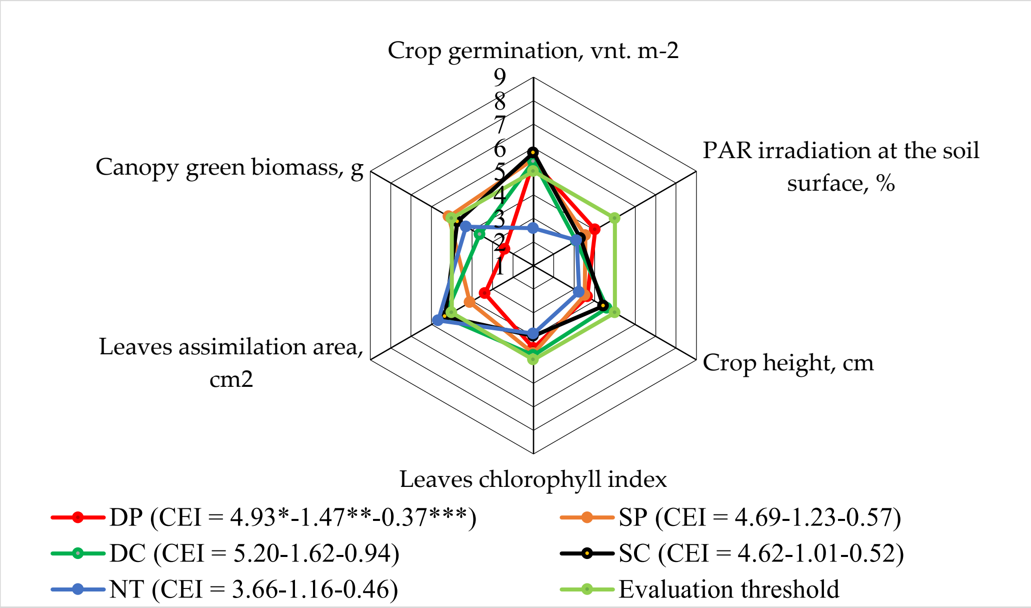

Figure 4. Complex assessment of the impact of tillage systems in the case of faba bean canopy fresh biomass, 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

The evaluation scores of various indices were calculated, their limited area and the integrated evaluation indices (CEI) were determined, consisting of the average of all EP, standard deviation and EP that do not exceed the evaluation limit and standard deviation. This shows that different tillage systems did not differ among themselves in terms of efficiency.

3.5. Yield of Faba Bean Seeds

The yield of faba bean seeds depended more on the meteorological conditions of the vegetative season than on the applied tillage systems. Seed productivity was also influenced by crop density (r_{2016} = 0.946*; p<0.05), the number of pods per square meter (r_{2016} = 0.950; p<0.05), as well as the assimilation area of faba bean plant leaves (r_{2017} = 0.887, p<0.05), plant height (r_{2017} = 0.712; p>0.05) and mass of 1000 seeds (r_{2018} = 0.916; p<0.05) [3;5].

When evaluating the yield of seeds, the evaluation scores did not reach the limit in the SP plots (Figure 5). The pre-harvest crop density score was found to be the lowest in the NT. The evaluation scores of all applied different systems were determined to be higher than the evaluation limit, when examining the assimilation area of crop leaves. After analyzing the air-dried biomass of perennial weeds at the end of the growing season and the number of faba bean pods, plant height, it was found that the scores did not rise above the assessment limit when applying all the studied tillage systems.

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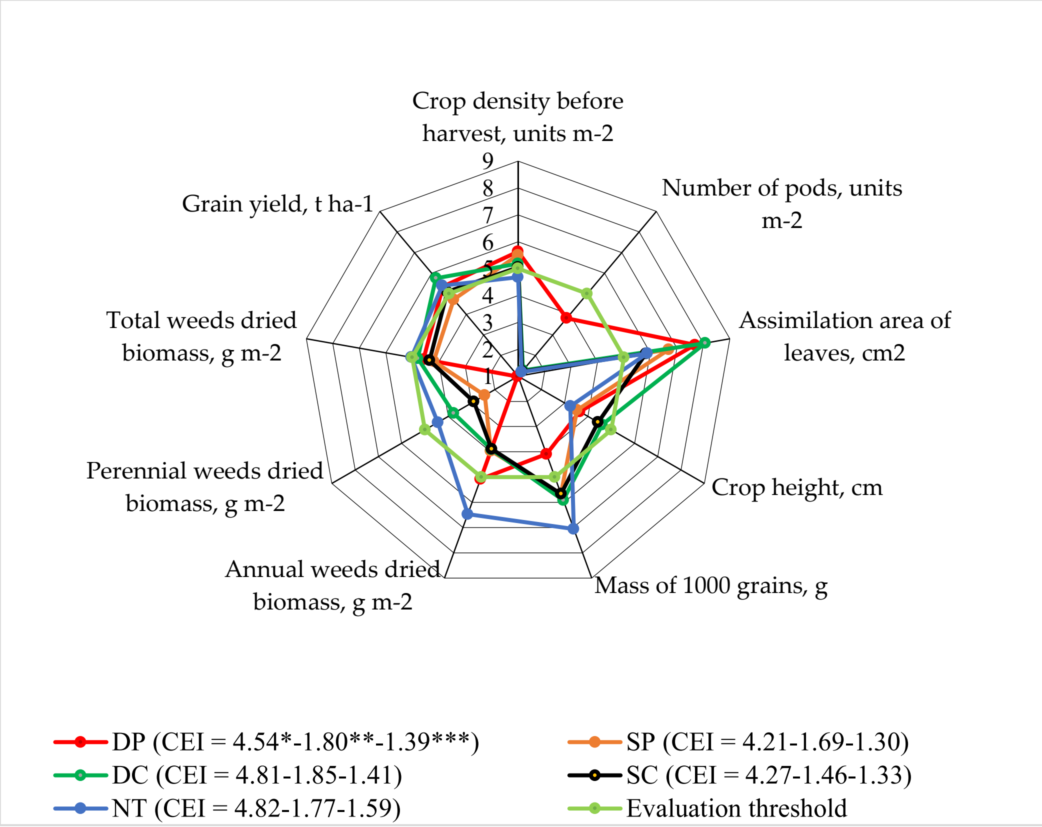

Figure 5. Complex assessment of the impact of tillage systems in the case of faba bean seed yield, 2016–2018

Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

Sinkevičienė [37] found opposite results. She claims that using different mulching technologies, the assessment scores for the number of perennial weeds rose above the assessment threshold. Also, Rudinskienė [25] states that the evaluation scores for competition with weeds, both when growing single, double and ternary crops, are higher than the evaluation limit. In our experiment, the highest score of 1000 seeds mass, annual and total weed air-dried biomass at the end of vegetation season was determined by direct seeding technology (NT). The calculated indicators of the complex assessment and the areas delimited by the assessment scores showed that NT had a greater impact on the agroecosystem.

3.6. Weed Density

In our experiment, the number of weeds at the beginning of the faba bean vegetative season (faba bean BBCH 25-27) was highest in the NT plots. At the end of the growing season, the differences between tillage systems were evened out, because the plots were sprayed with herbicides [16].

The scores of the total number of weeds at the beginning of the growing season, soil moisture at the beginning of the growing season in the 0-15 cm soil layer did not rise above the assessment (5 points) limit (Figure 6). The highest soil temperature at the beginning of the growing season in the 0-15 cm soil layer was determined using the DP system. However, after evaluating the DP system, the amount of total nitrogen at the beginning of vegetative season in the 0-15 cm soil layer, the amount of available potassium at the beginning of vegetative season in the 0-15 cm soil layer, the stability of the soil structure at the beginning of vegetative season in the 0-15 cm soil layer and the plant pre-crop cover after faba beans sowing evaluation scores are set to be the lowest.

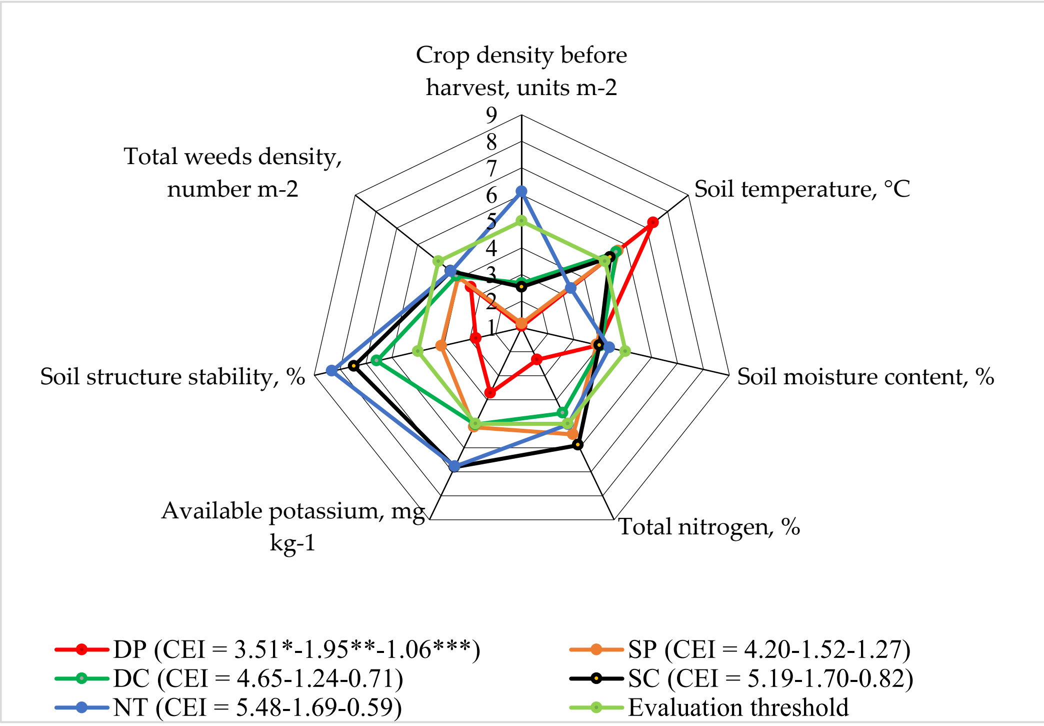

Figure 6. Complex assessment of the impact of tillage systems in the case of weeds density at the beginning of faba bean vegetative season (BBCH 25-27), 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

The calculated indicators of the complex assessment and the areas delimited by the assessment scores showed that the impact of SC and NT on the faba bean agroecosystem was higher than that of other applied systems.

3.7. Weed Air-Dried Biomass

In 2016 at the end of the faba bean growing season (BBCH 75–79), weed air-dried biomass was the highest. Total weed biomass was 25% higher in NT plots than in DP and 42% higher than in SP. DP plots tended to have the lowest total number of all observed weed species. Annual weeds predominated, there-fore, their influence on the total number of weeds was significant ($r = 0.946$, $p<0.05$) [16].

When evaluating the total weed air-dried biomass at the end of the vegetative season) and the total number of weeds, the highest evaluation scores were determined in the NT plots (Figure 7).

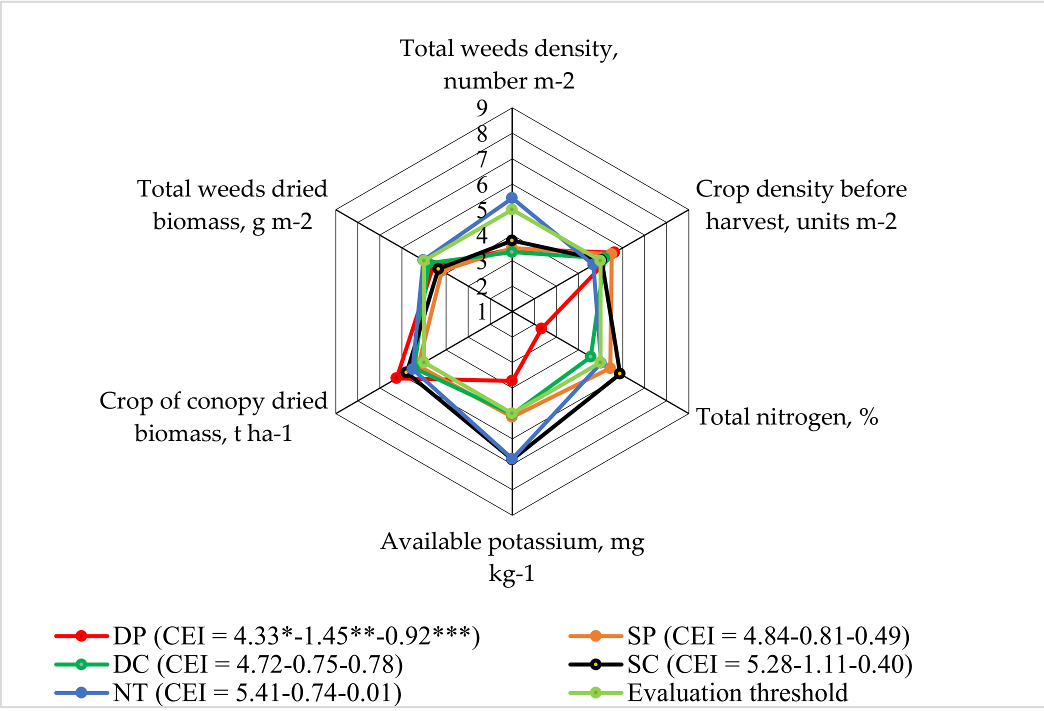

Figure 7. Complex assessment of the impact of tillage systems in the case of weeds air-dried biomass at the end of faba bean vegetative season (BBCH 75–79), 2016–2018. Note: DP– deep ploughing at 22–25 cm depth (control treatment); SP – shallow ploughing at 12–15 cm depth; DC – deep cultivation at 25–30 cm depth; SC – shallow cultivation at 10–12 cm depth; NT – not tilled soil (direct sowing). CEI – complex evaluation index, * – average of evaluation points (EP), ** – standard deviation of EP, *** – standard deviation of the average of the evaluation points below the evaluation threshold.

After determining the density of the faba bean crop before harvesting, the opposite trends in the application of the mentioned system were evaluated. When applying different tillage systems, it was found that the evaluation scores of the dried biomass of the canopy of faba beans are higher than the evaluation limit. After evaluating the SP, SC and NT systems, total nitrogen and available potassium at the beginning of vegetative season in 0-15 cm soil layer evaluation scores were higher than other comparative systems. Similar results were found by Sinkevičius [34]. Claims that no-tillage and no-catch crops technologies had the effect of increasing total nitrogen scores more than the assessment limit (5 points).

The calculated indicators of the complex evaluation and the areas limited by the evaluation scores showed that the impact of NT on the faba bean agroecosystem was the highest than that of other comparative systems.

4. Conclusions

The complex assessment of the faba bean agrosystem based on the endogenous factors, as structure durability, CO2 emissions from the soil, grain yield and weed biomass determined that the NT system has a greater positive impact on the agroecosystem than other comparative systems. Evaluating by the density of the faba bean crop at the beginning of the growing season and the green biomass of the faba beans canopy, it was found that different tillage systems did not differ in their efficiency compared to each other. When evaluating the agrosystem based on the number of weeds (BBCH 25-27), the calculated indicators of the complex evaluation and the areas limited by the evaluation scores showed that the impact of SC and NT on the faba bean agrosystem was greater than that of other applied Systems.

The calculated evaluation scores of various values, their limited areas and the determined complex evaluation indices show that the influence of the NT system was the greatest on the aba bean

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agrosystem than other system used. SC system was more efficient than DP and SP and DC systems. In the DP system there were calculated more minimal, i.e., close to 1 of the CEI values, which showed DP ineffectiveness.

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