Article

Impact of Tillage Intensity on the Development of Faba Bean Cultivation

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Abstract: At the time of tillage, properties of the soil change, thereby changing the conditions of crop development and ultimately their productivity and quality. The effect of non-inversion tillage or no till on faba bean development is stills not widely investigated. For this reason, investigations of tillage systems from deep and shallow ploughing, chiselling, disking to no tillage were tested in Vytautas Magnus University, Agriculture Academy, Lithuania. The results showed that different tillage methods had less influence on faba bean development than meteorological conditions during the growing seasons. Soil chiselling generally showed better faba bean canopy development rates than other treatments. Faba bean roots developed somewhat better in not tilled plots. Vegetative conditions had a significant influence on faba bean development indicators. The effects of vegetative conditions during all four years of the experimentation were significantly different from each other. This shows that, due to rapid climate change, the conditions of each vegetative season become unique and require precise attention.

Keywords: conservation tillage; *Vicia faba* L.; canopy height and biomass; assimilation area; chlorophyll index; root nodulation and biomass

1. Introduction

One of the main challenges of the 20th-21st centuries is to produce enough food for humanity, preserve the environmental quality, and maintain the economic well-being of the rural community [1-2]. Intensive agro-technologies has led to climate change, degradation of soil and water quality, the environment for humans and animals, and threats to human health [3-4]. The list of negative consequences related to the use of intensive farming technologies is growing [5]. Soil tillage intensity influences on the soil chemical, physical and mechanical properties, gas flows, as well as development of faba bean cultivation, production and quality [6-9]. Conservation tillage makes an appropriate soil environment for growing of crop mainly through the reduction in the intensity of tillage and retention of plant residues [10].

In European Union (EU) and other countries, different cropping systems were planned and new Greening programmes were developed to reduce the negative environmental impacts [2]. In Lithuania since 2015, farms must comply with the requirements of the Greening programme [5]. One of the requirements of the Greening programme is crop diversification [11]. Therefore, it is mandatory to grow 2–3 crops on farms. The second important requirement is the identification of ecologically important areas. Perhaps the most acceptable way to implement this requirement is to include at least 7% of the area of nitrogen-fixing plants in the composition of farm crops. Besides, Lithuania is favourable for growing of faba bean [11].

Today, faba bean is the second widely-grown grain legume in EU. The Faba bean is grown in climates ranging from temperate to semi-arid, using different cultivars and relatively different crop-management techniques [12]. The faba bean (*Vicia faba* L.) contains valuable human nutrients [13], provide protein to human diets and animal feed and also has medicinal value [14-15]. Faba bean is also very important in crop rotations [11, 16-18]. The introduction of legumes in the crop rotation becomes the main tool to maintain an acceptable soil fertility level [19], reduce the incidence of weeds, diseases and pests [20]. Faba bean bio-accumulates atmospheric nitrogen and is therefore classified

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as one of the most efficient sources of nitrogen [14, 21-22]. In Southern Europe, faba bean have shown the highest N yields [23-24]. This ecological service is usually using in intercropping of corn, potato and rapeseed cultivations [25]. In addition, faba beans generally improve the productivity of the following crops [26]. According to Unkovic et al. [27] N_2 fixation of legumes can be influenced by the previous cropping sequence, periods of fallow, cropping intensity, and reduced tillage.

Plant roots perform many functions, they influence the developing processes of the ecosystem [28-29]. Root function is very important to plant health and yield. Quantifications of root growth and root distributions are necessary to understand plant-soil interactions. The depth and distribution of roots are important parameters governing water and nutrient uptake by faba bean plants [30]. Faba bean (*Vicia faba* L.) is a crop with a shallow root system with little osmoregulation and is very sensitive to high temperatures and water stress [31–32]. Husain et al. [33] reported that faba beans have a potentially advantageous adaptation to water deficit that makes it change its root and aboveground biomass according to the soil moisture conditions. Depending on the nodule bacteria and the leguminous plant and the soil and climatic conditions, an effective symbiosis can accumulate nitrogen up to 400 kg ha^{-1} and more during the growing season [34].

According to the index of chlorophyll content, it is possible to determine the condition of plants, conditions of nitrogen nutrition and partially predict plant productivity. When there is a lack of nutrients, the amount of chlorophyll in young plants begins to decrease, and under favourable conditions, it increases [35].

Lithuanian and foreign researchers do not yet have a precise and comprehensive answer to the question of how faba bean cultivation under different tillage and meteorological conditions intensities could develop. Complex detailed research is required to answer these questions. Research tasks: 1) to determine the impact of tillage intensity and vegetative conditions on faba bean canopy height, biomass and photosynthetic parameters; b) to establish the effect on faba bean root biomass and nodulation; c) to find the interactions between faba bean development parameters and meteorological conditions.

2. Materials and Methods

2.1. Site description

The long-term stationary field experiment has been started in 1988 at the Experimental Station (54°52`N, 23°49` E) of Vytautas Magnus University, Agriculture Academy, Lithuania. In this study, the experimental data from 2016–2019 is analysed. The Lithuanian climate is surplus humid, average annual precipitation rate is 600–650 mm. The vegetative season lasts up to 150–180 days. The soil at the experimental site is a silty loam (45.6% sand, 41.7% silt, 12.7% clay) Planosol *(Eutric Endogleyic Drainic)* [36]. The soil of an experiment is approx. neutral, rich of available phosphorus (up to 384.0 mg kg^{-1}), consist average amount of available potassium (up to 201.0 mg kg^{-1}), rich of available magnesium (up to 634.0 mg kg^{-1}), and consist average amount of total nitrogen (1.20–1.73 g kg^{-1}).

2.2. Meteorological conditions

Last two decades Lithuanian climate became more ustable in the case of temperatures and precipitation rates. As you can see in Figure 1, all experimental sesons were different. If the beginning of vegetative period was arid, the meadle or end of vegetation could be sulplus humid. The same with air temperatures. The most warm was 2018 vegetative season, the most cold was 2017 season. The highest precipitation rates were in 2016, cops extremally felt lack of moisture in 2019.

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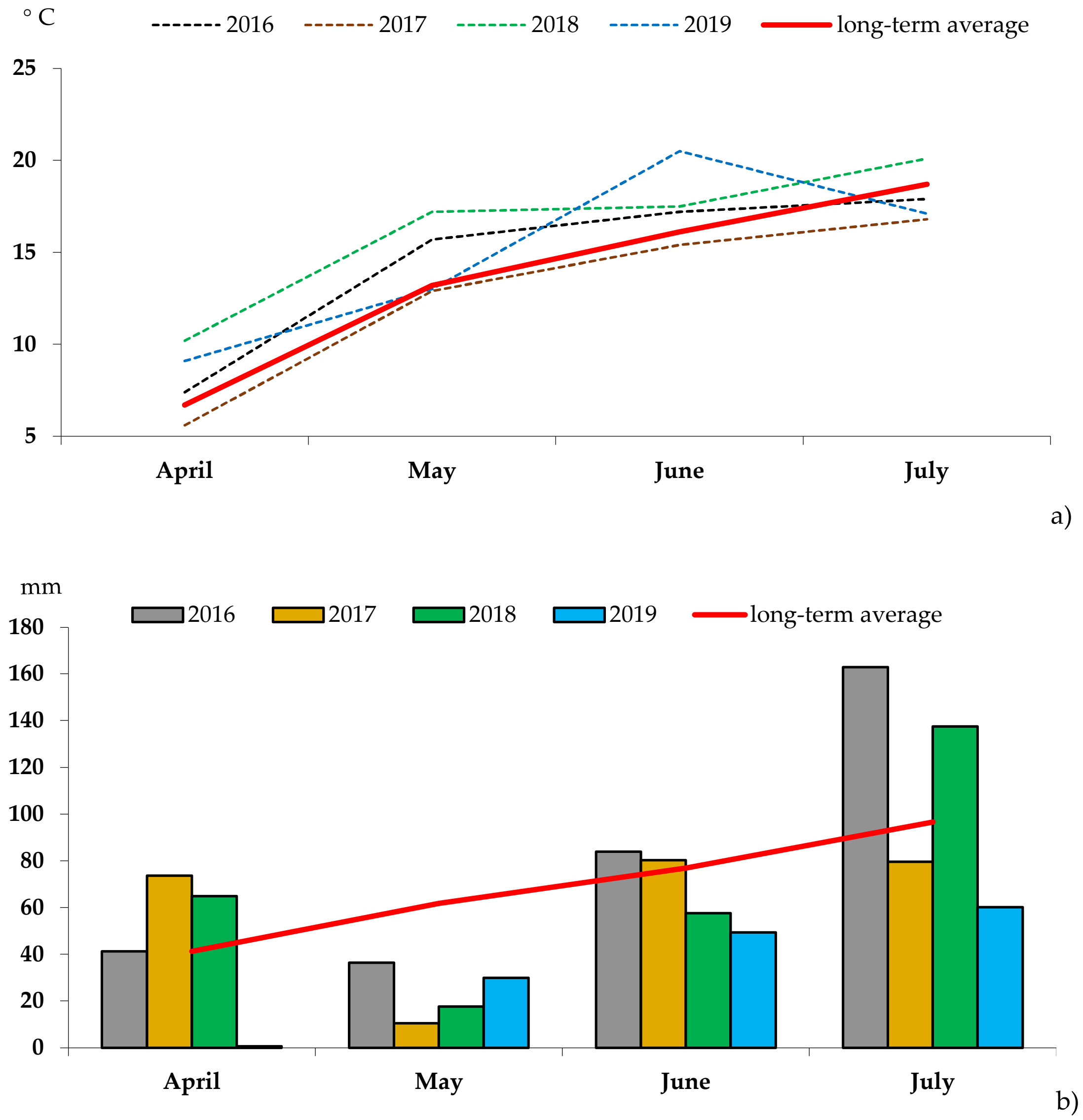

Figure 1. Monthly air temperatures (a) and precipitation rates (b) during faba bean germination and biomass development. Kaunas Meteorological Station, 2016–2019.

2.3. Experimental treatments and agronomic practices

In autumn, after the harvesting of pre-crop (winter wheat), the soil of an experiment was differently tilled: deeply and shallowly ploughed with mouldboard plough, chiselled, disked and not tilled (Table 1).

Table 1. Tillage treatments and implementation in an experiment

Tillage treatment	Tillage type	Tillage depth (cm)	Pre-crop residue coverage (%)
1. Ploughing	inversion	22–25	0.5–1.5
2. Ploughing	inversion	12–15	0.3–8.2
3. Chiselling	non-inversion	25–30	8.5–36.8
4. Disking	non-inversion	10–12	10.5–25.8
5. No-till	-	0	22.0–82.8

Faba bean was cultivated according to the conventional technology, which well described by Kimbirauskiene et al. [9]. Faba bean was sown at the end of April or beginning of May (Table 2). Local fertilization (NPK 7:16:32, 300 kg ha^{-1}) was done during sowing operation.

Table 2. Some agronomic operations and its timing

Operation	2016	2017	2018	2019
1. Sowing + fertilization	25 04	08 05	24 04	06 05
2. Insecticide application	10 05	07 06	15 05	06 06
3. Fungicide application	13 06	23 06	18 06	22 06

The distance between rows was 25 cm, sowing depth was approx. 5–6 cm. Variety 'Fuego' was sown at the rate 200–220 kg of grain per ha (40–45 seeds per m^2). Before sowing, the seeds were inoculated with a *Rhizobium leguminosarum* bacterial preparation (approximately 200 ml of preparation per 100 kg of seeds). A single application of the herbicide (a.i. *aclonifen* 600 g l^{-1}) was done just after the sowing of faba bean. Insecticide (a.i. *lambda-cyhalothrin*, 0.15 l ha^{-1}) was applied at the middle of May up to beginning of June. Fungicide (26.7% a.i. *boscalid* and 6.7% a.i. *pyraclostrobin*, 1 l ha^{-1}) was applied in June [37].

2.4. Methods and analysis

Faba bean development parameters were determined at the beginning of faba bean flowering (BBCH 60–63). 10 faba bean plants were pick-upped in each experimental plot for this study. The height of each plant was measured and weighed to determine its green biomass. There were weighted roots of faba beans. Number of symbiotic nodules also were calculated. 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).

All experimental data were processed using two-factor analysis of variance (ANOVA) from the statistical software package SYSTAT, version 10 [38]. The significance of differences among the treatments was estimated by the least significant difference (LSD) test. The method of correlation regression analysis was applied to evaluate the causality of the studied traits. We used the program STAT ENG from the package ANOVA [39–41].

3. Results and Discussion

3.1. Height of faba bean canopy

After performing the statistical analysis of the results of two factors, it became clear that the height of faba beans in differently cultivated soil (factor A) differed significantly (Table 3).

Table 3. The impact of tillage intensity on faba bean canopy average height, cm

Year of investigation (factor B)	Tillage treatments (factor A)					Average (B)
	DP	SP	DC	SC	NT	
2016	50.0	51.2	52.2	55.6	50.4	51.9d
2017	86.0	82.3	93.8	101.0	72.1	87.0a
2018	64.7	65.0	73.3	62.6	70.6	67.3c
2019	75.3	70.6	80.1	79.7	68.9	74.9b
Average (A)	69.0B	67.3B	74.8A	74.7A	65.5B	
Interaction AxB, *F-act.* 3.3, $P \leq 0.01 > 0.001$, LSD_{05} – 8.94, LSD_{01} – 11.90						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). Different upper case letters indicate significant differences between tillage treatments at $P \leq 0.05 > 0.01$. Differ lower case letters indicate significant differences between experimental year conditions at $P \leq 0.05 > 0.01$.

On average, the tallest plants grew in the DC and SC plots. Vegetation conditions (factor B) influenced the average faba bean plant height significantly. The highest faba beans grew in 2017, when the average daily air temperature was usually lower than the long-term average, and the precipitation was more evenly distributed than in the other years of the experiment because faba bean is temperate climate crop. Precipitation rate and average air temperature weakly correlated with the average height of faba bean plant. According to Chaves et al. [42] the most common environmental factors limiting plant productivity are drought and extreme temperatures. Research conducted by Šliogerytė [43] also proved that the water deficit had a negative impact on the physiological indicators of plants. Faba beans have coping mechanisms that allow them to mitigate potential negative water stress effects. According to Husain et al. [33], these mechanisms consist of reducing its rate of height increase, decreasing its rate of leaf-area expansion slightly, greatly increasing root growth, producing leaves of smaller specific area and shedding leaves. We found a significant interaction between both experimental factors. The highest average faba bean plant height (101 cm) was determined in 2017 in the SC plots, and the lowest was in 2016, in SC plots (51.2 cm) (Table 3).

3.2. Faba bean leaves chlorophyll index

Tillage intensity (factor A) had no significant effect on faba bean leaves chlorophyll index. However, the vegetation conditions of the experimental years had a significant influence (factor B) (Table 4).

Table 4. The impact of tillage intensity on faba bean leaves chlorophyll index

Year of investigation (factor B)	Tillage treatments (factor A)					Average (B)
	DP	SP	DC	SC	NT	
2016	28.2	30.0	29.9	31.0	29.6	29.7c
2017	25.7	27.7	27.4	23.2	27.6	26.3d
2018	47.0	45.2	46.3	42.2	37.9	43.7a
2019	31.0	37.2	33.9	30.4	43.8	33.5b
Average (A)	33.0A	35.0A	34.4A	31.7A	32.5A	
Interaction AxB, *F-act. 1.07*, $P > 0.05$, $LSD_{05} - 6.90$, $LSD_{01} - 9.18$						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). The same upper case letters indicate nonsignificant differences between tillage treatments, $P > 0.05$. Different lower case letters indicate significant differences between experimental year conditions at $P \leq 0.05 > 0.01$.

The highest faba bean leaves chlorophyll index was determined in 2018 (43.7). In other research years, this indicator differed significantly from year to year. It was significantly the lowest in 2017 (26.3). The process of photosynthesis is influenced by key factors such as nutritional, tillage and meteorological conditions [44-45]. In our experiment, the meteorological conditions had significant impact, but interaction between factors A and B was non-significant. Chlorophyll index mainly correlated with average air temperature (r=0.437, $P > 0.05$). In addition, the chlorophyll index also correlated to a greater extent on the amount of magnesium in the soil, the abundance of annual and perennial weeds at the beginning of the growing season (r = 0.570; -0.859; -0.776, $P > 0.05$) (data are not presented).

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3.3. Faba bean leaves assimilation area

Leaf assimilation area is important for photosynthetic productivity [46-47]. In our experiment, tillage treatments (factor A) had a lower influence on the assimilation area of faba bean plant leaves than the vegetation conditions of the research year (factor B) (Table 5), but the largest assimilation area was determined in the DC plots. The year 2017 was the most favourable for the development of faba beans and the leaf area of the faba bean plant was the largest (1153.6 cm). No significant interaction was found between the two experimental factors.

Table 5. The impact of tillage intensity on faba bean leaves average assimilation area, cm^2 $plant^{-1}$

Year of investigation (factor B)	**Tillage treatments (factor A)**					**Average (B)**
	DP	SP	DC	SC	NT	
2016	337.2	409.7	360.6	381.7	367.3	371.3c
2017	1132.4	1191.9	1270.9	1227.5	945.4	1153.6a
2018	764.4	809.7	1052.7	675.2	866.8	833.8b
2019	1053.7	1096.8	1102.1	1073.1	866.6	1038.5a
Average (A)	821.9A	877.0A	946.6A	839.4A	761.5A	
Interaction AxB, *F-act. 0.48*, $P > 0.05$, LSD_{05} – 392.08, LSD_{01} – 521.78						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). The same upper case letters indicate nonsignificant differences between tillage treatments, $P > 0.05$. Different lower case letters indicate significant differences between experimental year conditions at $P \leq 0.05 > 0.01$.

Correlation analysis of the experimental data showed high correlation between leaves assimilation area and plant average height (r=0.937, $P \leq 0.010 > 0.001$). Precipitation rate and average air temperature had weak correlation with leaves assimilation area.

3.3. Faba bean canopy dried biomass

The assimilation area of the leaves is important for photosynthesis productivity. The highest biomass of the dried canopy of the faba bean plant was found in the DC plots (Table 6). In NT plots, the biomass was significantly lower only (1.2 times). Meteorological conditions of the experimental vegetation periods had a significant influence on the dry biomass of the faba bean canopy.

Table 6. The impact of tillage intensity on faba bean plant canopy average dried biomass, g $plant^{-1}$

Year of investigation (factor B)	**Tillage treatments (factor A)**					**Average (B)**
	DP	SP	DC	SC	NT	
2016	11.4	10.6	10.7	10.9	9.9	10.7c
2017	11.2	10.1	11.8	12.5	8.9	10.9c
2018	18.0	13.0	16.3	11.6	13.7	14.4b
2019	16.8	21.7	23.5	20.1	18.3	20.1a
Average (A)	14.3AB	13.9AB	15.6A	13.6AB	12.7B	
Interaction AxB, *F-act. 1.32*, $P > 0.05$, LSD_{05} – 5.01, LSD_{01} – 6.67						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). Different upper case letters indicate significant differences between tillage treatments at $P \leq 0.05 > 0.01$. Different lower case letters indicate significant differences between experimental year conditions at $P \leq 0.05 > 0.01$.

The highest dry biomass of the faba bean plant canopy was determined in 2019, although this year's vegetation period was dry enough, but warmer than in other research years. We found slight correlation between average air temperature and canopy dried biomass (r=0.337, *P> 0.05*). No interaction between the two experimental factors was found. Robertson and Swinton [1] found that the productivity of crops depended on chlorophyll concentration in the leaves. In our experiment, we also found average correlation between faba bean plant canopy dried biomass and leaves chlorophyll index (r=0.433, *P> 0.05*) and assimilation area of leaves (r=0.404, *P> 0.05*).

3.4. Faba bean roots dried biomass

According to the average data of factor A, the highest (8.0 g) average dry biomass of the roots of the bean plant was found in NT and DC plots (Table 7). It was similar in the plots of ather treatments. According to the average data of factor B, just like the canopy of the plant, the roots also developed best in 2017. No significant interaction between the factors was found.

Table 7. The impact of tillage intensity on faba bean roots average dried biomass, g plant^{-1}

Year of investigation (factor B)	**Tillage treatments (factor A)**					**Average (B)**
	DP	SP	DC	SC	NT	
2017	9.2	8.3	9.5	8.0	11.4	9.3a
2018	5.1	6.2	6.6	5.0	6.4	5.9bc
2019	6.1	7.0	6.6	7.0	6.6	6.5b
Average (A)	6.4BC	6.9BD	7.6AB	6.0B	8.0A	
Interaction AxB, *F-act. 1.54, P> 0.05, LSD_{05}* – 2.04, *LSD_{01}* – 2.72						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). Different upper case letters indicate significant differences between tillage treatments at *P ≤ 0.05 > 0.01*. Differ lower case letters indicate significant differences between experimental year conditions at *P ≤ 0.05 > 0.01*.

It is known that tillage systems influence soil properties such as bulk density, aggregation and pore continuity, temperature, aeration and moisture levels, which can affect root growth [48-49]. In our experiment, we found negative correlation between air temperature and roots dried biomass (r=-0.505, *P> 0.05*). Precipitation rate had positive effect (r=0.381, *P> 0.05*). Research conducted by Šliogerytė et al. [43] showed that moisture deficit disturbs the distribution of dry mass in the plant and more of it accumulates in the roots than in the above-ground part. Similarly, we found negative correlation between faba bean canopies dried biomass and roots dried biomass (r=-0.520, *P≤ 0.05>0.01*). We also found correlations between roots dried biomass and plant canopy height (r=0.545, *P≤0.05>0.01*), chlorophyll index (r=-0.726, *P≤0.010>0.001*) and leaves assimilation area (r=0.565, *P≤ 0.05>0.01*). In addition, the dry biomass of the roots of the faba bean at the time of flowering correlated with the volume of pre-crop residues on topsoil after faba bean sowing (r = 0.703, *P> 0.05*), the density of the crop at the beginning of the growing season (r = -0.926, *P≤0.05>0.01*), the total weediness of the crop at the beginning of the growing season (r = -0.928, *P≤0.05>0.01*), magnesium amount in the soil in the 15-25 cm layer at the beginning of vegetative period (r = 0.980, *P≤0.010>0.001*) (data are not presented).

3.5. Number of nodules on faba bean roots

In our experiment, in differently cultivated soil (factor A), the number of nodules on the roots of the faba bean plant differed insignificantly (Table 8). Despite this, the most nodules were found in the SP and NT plots. López-Bellido et al. [50] similarly concluded that number of nodules is also influenced by the chosen method of tillage and which plants we grow in the experiment.

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Trinick et al. [51] found that adequate supply and balance of photosynthetic products must be ensured to maintain the required number of nodules on the roots [52]. In our experiment, leaves chlorophyll index slightly correlated with number of nodules (r=-0.327, $P > 0.05$) and canopy dried biomass (r=-0.610, $P \le 0.05 > 0.01$). Also we found correlations between number of nodules and roots dried biomass (r=0.397, $P > 0.05$).

Table 8. The impact of tillage intensity on the average number of symbiotic noodles on the faba bean roots, units plant^{-1}

Year of investigation (factor B)	Tillage treatments (factor A)					Average (B)
	DP	SP	DC	SC	NT	
2017	100.6	190.4	101.0	69.5	96.4	111.6a
2018	70.8	73.8	70.4	90.2	92.4	79.5ab
2019	47.0	55.2	66.6	68.9	71.8	61.9b
Average (A)	72.8A	106.4A	79.4A	76.2A	86.9A	
Interaction AxB, *F-act. 1.05*, $P > 0.05$, LSD_{05} – 83.72, LSD_{01} – 111.93						

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). The same upper case letters indicate nonsignificant differences between tillage treatments, $P > 0.05$. Different lower case letters indicate significant differences between experimental year conditions at $P \le 0.05 > 0.01$.

Examining the influence of factor B, it was found that the most favorable year for the development of bean symbiotic nodules was 2017, during which the average number of nodules on the roots of the bean plant was the highest (111.6 units) or from 1.4 to 1.8 times higher than in subsequent years of the experiment. According to the Amanuel et al. [53] and Puschel et al. [54], the roots of faba beans and other legumes with root nodules are very sensitive to nitrogen, phosphorus, potassium and water levels. In our experiment, between the number of symbiotic nodules and soil phosphorus content, potassium content, and nitrogen content in the 15-25 cm soil layer at the beginning of the growing season, a moderately strong positive relationship was established (r=0.681; 0.585; 0.523, $P > 0.05$). A positive relationship was also found between soil structural stability, number of earthworms and number of nodules (r=0.815 and 0.611, $P > 0.05$) (data are not presented). In addition, precipitation rates and air temperatures weakly correlated with number of nodules. We did not find significant interactions between the experimental factors.

4. Conclusions

Different tillage methods (factor A) had less influence on faba bean development than vegetative conditions during the growing seasons (factor B). Despite this, DC generally showed better faba bean canopy development rates than other treatments. Faba bean roots developed somewhat better was in NT plots.

Vegetative conditions during vegetative seasons (factor B) had a significant influence on faba bean development indicators. In addition, in most cases, the effects of meteorological conditions in all four years of the experiment were significantly different from each other. This shows that, due to climate change, the conditions of each vegetative season become unique and require precise attention in agricultural practice.

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