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Vermicompost Treatment Boosts Root System Architecture in Lentil Under Low-Organic Matter Field Conditions*

Vermikompost Uygulaması Düşük Organik Maddeye Sahip Tarla Koşullarında Mercimekte Kök Sistem Mimarisini Geliştirir*

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Abstract: The Although the above-ground parts are important in most cultivated plants, all plants need to have a healthy and strong root system to appear healthy, meet their water and nutrient needs properly, and produce high yields and quality products. This study aims to monitor the effects of different vermicompost doses on the root system architecture of lentils under field conditions at periodic intervals. The study was conducted as a field trial at the Faculty of Agriculture of Siirt University during the 2018-19 season. Four different vermicompost doses were used in the study, and examinations were made on plant materials collected at three different periods. According to the research results, it was determined that root development significantly accelerated after 40-60 days from emergence. Lateral root formation increased by 119% from the 40th to the 60th day. The results denoted that vermicompost doses up to 10 t ha^{-1} promoted total root biomass and dry matter accumulation, however, higher than 5 t ha^{-1} inhibited lateral root formation and growth. As a result, the use of vermicompost in lentil production areas, not exceeding 5 tons per 5 hectares, has been identified as a sustainable and organic practice that positively affects root development and lateral root formation.

Keywords: Dry matter accumulation, lateral root, lens culinaris, organic manure, *Shavelomics*

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Öz: Çoğu kültür bitkisinde önemli olan kısımlar toprak üstü aksamlar olsa da tüm bitkilerin sağlıklı görünmesi, su ve besin maddesi ihtiyaçlarını düzgün bir şekilde karşılaması, yüksek verim ve kaliteli ürün oluşturması için sağlıklı ve güçlü bir kök sistemine sahip olması gerekmektedir. Bu çalışmanın amacı farklı vermikompost dozlarının tarla koşullarında uygulanmasına bağlı olarak mercimekte kök sistem mimarisi üzerine etkilerini periyodik aralıklarla takip etmektir. Çalışma 2018-19 sezonunda Siirt Üniversitesi, Ziraat Fakültesinde tarla denemesi olarak gerçekleştirilmiştir. Çalışmada 4 farklı vermikompost dozu kullanılmış ve 3 farklı dönemde toplanan bitkisel materyaller üzerinde incelemeler yapılmıştır. Araştırma sonuçlarına göre, kök gelişiminin çıkıştan 40-60 gün sonra önemli ölçüde ivme kazandığı belirlenmiştir. Öyle ki, lateral kök oluşumu 40. günden 60. güne kadar %119 oranında artış göstermiştir. Sonuçlar, hektar başına 10 ton vermikompost dozuna kadar olan miktarların toplam kök biyo-kütlesini ve kuru madde birikimini teşvik ettiğini ancak hektar başına 5 tonu aşan miktarların yan kök oluşumunu ve büyümesini engellediğini gösterdi. Sonuç olarak, mercimek üretim alanlarında, hektar başına 5 tonu aşmayacak şekilde vermikompost kullanımı, kök gelişimini ve yan kök oluşumunu olumlu yönde etkileyen sürdürülebilir ve organik bir uygulama olarak belirlenmiştir.

Anahtar Kelimeler: Kuru madde birikimi, lateral kök, *Lens culinaris*, organik gübre, shavelomics

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INTRODUCTION

This lentil (*Lens culinaris* Medikus) is a vital pulse crop grown in all but a few regions of the World for human and animal nutrition. Its grain and straw are rich in protein, starch, dietary fiber, and some micronutrients such as Zn, Fe, and β-carotene but low in sodium and fat (Li and Ganjyal, 2017). Due to its effects on soil chemical composition and microbial population, lentil is an important part of rotation systems with cereals that contribute to sustainable agriculture (Erskine et al., 2018). According to Statpup data, 5.4 million tons of lentils were produced on 5.2 million hectares worldwide in 2023-24. Red and green lentils account for 85.5% and 14.5% of the lentil-cultivated areas, respectively. According to FAO (2023), Canada ranks first with 1.606 million tons, followed by India with 1.490 million tons. Türkiye cultivated 290 thousand hectares and produced 400 thousand tons of lentils.

The most important factors for high grain yield and quality are genotype selection, protection against pathogens, and supplying nutrition requirements. On the other hand, researchers indicate that morphological characteristics are directly correlation in yield attributes in grain legumes (Özaktan et al., 2022, 2023). The early vegetative stage has a vital role in adaptability, growth and yield components in lentil due to restriction by various stress factors such as salinity, drought, chilling and waterlogging (Erman et al., 2021). Legumes require a starter nitrogen application to begin symbiotic nitrogen fixation (Huang et al., 2016) and phosphorus addition for effective root growth (Singh and Singh, 2016). However, excessive chemical fertilizers have threatened human and animal health, microorganisms, soil quality, and the environment (Nayana and Ritu, 2017). Vermicompost, which is a next-generation and environment-friendly organic material, stands out as an important source to prevent the harmful effects of chemical fertilizers and to meet the nutrient requirements that the plant needs during growth and development (Ceritoglu et al., 2018).

Vermicompost or vermicast is rich in antioxidants, nutrition, vitamins, humic substances, and various phyto-hormones. It is superior compared to other organic materials such as farm manure, green manure produced by various plant materials and poultry manure (Tognetti et al., 2013). Moreover, vermicompost contributes to forming an effective root system (Blouin et al., 2019) and rich rhizosphere by improving soil microbial activity and productivity (Dominguez et al., 2019). It was demonstrated that different fractions of vermicompost positively affect the rhizosphere root characteristics, nodulation and mycorrhizal population (Jing et al., 2017; Maji et al., 2017).

The first step in optimum plant growth depends on the constitution of an effective root system. All root traits of plants, described as root system architecture (RSA), determine water and nutrition uptake efficiency, tolerance to stress factors, and growth regime of plants (Saleem et al., 2018). Various techniques have been used to investigate such as plexiglass plate method (Hohn and Bektas, 2020), hydroponic systems (Qiao et al., 2018), cylindrical container technique (Açıkbaş et al., 2021) and shovelomics (Burridge et al., 2016). Although the other methods have some advantages such as non-destructive and easy screening of the RSA, easy root development observation, time-saving processing, easy repeatability and no need for any root washing, the shovelomics technique enables to investigation of root characteristics in natural habitats and more clearly understand of their responses (Trachsel et al., 2011). Shovelomics is a method in which plants are excavated by a shovel under field conditions. Then, roots are carefully washed, scanned by a scanner and analyzed by image analysis software (Ceritoglu et al., 2020)

Although researchers have examined the effects of vermicompost applications on lentil growth, yield, and quality under laboratory (Ceritoglu et al., 2021) and field conditions (Ceritoglu and Erman, 2020), investigating the impact of vermicompost application on the root system architecture of lentils under field conditions highlights the uniqueness of this study. Additionally, periodic sampling based on different doses of vermicompost applications and the examination of results increases the study's importance in monitoring vermicompost effectiveness. This study aimed to research some root characteristics and observe periodic alterations in RSA using the shovelomics method under low organic matter field conditions.

MATERIAL AND METHOD

Experimental Materials

The *Lens culinaris* cv. Fırat 87 was used in the experiment. Fırat 87, registered in 2012 by GAP International Agricultural Research and Training Center, is a large-seed lentil and has high adaptation to the region (GAPUTAEM, 2019). It has been the most used cultivar in the region for many years and has high stability in terms of agronomic and yield traits. The vermicompost was obtained from a traditional company (Ekosol Tarım ve Hayvancılık A.Ş) and its chemical composition was summarized in Table 1.

Table 1. Some physico-chemical components of vermicompost used in the study.
Çizelge 1. *Çalışmada kullanılan vermikompostun bazı fiziko-kimyasal komponentleri.*

OM (%)	TN (%)	ON (%)	C/N	EC (dS m^{-1})	HA+FA (%)	MM (%)	pH	TP (%)	TK (%)
35	1.2	1.0	14	5.0	20	35	6.8	1.5	2.1

(OM: Organic matter, TN: Total nitrogen, ON: Organic nitrogen, C/N: Carbon/nitrogen ratio, EC: Electrical conductivity, HA: Humic acid, FA: Fulvic acid, MM: Maximum moisture, TP: Total phosphorus, TK: Total potassium)

Experimental Location

The experiment was conducted in the 2018-2019 growing season in the Siirt University, Türkiye. The city is located on 37° 57' N and 41° 51' E, Southeastern Anatolia Region of Türkiye. The altitude of the location is 585 m.

Experimental Soil and Climatological Characterization of the Region

Soil samples taken from A horizone were analyzed in the Central Laboratory of Siirt University. It was composed of medium-deep soil which is enough in potassium, low in organic matter and soluble phosphorus content, mild saline, and limy. The pH was light alkaline near neutral and the texture was clay loam. Characteristics of the experimental soil was given in Table 2.

Table 2. Some chemical properties of soil taken from the experiment area before sowing time.
Çizelge 2. *Ekim öncesinde deneme alanından alınan toprağın bazı kimyasal özellikleri.*

Depth (cm)	Texture	pH	EC (dS m^{-1})	Lime (%)	OM (%)	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})
0-20	Clay-loam	7.59	6.68	9.2	0.8	1.66	155

(OM: Organic matter)

The region exhibits characteristics of terrestrial climate. Temperature values of the vegetation period were nearly similar to the long years' average ranges. However, the rainfall during 2018-19 were erratic and higher compared with the long years average. Some climate data were given in Figure 1.

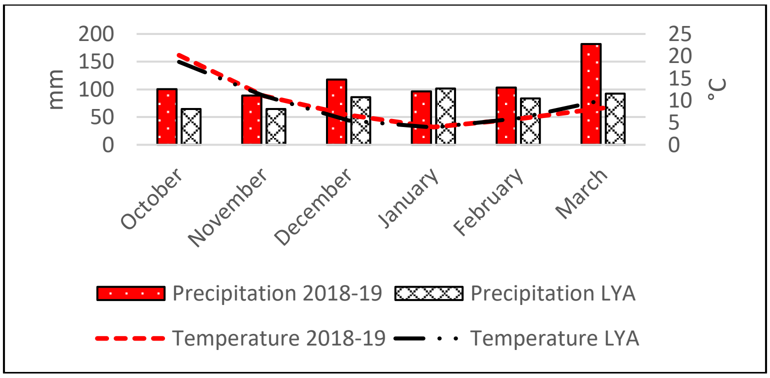

Figure 1. Climatological data of the experimental area during 2018-19 and long years average.
Şekil 1. *Deneme alanının 2018-19 süresince ve uzun yıllar ortalamasındaki klimatolojik veriler.*

Plant Material and Experimental Design

Each plot was formed from 5 rows. The row spacing and length were arranged as 25 cm (Kraska et al., 2020) and 5 m, respectively (1x5=5 m^2). The distances between plots and blocks were set as 1.5 m due to vermicompost application. So, vermicompost applied to each plot is aimed not to affect other plots. Also, 140 kg diammonium phosphate (DAP) ha^{-1} was applied as a starter dose with sowing under the seed drill (Dona et al. 2020). The 200 seeds m^{-2} per plot (Biçer, 2014) was sown on 15th December in dry conditions.

The study was conducted in a completely rendomized split-plot design with 5 replications. Three different times with 20 days intervals, i.e., 20, 40 and 60 days later emergence (DAE), and five doses of vermicompost (control, V1: 2.5 t ha^{-1}, V2: 5 t ha^{-1}, V3: 7.5 t ha^{-1}, and V4: 10 t ha^{-1}) were used in the experiment. Observation time and vermicompost treatment were placed in the main and sub-plots, respectively. Vermicompost materials were mixed into soil 30 days before sowing.

Weed control was done by mechanical methods 4 weeks after stand-establishment. Any herbicide or insecticide was used throughout the experimental process. The experiment was laid out under rainfed conditions.

Excavation of Plants, Image Analysis and Observations

The 10 samples were selected from each plot at each observation time and carefully excavated by shovel. Firstly, plants were gently shaken to remove coarse soil, and then they were labeled and placed in plastic bags. Plants were washed and removed adhered soil particles on roots. Then, plants were cut at root neck. Root fresh weight (RFW) was determined. Root samples were scanned on colored scale at 600 dpi resolution using a portable scanner (ISCAN, handheld scanner). Root images were analyzed using ImageJ image analysis software to evaluate the phenotypic variability of root architecture. Taproot length (TRL), number of lateral roots (NLR) and total lateral root length (TLRL) was determined with image analysis (Ceritoglu et al., 2020). After the phenotyping process, root samples were placed in an oven set to 68 °C for 3 days and root dry weight (RDW) was observed to determine dry matter accumulation.

Statistical Analysis

The normality of the data was tested using the Shapiro-Wilks (1965) normality test. The data showing normal distribution were subjected to statistical analysis (ANOVA) for the evaluation of significance within characteristics. Tukey's honestly significant difference test (Tukey's HSD) test was applied to calculate multiple comparison values using JMP (Pro 14) statistical analysis software.

RESULTS AND DISCUSSION

Results

Four vermicompost doses treated lentil plots under field conditions and alterations in RSA were periodically observed at three different times, i.e., 20, 40 and 60 DAE. Thus, the experiment provided the observation of root distribution under normal field conditions and also the determination of alterations with organic matter additions into soils. Analysis of variance indicated that observation time caused statistically significant differences ($p<0.01$) in all characteristics. The RDW, NLR and TLRL were significantly ($p<0.01$) affected by vermicompost doses but did not influence RFW and TRL. In addition, TxV interaction led to statistically significant differences in RDW and TLRL at $p<0.01$ and $p<0.05$, respectively (Table 3).

The study recorded that RFW increased in parallel with the developmental period, reaching its highest root weight at 60 DAE. The periods with the lowest (0.0786 g) and highest (0.2646 g) RFW values were determined to be 20 and 60 DAE, respectively. Similar results were observed for RDW as well. That is, the lowest (0.0290 g) and highest (0.0675 g) RDW values were detected at 20 and 60 DAE, respectively. It was observed that increasing vermicompost doses enhanced dry matter accumulation in the roots. Particularly, 7.5 and 10 tons ha^{-1} vermicompost doses significantly increased RDW, though they were statistically within the same group. Regarding the TxV interaction, RDW ranged from 0.0188 to 0.0882 g. The lowest and highest RDW were detected in plants without vermicompost on the 20th day and 10 t ha^{-1} of vermicompost on the 60th day, respectively (Table 4).

Table 3. Analysis of variance for data belong to different observation times and vermicompost levels.
Çizelge 3. Farklı gözlem dönemleri ve vermikompost seviyelerine ait data için varyans analizi.

Traits	Mean of square - F prob.		
	Time (T)	Vermicompost (V)	TxV
Root fresh weight	0.2163**	0.0023ns	0.0019ns
Root dry weight	0.0093**	0.0020**	0.00015**
Taproot length	388.4**	3.68ns	11.06ns
Number of lateral roots	691.3**	60.7**	9.1ns
Total lateral root length	21107.9**	798.8*	200.2*

Table 4. Root fresh weight and dry weight during growing period under different vermicompost levels.
Çizelge 4. Farklı vermikompost seviyeleri altında farklı gelişme dönemlerinde kök yaş ve kuru ağırlıkları.

Observation time	Vermicompost doses					
	Root Fresh Weight (g)					
	Control	V1	V2	V3	V4	Mean
20 DAE	0.0798	0.0913	0.0734	0.0751	0.0732	0.0786 C
40 DAE	0.1798	0.1595	0.1569	0.1870	0.1727	0.1712 B
60 DAE	0.2292	0.2809	0.2593	0.3100	0.2435	0.2646 A
Mean	0.1629	0.1772	0.1632	0.1907	0.1631	
	Root Dry Weight (g)					
20 DAE	0.0188 e	0.0301 de	0.0221 e	0.0390 d	0.0348 d	0.0290 C
40 DAE	0.0401 cd	0.0408 cd	0.0381 d	0.0606 b	0.0585 b	0.0476 B
60 DAE	0.0583 b	0.0571 b	0.0515 bc	0.0821 a	0.0882 a	0.0675 A
Mean	0.0392 B	0.0427 B	0.0372 B	0.0606 A	0.0605 A	

(DAE: Day after emergence, V1: 2.5 t ha^{-1}, V2: 5 t ha^{-1}, V3: 7.5 t ha^{-1}, and V4: t ha^{-1})

Table 5. Root characteristics during growing period under different vermicompost levels.
Çizelge 5. Farklı vermikompost seviyeleri altında farklı gelişme dönemlerinde kök karakteristiği.

Observation time	Vermicompost doses					
	Number of Lateral Roots					
	Control	V1	V2	V3	V4	Mean
20 DAE	5.4	6.8	11.0	9.4	6.2	7.8 B
40 DAE	7.4	10.0	9.2	7.8	6.6	8.2 B
60 DAE	13.6	18.4	20.8	17.8	14.8	17.1 A
Mean	8.8 B	11.7 AB	13.7 A	11.7 AB	9.2 B	
	Taproot Length (cm)					
20 DAE	9.3	9.1	9.4	8.3	9.5	9.1 B
40 DAE	8.8	7.0	10.1	8.8	9.8	9.9 B
60 DAE	13.7	17.0	14.4	18.2	15.5	15.8 A
Mean	10.6	11.1	11.3	11.7	11.8	
	Total Lateral Root Length (cm)					
20 DAE	8.5 d	13.2 d	26.7 b-d	15.8 d	8.4 d	14.5 C
40 DAE	21.4 cd	22.3 cd	28.6 b-d	25.3 b-d	26.4 b-d	24.8 B
60 DAE	52.6 a-c	74.6a	82.8a	78.1 a	57.8 ab	69.2 A
Mean	27.5 B	36.7 AB	46.0 A	39.7 AB	30.9 AB	

(DAE: Day after emergence, V1: 2.5 t ha^{-1}, V2: 5 t ha^{-1}, V3: 7.5 t ha^{-1}, and V4: 10 t ha^{-1})

According to the research results, NLR showed a significant increase particularly between 40-60 DAE. While the increase in NLR values was approximately 5% between 20-40 DAE, the increase rate was determined to be 119% between 40-60 DAE. When examining the effect of vermicompost addition on NRL, it was observed that the NLR increased up to a level of 5 t ha^{-1}, but then decreased with higher doses. Plants treated with 10 t ha^{-1} vermicompost were inhibited and fell into the same statistical group as the control plants. Effective root depth, or in other words, TRL, significantly varied only according to observation periods. The lowest (9.1 cm) and highest (15.8 cm) TRL were detected at 20 DAE and 60 DAE, respectively. Both the number of lateral roots on the taproot and the total length of secondary roots varied significantly according to observation times. The TLRL was determined to be 14.5 cm at 20 DAE and 69.2 cm at 60 DAE. Vermicompost applications had a similar effect on TLRL values as they did on NLR. The TLRL reached its maximum value (82.8 cm) at a level of 5 t ha^{-1}, but decreased to 30.9 cm with 10 t ha^{-1} vermicompost application. In the study, it was determined that TLRL values ranged from 8.5 to 82.8 cm depending on the TxV interaction, with the lowest and highest values detected at 20 DAE without vermicompost and at 60 DAE with 5 t ha^{-1} vermicompost application, respectively (Table 5).

DISCUSSION

Experiment results showed that root growth increased and lateral root formation was promoted depending on the development periods of the plants. It was determined that there was not much difference in the accumulation of dry matter in the plant and the factors forming the RSA between 20-40 DAE, but during the 60 DAE period, there was rapid development that led to significant differences (Table 4, 5). Erman et al. (2008) indicated that lentil has a slow growth rate during early growting stage. Because low temperature restricts vegetative growth especially at the early growth period (Öktem et al., 2008). Also, low temperatures especially the night period reduces physiological and metabolic activities, thereby, water and nutrient uptake, cell division, morphological growth are restricted (Khan et al., 2017). In addition, low temperatures lead to induce noteworthy changes in gene expression and lipid composition of biomembrane, thereby, many tropical or sub-tropical plants are damaged or killed at low temperatures which are lower than 10 °C (Niu and Xiang, 2018). During the experiment, the 40 DAE period corresponded to January, while the 60 DAE period, when the study was completed, corresponded to February. According to Figure 1, the average temperatures and rainfall showed a slight increase towards February. Additionally, it is believed that the growth rate increased because the developing plant roots were able to better utilize the water and nutrient elements in the soil.

Increasing vermicompost doses provided higher total biomass and dry matter accumulation in plants. On the other hand, vermicompost doses by 5 t ha^{-1} promoted lateral root formation and growth, however, higher doses inhibeted them. Sinha et al. (2010) reported that the application of vermicompost increased the total biomass of chickpeas (*Cicer arietinum*) and peas (*Pisum sativum*) by enhancing the number of primary and secondary branches. Vermicompost is a material rich in macro and micronutrients, hormones, vitamins, amino acids, some enzymes, antioxidants, humic substances, and organic matter (Arancon et al., 2004). Vermicompost, which acts as a slow-release fertilizer, not only provides the necessary nutrients for the plant but also significantly increases the amount of bacteria (PGPR) that promote plant growth in the root region (Benitez et al., 2005). Therefore, it is thought that it might contribute to the increase in root development by enhancing the density of bacterial species that aid in the formation of root nodules and the uptake of other plant nutrients. Additionally, different researchers have identified that the water retention capacity of soils with a lack of organic matter is reduced (Yılmaz and Alagöz, 2008; Blouin et al., 2019). Thus, it is estimated that the increased amount of organic matter in the soil towards the 60 DAE period prepares an environment where roots can develop comfortably, facilitating the uptake of water and nutrients by adhering to the organic material. Furthermore, it is known that humic and fulvic acid compounds present in vermicompost have positive effects on root and shoot development in plants, contributing to the dissolution of organic compounds in the root region and easing nutrient uptake (Bozoğlu et al., 2004; Öktem et al., 2017). Conversely, Rupani et al. (2018) investigated the effects of vermicompost applied at different doses on germination and seedling development. The study found that low doses of vermicompost had positive effects on germination and contributed to the formation of a more efficient root system in the early seedling stage. However, as the doses of vermicompost increased, the pH of the environment deteriorated, making nutrient uptake more difficult, and the negative effects of ion toxicity were observed. The findings of Rupani et al. (2018) support the results obtained from our research.

Similarly, Ceritoglu ve ark. (2021) demonstrated that although optimum doses of vermicompost had a stimulative effect on germination and seedling growth, higher doses restrict growth and development depending on genotypes in grain legumes.

CONCLUSION

The experiment focused on periodic sampling under different doses of vermicompost and alteration of root system architecture. The results denoted that vermicompost doses up to 10 t ha^{-1} promoted total root biomass and dry matter accumulation, however, higher than 5 t ha^{-1} inhibited lateral root formation and growth. Moreover, it was concluded that root development, which progresses relatively slower until 40 days after emergence, showed a significant increase in the 40-60 day period. As a result, the use of vermicompost in lentil production areas, not exceeding 5 tons per 5 hectares, has been identified as a sustainable and organic practice that positively affects root development and lateral root formation.

CONFLICT OF INTEREST

The author declares that there are no conflicts of interest.

DECLARATION OF AUTHOR CONTRIBUTION

The MC designed and laid out the experiment, collected data, subjected the statistical analysis and wrote Ms.Draft.

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