Effect of Irrigation Depths Using Soil Cover in Arugula (*Eruca sativa*) Cultivation

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Received 28 March, Accepted 20 May, Published 30 May 2026

Direct Research Journal of Agriculture and Food Science

Vol. 14(2), Pp. 61-67, May 2026

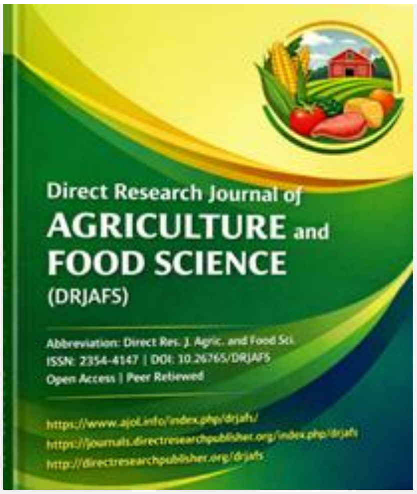
https://journals.directresearchpublisher.org/index.php/drjafs; https://www.ajol.info/index.php/drjafs

Research Article
ISSN: 2354-4147

ABSTRACT

Effective irrigation management is critical for maximizing crop productivity. This study aimed to investigate the effects of different irrigation depths and soil cover on the productive performance of arugula (Eruca sativa), a crop characterized by a shallow root system and high water sensitivity. The research was conducted in Viçosa, Minas Gerais, Brazil, using a Completely Randomized Design (CRD) in a split-plot scheme. Treatments consisted of two soil cover conditions (with and without polyethylene cover) and five irrigation levels (20%, 40%, 60%, 80%, and 100% of crop evapotranspiration), with four replications. Morphological development was evaluated by measuring plant height at 24 and 31 days after transplanting. Regression analysis at $p < 0.05$ revealed that soil cover significantly enhanced early growth, with covered plants averaging 3.97 cm taller than bare-soil plants at 24 days. This positive response is attributed to improved thermal stability and reduced evaporation. By day 31, irrigation levels became a dominant predictor of growth, exhibiting a quadratic response. Plant height increased with increasing irrigation from 20% to 60%, but declined significantly at 100% saturation. This decline indicates that over-watering leads to root hypoxia and nutrient leaching, inhibiting vertical elongation. No significant interaction effect was found between the two variables, suggesting the benefits of soil cover remain consistent across varying water depths. Optimal arugula production is achieved by maintaining moderate irrigation depths (40–60%) in combination with soil cover. This management strategy stabilizes the soil microclimate and maximizes water use efficiency, mitigating the risks of both water deficit and excessive saturation.

Keywords: *Drip irrigation, Soil cover, Water use efficiency, Morphological components*



Direct Research Journal of
AGRICULTURE and
FOOD SCIENCE
(DRJAFS)

Abbreviation: Direct Res. J. Agric. and Food Sci.
ISSN: 2354-4147 | DOI: 10.26765/DRJAFS
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Citation: Ndagi, A., Awoniyi, G. O., Shaaba, M. U. & Yunusa, A. (2026). Effect of Irrigation Depths Using Soil Cover In Arugula (Eruca sativa) Cultivation. *Direct Research Journal of Agriculture and Food Science*. Vol. 14(2), Pp. 61-67. https://doi.org/10.26765/DRJAFS65500924

INTRODUCTION

Irrigation is one of the most effective practices for ensuring agricultural production in regions with irregular rainfall distribution. Irrigation management is a key factor in productive success in vegetable cultivation, particularly in areas with limited water availability (Dukes et al., 2010). The sustainability of water resources in agriculture requires the development of technologies that optimize crop productivity per quantity of water applied, a concept known as water use efficiency (Santo et al., 2021). Proper irrigation management, providing water in the correct quantity and at the right time for the crop, can significantly increase efficiency. The use of soil cover is a technique that complements irrigation management, helping to control water availability and improve irrigation system efficiency (Li et al., 2019). In drip irrigation systems, the cover can modify the distribution and retention of water in the soil, thereby directly affecting plant absorption (Kasirajan & Ngouajio, 2012). Research with other vegetables shows that cover can reduce the crop's water needs, but there is still a lack of specific data on how this impacts the arugula crop. Therefore, studying the relationship between different irrigation levels and the use of ground cover may bring new solutions to enhance crop productivity (Sinkevičienė et al., 2009).

Controlled deficit irrigation is an advanced strategy for water management that can enhance water-use efficiency without significantly compromising crop productivity (Fereres & Soriano, 2007). However, applying this technique in arugula cultivation requires a deep understanding of the crop's tolerance limits to water stress and the phenological stages most sensitive to water restriction (Becari, 2015). Therefore, investigating the productive response of arugula to varying intensities of water restriction, combined with the use of ground cover, can significantly contribute to the development of more sustainable irrigation systems.

The operating costs of irrigation systems account for a significant share of vegetable production expenses, mainly due to energy consumption in water pumping (Dukes & Muñoz-Carpena, 2020). Adjusting the amount of water applied can lead to substantial savings in energy use and production costs, especially when combined with techniques that improve irrigation efficiency. Precision in managing the irrigation of leafy vegetables requires an understanding of the relationships between soil water tension, the crop's evapotranspiration demand, and the plants' productive response (Howell, 2001). The complexity of these interactions is further amplified by the need to maintain adequate soil moisture throughout the arugula production cycle, which has a shallow root system and a high leaf area (Minami and Tessaroli Neto, 1998).

Arugula (*Eruca sativa)* is a high-water-demand crop that requires frequent irrigation due to its shallow root system and rapid growth cycle (Carvalho et al., 2020). Studies indicate that water deficiency significantly reduces productivity and leaf quality, increasing sensitivity to stress and lignification (RESENDE et al., 2019). Water is crucial for maintaining plant metabolism and photosynthetic rate, with irrigation rates of 6-8 mm·day^{1} often recommended for temperate climates (Santos et al., 2021). However, management should consider water use efficiency to avoid waste without compromising yield (Allen et al., 1998).

Given the above, the need to study the systematic of the effects of interactions between irrigation volumes and soil cover in arugula cultivation becomes evident. However, there is evidence that this interaction may lead to greater water-use efficiency and crop productivity (Pereira et al. 2009). Thus, this study aimed to fill this knowledge gap, specifically investigating whether the use of soil cover, associated with the management of irrigation with different volumes, significantly impacts water savings and the productivity of arugula cultivation, contributing to the development of technologies that reconcile environmental sustainability and economic viability in the production of leafy vegetables.

MATERIAL AND METHODS

Study area

The study was conducted at the Experimental Irrigation and Drainage Area of the Department of Agricultural Engineering of the Federal University of Viçosa, located in the city of Viçosa, Minas Gerais, Brazil (Figure 1). According to the Koppen climate classification, the region's climate is humid temperate with dry winters and hot summers, with annual precipitation of 1229 mm and an average temperature of 20.6 °C (Martins et al., 2018). The soil in the area is classified as sandy clay loam with a density of 1.3 g/cm3 obtained following recommendations from EMBRAPA (2011), and water contents equivalent to field capacity of 29% and permanent wilting point of 18%, obtained through the soil water retention curve, specifically for tensions of 30 kPa and 1500 kPa respectively, using the Richards extractor (Richards, 1949).

Figure 1: Location of the Irrigation and Drainage Experimental Area Department of Agricultural Engineering, Federal University of Viçosa (DEA-UFV) Hhighlighting the Location of the Eexperiment. Source: Google Earth Pro, 2025.

Experimental Design

The experimental design adopted was a Completely Randomized Design (CRD), in split plots, with two soil cover types (with and without cover) and five irrigation levels (20%, 40%, 60%, 80%, and 100% of the crop evapotranspiration), with four replications, totaling 40 experimental units. Each experimental unit was composed of 18 plants (Figure 2), totaling 720 plants in the experiment.

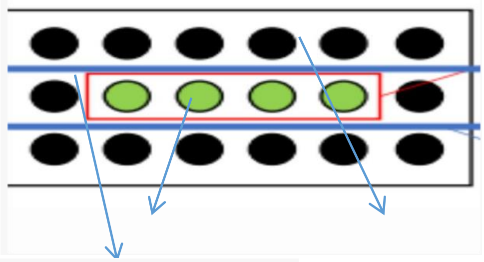

Figure 2: Eexperimental Layout

Drip Irrigation Plant selected for evaluation

Setting up the Experiment

The experiment was conducted in the field (Figure 3), using seedlings from a nursery near Federal University Viçosa, with the selected cultivar being *Roka*. The seedlings were transplanted on 05/29/2025. The spacing adopted was 10 cm between plants and 20 cm between rows, with four useful plants per block, each bed comprising three rows of the crop and two rows of drip tape. The irrigation system adopted was drip irrigation, with two polyethylene drip lines per bed and a spacing of 20 cm between emitters and lines. In order to adjust the amount of water applied to the crop to the field experiment conditions, an evaluation of the irrigation system was carried out following the methodology proposed by Keller and Karmelli (1975), which resulted in a Distribution Uniformity Coefficient (DUC) of 87%, which can be categorized as excellent.

The irrigation management of the experiment was carried out using meteorological data obtained from the Automatic Meteorological Station (A510) of INMET located in Viçosa-MG. Daily meteorological data on maximum and minimum temperatures were used to estimate the reference evapotranspiration (ETo) using the Hargreaves and Samani (1985) equation. The extraterrestrial solar radiation values used for the calculations were 9.78 and 10.15 MJ m-2 day-1. These daily ETo data were used to estimate crop Evapotranspiration (ETc) using the FAO method (1977) with a crop coefficient of 0.8. Nitrogen fertilization was applied using urea at a rate of 50 kg ha^{-1} to ensure adequate nutrient supply for crop growth and development. During the cultivation period, plant height, as a key morphological parameter, was measured at 24 and 31 days after transplanting. Measurements were obtained using a graduated ruler with a precision of 1 mm. The collected data were subjected to response surface regression analysis to evaluate the effects of irrigation levels and soil cover on plant growth. Model selection was based on the significance of regression coefficients as determined by the t-test. Significance levels of 5% and 1% probability were adopted to assess the behavior of the variables under study. All statistical analyses were performed using the R software environment.

Figure 3 - Field Eexperiment on July 3, 2025 Source: The Aauthors, 2025.

RESULTS AND DISCUSSION

The responses of arugula height to different irrigation depths and soil cover treatments are presented in (Table 1 and Figures 4 and 5). Table 1 and Figure 4 illustrate the effects of irrigation levels on arugula height at 24 and 31 days after planting, while Figure 5 shows the effects of soil cover and uncovered soil on arugula height, respectively.

Plant Height against Irrigation Level

Figure 4 presents the line graph illustrating the mean plant height of arugula at 24 and 31 days after planting under different irrigation levels (20%, 40%, 60%, 80%, and 100% soil saturation). The growth pattern revealed a progressive increase in plant height as irrigation levels increased from 20% to 60%, indicating that moderate water supply promoted vegetative development. However, a marked decline in plant height was observed at the 100% irrigation level, demonstrating a non-linear growth response. This trend supports the regression analysis, which showed a significant negative linear coefficient at the 31-day growth stage. The reduction in growth under maximum irrigation suggests that excessive water supply or over-irrigation negatively affected plant performance, possibly due to poor soil aeration and temporary waterlogging conditions that restricted root respiration and nutrient uptake.

Table 1: Mean Height of Arugula Plants according to Different Irrigation Levels with Soil Cover and without Soil Cover to the Soil Surface.

Irrigation level %	Plant height at 24 days with cover (cm)	Plant height at 24 days with no cover (cm)	Plant height at 31 days with cover (cm)	Plant height at 31 days with no cover(cm)
100	13.63	5.63	14.38	8.88
100	12.75	3.25	14.25	7.25
100	9.75	6.88	10.25	6.38
100	9.13	3.94	12.50	11.50
80	20.75	14.00	26.13	16.13
80	19.50	18.50	26.13	22.25
80	15.75	16.63	18.25	19.25
80	16.13	16.75	17.00	21.00
60	17.88	17.88	22.38	17.25
60	20.50	18.63	24.88	22.63
60	22.00	14.50	27.88	17.00
60	17.88	14.00	20.88	15.38
40	21.75	18.00	25.63	24.13
40	19.50	15.63	25.50	18.00
40	14.38	15.88	14.75	19.25
40	11.75	15.63	13.50	18.88
20	17.50	14.75	13.13	19.88
20	18.00	13.75	20.00	17.13
20	14.88	10.13	15.75	11.50
20	0.00	2.13	0.00	8.25

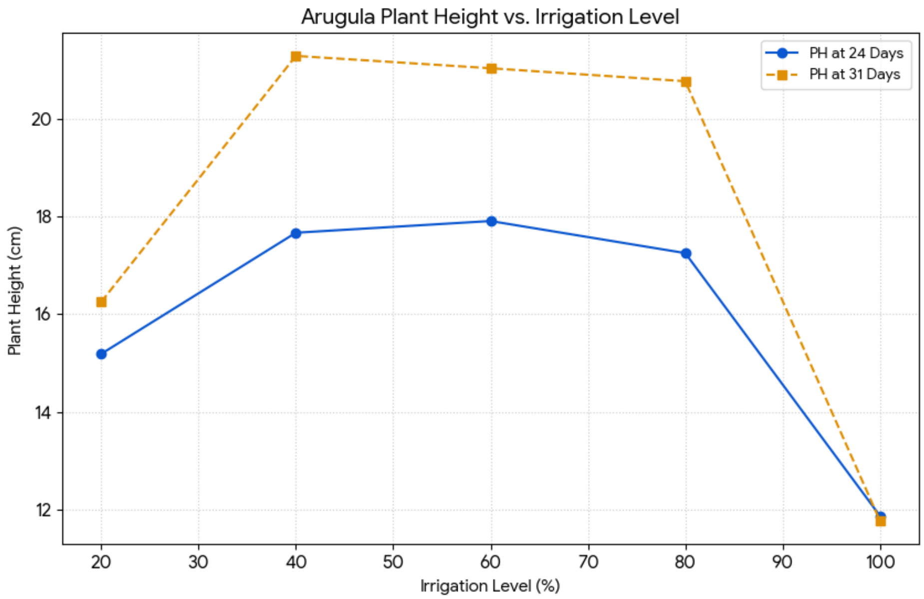

Figure 4: Effect of Irrigation level on Arugula Plant Height

Plant Height against Soil Cover and No Cover

Figure 5 presents a bar chart comparing the average height of plants grown with soil cover and those without. The graph clearly shows that soil cover leads to taller plants at both 24 and 31 days. This visual aligns with the high statistical significance of the Soil Cover variable in the model ($p > 0.05$). The difference between the bars represents the growth advantage provided by covering, which enhances moisture retention and creates a more stable thermal environment for the roots. These visualizations confirm that while irrigation is essential, it must be managed within an optimal range (40-60%) to avoid growth inhibition, whereas the application of soil cover provides a consistent and significant boost to the vertical development of arugula. The regression model equation that describes the height of Arugula can be generally written as:

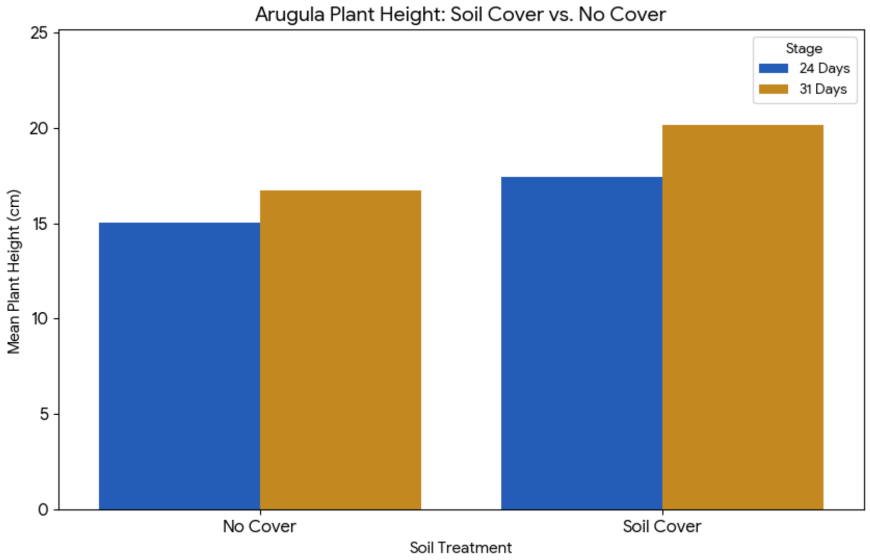

Figure 5: Effect of Soil Cover and No Cover on Arugula Plant Height

$$\gamma = \beta_0 + \beta_1 I + \beta_2 CN + \beta_3 ICN \tag{1}$$

Where
γ_i is the Plant Height, I is the Irrigation Level, CN is the Soil Cover, I and CN are the interaction term between irrigation and soil cover.

Regression Model for Plant Height at 24 Days

$$\gamma_1 = 16.3643 - 0.0229I + 3.9662CN - 0.244ICN \tag{2}$$

Regression Model for Plant Height at 31 Days

$$\gamma_2 = 19.8377 - 0.0524I + 3.8683CN - 0.0039ICN \tag{3}$$

The regression analysis conducted at a 5% significance level ($p \leq 0.05$) revealed that both irrigation depth and soil cover significantly influenced the vegetative growth of arugula (Eruca sativa), although the magnitude of their effects varied throughout the growth period. At 24 days after planting, soil cover had a highly significant effect on plant height, with plants grown under covered soil conditions recording an average increase of approximately 3.97 cm compared to those cultivated on uncovered soil. This response may be attributed to the ability of soil cover to stabilize soil temperature and reduce water loss through evaporation, which is particularly beneficial for leafy vegetables such as arugula that possess shallow root systems and high transpiration rates, as reported by Silva et al. (2020). At 31 days after planting, irrigation level became statistically significant and exhibited a negative linear coefficient ($\beta = -0.052$), indicating that excessive irrigation adversely affected plant growth. Analysis of the raw data further showed that arugula height increased under moderate irrigation levels (40–60% of soil saturation), whereas plant growth declined considerably at full soil saturation (100%), suggesting that excessive water availability may have caused temporary waterlogging and reduced root aeration. This suggests a threshold at which excessive moisture may cause root hypoxia (oxygen deficiency) or nutrient leaching (nutrient loss), inhibiting vertical growth (Freitas et al., 2017). At 31 days, soil cover remained positive, but its statistical significance fell below the 0.05 threshold, suggesting that as growth continues, the water regime will have the primary influence. These findings match recent literature, which notes arugula's quadratic response (growth rises then falls with increasing water) to watering optimal when moderate deficit irrigation is paired with soil cover (Çakmakcı, 2025). No significant interaction effect ($p > 0.05$) between irrigation and soil cover occurred, indicating that the benefits of soil cover on moisture and microclimate (local conditions around the plant) remain consistent regardless of irrigation depth. This supports the use of soil cover as a strategy to enhance crop uniformity and height in tropical and subtropical systems (Torres et al., 2024; Kosterna, 2014).

Moisture Retention and Temperature Regulation

In this study, soil cover (a layer of organic or synthetic material placed on the soil surface) acts as a physical barrier that reduces soil water evaporation and maintains consistent moisture levels in the root zone (soils surrounding the plant's roots). This is vital for arugula, which has a shallow root system (roots close to the soil surface) and is highly sensitive to moisture fluctuations. As reported by Cultivated Earth (2026) and Kosterna (2014), soil cover improves the soil's thermal conditions (temperature stability), often leading to taller above-ground parts and larger leaf areas compared to cultivation in open soil.

Reduced Stress and Weed Suppression

By stabilizing soil temperatures and suppressing weed competition (preventing unwanted plants from growing and taking resources), soil cover allows the plant to allocate more energy toward vegetative vertical growth rather than competing for nutrients or surviving heat stress. This explains why the positive effect was so pronounced early in the cycle (24 days), establishing a stronger structural foundation for the plant, which agrees with (Freitas et al., 2017)

Effect of Irrigation Level (I) on Arugula Production

The data demonstrate that arugula is highly sensitive to the volume of water applied (irrigation level, i.e., the percentage of soil water saturation). Maximum heights were observed at the 60% irrigation level (21.78 cm with soil cover). This quadratic behavior (where growth increases with rising water up to a point, then decreases) is consistent with findings by (Freitas et al. 2017), who noted that while arugula requires consistent moisture, excessive irrigation can lead to diminishing returns in plant height and yield. The severe stunting observed at 100% irrigation without cover (mean height of 7.50 cm) likely indicates waterlogging-induced hypoxia (a lack of oxygen for roots due to excess water). Excessive water in the root zone limits oxygen availability, which is essential for root respiration (energy creation in roots) and nutrient uptake. The impact of irrigation became more statistically significant as the plants matured. By day 31, the irrigation level showed a significant effect ($p = 0.05$); however, the negative coefficient ($\beta = -0.052$) indicates that increasing irrigation linearly did not result in taller plants at the highest levels.

Over-Irrigation Threshold

Arugula requires adequate water, but excessive irrigation can lead to growth inhibition. The data from this study showed a sharp decline in height at the 100% irrigation level compared to the 40% and 60% levels. This suggests a quadratic response (growth increases with moderate water but declines with excessive water), with moderate water application optimal. (Silva et al. 2020) observed that while arugula is responsive to irrigation, water use efficiency (WUE, meaning the amount of yield per unit of water used) is often highest at lower to intermediate irrigation depths. Excessive water can cause soil saturation, leading to anaerobic conditions in the root zone (where there is little or no oxygen available to roots, called hypoxia), which result in stunted cell elongation and also diminished vertical growth.

Water Sensitivity

While arugula is considered somewhat drought-tolerant (can survive short dry periods), its rapid growth cycle means that any water stress (insufficient or excessive water), either deficit or excess, can have irreversible effects on final height (Freitas et al., 2017; Çakmakcı, 2025). The transition of irrigation from a non-significant factor at 24 days to a significant one at 31 days indicates that the cumulative effect (combined or accumulated impact) of the water regime (total pattern of water application) is more critical during the late vegetative stage when biomass accumulation (increase in plant mass) peaks.

Interaction and Synergistic Effects

The interaction between irrigation treatments (different water volumes applied) and soil cover did not show a statistically significant difference. However, when evaluating the isolated effects of each treatment, significant differences were observed. The interaction between irrigation and soil cover was particularly evident at the extreme 100% level. In bare soil (soil without any protective cover), the plants suffered the most (7.50 cm), whereas soil cover mitigated this impact, maintaining a height of 12.08 cm. This suggests that soil cover may help prevent the physical barrier (compaction or crusting at the soil surface) under high water application, potentially improving aeration (air movement in the soil for roots) and moisture distribution compared with bare soil. This aligns with the principle that mulch (a type of soil cover) helps maintain soil structure and prevents the negative impacts of water saturation (Almhemed & Ustuner, 2023). The best results were obtained with moderate irrigation (40-60%) and soil cover, confirming the findings of Freitas et al. (2017). Soil cover buffers against moisture loss and physical crusting, extending the benefit of applied water in both moderate and high-irrigation bare-soil scenarios.

Conclusion

Arugula growth benefits most from moderate irrigation (40–60%) with soil cover. Each factor’s influence varies by growth stage, underscoring the need for precise water and soil management. Growth follows a quadratic trend: plant height increases with irrigation from 20% to 60%, but drops at full saturation due to likely root hypoxia and nutrient leaching. Soil cover provides consistent height gains and stabilizes conditions by reducing moisture loss and competition.

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