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Original Research Article

Effects of Biopore Infiltration Holes Depth and Filling Media on Infiltration Rate in Different Soil Types

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Abstract

Biopore infiltration holes are widely used as a simple and environmentally friendly approach to improve soil infiltration and reduce surface runoff in built-up areas. However, the combined effects of hole depth and filling media under different soil types have not been clearly elucidated. This study aimed to evaluate the effects of depth and filling media variations on the infiltration performance of biopore infiltration holes and to determine the most effective treatment combination under different soil conditions. An experimental study was conducted at two sites in Semarang, Indonesia, representing clay and clay-loam soils. Three hole depths (100, 75, and 50 cm) and three types of filling media (leaf litter, fruit waste, and mixed organic waste) were tested. Infiltration was measured using a double-ring infiltrometer and analyzed using the Horton model, non-parametric statistics, and a generalized linear mixed model. The results showed that infiltration increased until week 3 and declined in weeks 4 and 5 at both sites. Depth and filling media did not significantly affect the infiltration rate, but the 75 cm depth combined with fruit waste showed the most recommended configuration and consistent infiltration response.

Keywords: Biopore infiltration holes; infiltration rate; organic waste; water infiltration

1. Introduction

Water has become an increasingly critical resource amid climate crises and expanding development. Approximately 80 metropolitan cities worldwide have experienced water crises over the past decade (Savelli et al., 2023), and one-third of the global urban population is projected to face water scarcity by 2050 (Narayan and Davis, 2023). Rapid urbanization, land-use changes, and population growth have significantly increased water demand in urban areas (Koop and Van Leeuwen, 2017). This growing demand has contributed to water scarcity and declining soil quality (Biswas and Gangwar, 2021).

Biopore infiltration holes (BIHs) are simple technologies that have been widely developed to enhance water infiltration into the soil, reduce waterlogging, and support groundwater conservation. Several studies have shown that the effectiveness of BIHs is influenced by both technical design and site-specific environmental conditions. In built-up areas, BIHs are particularly important because land cover change and soil compaction tend to reduce infiltration capacity and increase surface runoff (Annisa and Maknun, 2024).

Previous studies have examined the application of BIHs under different conditions. Santosa (2018) evaluated the effectiveness of fruit waste as a filling medium in BIHs at a depth of 100 cm and found that banana fruit waste was more effective in increasing infiltration. Setiawan and Rohmat (2019) applied BIHs at a depth of 35 cm and found that grass planted around the holes contributed to increased infiltration, although the study did not use organic waste as a filling material. BIHs have also been applied in agricultural land, including oil palm plantations (Devianti et al., 2019), coffee plantations (Hanuf et al., 2021), and clove plantations (Umasugi et al., 2021). These findings indicate that BIHs have a broad potential for improving infiltration across different land-use types. Ichsan and Hulalata (2018) further reported that a single biopore infiltration hole on a 100 m^2 plot could reduce runoff discharge by 10.82%. However, achieving most promising infiltration performance through BIH application requires an effective hole depth determination. In addition to depth, the filling medium is another factor affecting BIH performance. Andrade et al., (2021) stated that infiltration rate is influenced by the type of waste used, while (Santosa, 2018) reported that under low-porosity soil conditions, organic waste filling media reached an effectiveness value of 41.06%.

However, previous studies have generally been limited to the application of a single depth variation at a single location with one soil type. In studies focusing on BIH infiltration performance, the depth used has also tended to be fixed and has not clearly identified the most promising depth for achieving the best infiltration response (Devianti et al., 2019). In addition, the presence of organic waste inside BIHs has been more often associated with its composting function than specifically analyzed in relation to infiltration rate. Dammayatri et al. (2023) explained that the primary function of BIHs is to improve infiltration, reduce waterlogging, support groundwater management, and maintain environmental sustainability. In contrast, Sumartono et al. (2023) and Sarminingsih et al. (2023) showed that BIHs can also be used as a medium for composting organic waste. This raises a scientific question as to whether the addition of organic waste as a filling material may simultaneously affect the infiltration performance of BIHs.

Based on this review, it is evident that no previous study has systematically examined the combined effects of BIH depth and filling media type on infiltration performance across different soil types, as existing research has largely tested these factors in isolation at a single site with a single soil type. Therefore, a study comparing the combination of these factors is important for determining the most effective and context-specific BIH design according to local soil characteristics. Therefore, a study comparing the combination of these factors is important for determining the most effective and context-specific BIHs design according to local soil characteristics. Accordingly, this study aimed to analyze the effect of biopore infiltration hole depth and filling media variations on runoff infiltration capacity under different soil types and to determine the most effective design combination for improving infiltration performance.

2. Methods

2.1 Study Area

The study was conducted at two locations in Semarang, Central Java, Indonesia: the Faculty of Engineering Park, Universitas Diponegoro (location 1) and North Tlogosari Road VIB, Tembalang District (location 2). These locations were selected to represent different soil types for evaluating the infiltration performance of the biopore infiltration holes. Based on the Semarang soil type map, the first site was dominated by dark brown Mediterranean soil, whereas the second site was characterized by reddish soil. Preliminary field observations confirmed differences in soil characteristics between the two sites. Site selection further considered the technical criteria for biopore infiltration hole placement according to SNI 03-2453-2002, including safe distances from building foundations, clean water wells, and septic tanks, as well as relatively flat land.

2.2 Experimental Design

An experimental study was conducted to assess the influence of treatment variations on the infiltration performance of biopore infiltration holes at two locations with different soil characteristics. A total of 18 biopore infiltration holes were prepared, comprising 9 holes at each of the two study sites. The holes were installed with a spacing of 1 m between the adjacent units. The experimental factors included variations in the hole depth and filling media. The measured response variables were soil permeability and infiltration rates. Infiltration testing was performed 5 times for each treatment at 7 day intervals over a 35 day experimental period. The detailed treatment is presented in Table 1.

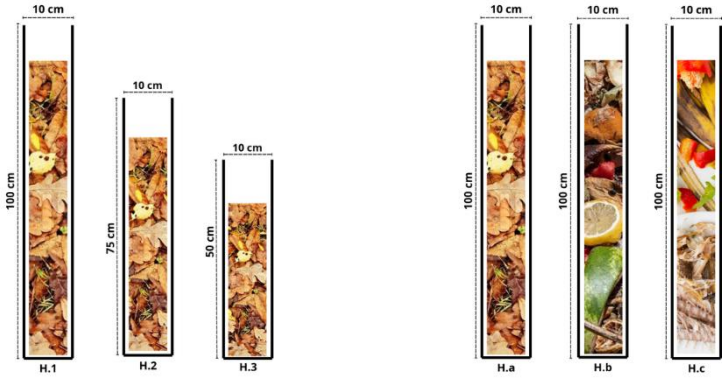
Table 1. Biopore infiltration hole (BIH) treatments by location, depth, and filling media

Location	BIH Code	Depth (cm)	Filling Media
Location 1	H1a	100	Leaf litter
	H1b	100	Fruit waste
	H1c	100	Mixed organic waste
	H2a	75	Leaf litter
	H2b	75	Fruit waste
	H2c	75	Mixed organic waste
	H3a	50	Leaf litter
	H3b	50	Fruit waste
	H3c	50	Mixed organic waste
Location 2	R1a	100	Leaf litter
	R1b	100	Fruit waste
	R1c	100	Mixed organic waste
	R2a	75	Leaf litter
	R2b	75	Fruit waste
	R2c	75	Mixed organic waste
	R3a	50	Leaf litter
	R3b	50	Fruit waste
	R3c	50	Mixed organic waste

2.3 Treatment Variables and Biopore Configuration

The experimental treatments consisted of two main factors: hole depth and filling media type. Three depth levels were applied, namely 100, 75, and 50 cm, while the filling media consisted of leaf litter, fruit waste, and mixed organic waste. The filling media were placed into each biopore infiltration hole according to the assigned treatment. For all depth treatments, the media were inserted while leaving approximately 5 cm of empty space at the upper part of the hole. This empty space was maintained consistently across all treatments to prevent overflow, allow water to enter the hole during infiltration testing, and ensure comparable filling conditions among the treatment units.

The combination of the three depth levels and three filling media types produced nine treatment combinations at each study site. The treatment codes were assigned based on depth and media type. The numeric code represents hole depth, where 1 = 100 cm, 2 = 75 cm, and 3 = 50 cm. The letter code represents filling media, where a = leaf litter, b = fruit waste, and c = mixed organic waste. The letter H refers to Location 1, while the letter R refers to Location 2. The schematic treatment configuration used in this study is shown in Figure 1. The detailed spatial arrangement of the nine biopore infiltration holes in this study is shown in Figure 2.



(a) (b)

Figure 1. Schematic configuration: (a) depth variations and (b) filling media variations

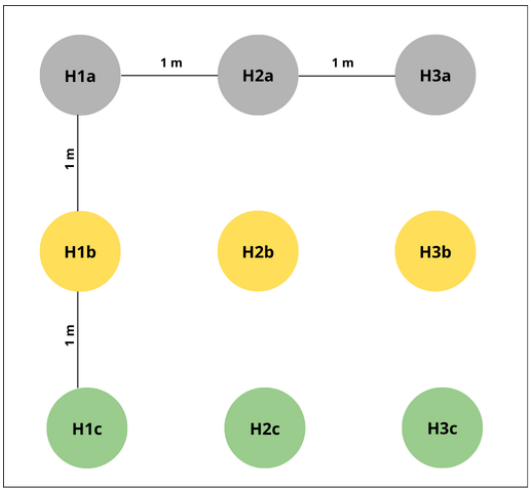


Figure 2. Spatial arrangement of biopore infiltration hole treatment units at each study site.

Based on Figure 2, the holes were installed with a spacing of 1 m between the adjacent units. This distance was selected because it falls within the commonly recommended spacing range of 0.5–1.0 m for biopore infiltration holes, while also providing sufficient separation to reduce possible hydraulic interference among neighbouring holes during repeated infiltration measurements.

2.4 Soil Sampling and Characterization

Soil sampling was conducted prior to the installation of the biopore infiltration holes to characterize soil conditions at each study site. The sampling procedure followed SNI 19-2487-2002, and representative sampling points were selected by considering soil variability, environmental conditions, and research objectives. Soil samples were collected from two sampling points, with the sampling depth kept consistent at each point to ensure comparability between locations. A soil auger was used for sample collection, and the auger was inserted vertically to minimize cross-contamination from upper soil layers. After collection, the samples were stored in airtight and properly labeled containers indicating the sampling location, date, depth and soil type. The samples were then transported to the Soil Laboratory of Syslab Semarang for further analyses. In this study, soil characterization focused on determining soil permeability as the main parameter used to represent the infiltration-related characteristics of the two study sites.

2.5 Infiltration Measurement

Infiltration measurements were performed using a double-ring infiltrometer to evaluate the infiltration response of the soil surrounding each biopore infiltration hole. The instrument consisted of an inner ring with a diameter of 15 cm, an outer ring with a diameter of 30 cm, and a height of 20 cm (Rauber et al., 2024). For each treatment unit, a double-ring infiltrometer was installed at a distance of 5 cm from the biopore infiltration hole. The rings were inserted vertically into the soil to a depth of approximately 10-15 cm to minimize water leakage from the base and ensure stable installation during the test (Balogun and Nasirudeen, 2025).

Prior to the measurements, water was poured into both the inner and outer rings until the water level reached 15 cm. During the test, the water level was maintained to keep the hydraulic head as constant as possible. Infiltration observations were conducted by recording the decrease in water level at 5-minute intervals over a total measurement period of 25 minutes (Rauber et al., 2024). To obtain more stable and representative results, the infiltration test at each point was repeated 5 times. The infiltration rate was analyzed using the Horton infiltration model, expressed as:

$$F = fc + (fo - fc)\, e^{-kt} \quad (1)$$

In Eq. (1) where F is the infiltration rate (mm/min), f_c is the constant infiltration rate (mm/min), f_0 is the initial infiltration rate (mm/min), k is the infiltration decay constant, and t is time. In this study, f_c was determined when the soil approached saturation and the infiltration rate became relatively constant, while f_o was obtained from the first infiltration measurement when the soil was relatively dry. The value of k was determined based on the decline pattern of the infiltration rate during the measurement period and reflected the physical characteristics of the soil at each study site.

2.6 Data Analysis

The infiltration data obtained from field measurements and subsequent Horton model fitting were statistically analyzed to assess the effects of hole depth, filling media, and soil type on the infiltration performance of the biopore infiltration holes. All analyses were conducted using the IBM SPSS Statistics 22 software. Differences between two independent groups were evaluated using the Mann-Whitney U test, whereas differences among multiple treatment groups were examined using the Kruskal-Wallis test. In addition, a Generalized Linear Mixed Model (GLMM) was applied to accommodate grouped data structures and repeated measurements, as well as to further examine the effects of treatment factors on the infiltration response The recommended configuration was identified based on estimated marginal means and descriptive response patterns, while considering results of the statistical analysis.

3. Result and Discussion

3.1 Result of Soil Characteristics and Infiltration Rate Value

Initial soil characterization was conducted to identify the baseline physical and chemical properties of the two study sites before discussing the infiltration response of the biopore infiltration holes. Soil texture, permeability, and C-organic content were analyzed because these parameters may influence the soil's capacity to transmit and retain water. The results of soil characterization are summarized in Table 2.

Table 2. Soil characteristics

Sampling Location	Parameter	Result	Unit
Location 1	Permeability	1.95	cm/hour
		0.0325	cm/min
	C-organic	1.16	%
	Soil texture		
	Sand	39.2	%

Sampling Location	Parameter	Result	Unit
	Silt	19.7	%
	Clay	41.1	%
Location 2	Permeability	2.18	cm/hour
		0.0363	cm/min
	C-organic	1.57	%
	Soil texture		
	Sand	29.2	%
	Silt	36.5	%
	Clay	34.3	%

Based on Table 2, the results of soil characterization showed differences in texture, permeability, and C-organic content in the two study sites. The soil at the Faculty of Engineering, Universitas Diponegoro (location 1), was classified as clay, with a composition of 41.1% clay, 39.2% sand, and 19.7% silt. The soil at North Tlogosari Road VIB (location 2), Tembalang District was classified as clay loam, with a composition of 34.3% clay, 29.2% sand, and 36.5% silt. The permeability at the second site was also slightly higher, reaching 2.18 cm/h (0.0363 cm/min), compared with 1.95 cm/h (0.0325 cm/min) at the first site. Similarly, the C-organic content at the second site (1.57%) was higher than that at the first site (1.16%).

From a hydrological perspective, soil texture strongly influences infiltration because fine-textured soils with high clay content tend to have smaller pore spaces, lower pore connectivity, and lower hydraulic conductivity. Therefore, clay-dominated soils are generally expected to restrict water movement more strongly than clay-loam soils. This interpretation is consistent with previous studies reporting that infiltration variability is controlled not only by soil texture, but also by soil structure, hydraulic conductivity, bulk density, porosity, and antecedent moisture conditions (Sharghi S. et al., 2025). In this study, the slightly higher permeability observed at Location 2 supports the expectation that clay-loam soil can provide a more responsive infiltration environment than clay soil.

The higher C-organic content at Location 2 may also contribute to better infiltration conditions. Organic matter can improve soil aggregation, increase pore stability, and support the formation of preferential flow pathways, thereby enhancing water movement through the soil matrix. Previous studies have similarly shown that organic matter and soil physical properties play important roles in regulating infiltration capacity and hydraulic conductivity (Bondì et al., 2022). Therefore, the differences in soil texture, permeability, and C-organic content between the two sites provide an initial justification for comparing BIH performance under different soil conditions. However, because the permeability difference between the two sites was relatively small, the subsequent infiltration response may also be influenced by treatment configuration, temporal changes, and field moisture conditions rather than just the texture of soil. To examine the temporal response of infiltration during the observation period, the infiltration rates at both study sites were evaluated from Week 1 to Week 5 based on the Horton model results. The temporal patterns of infiltration at locations 1 and 2 are presented in Figure 2 and 3, respectively.

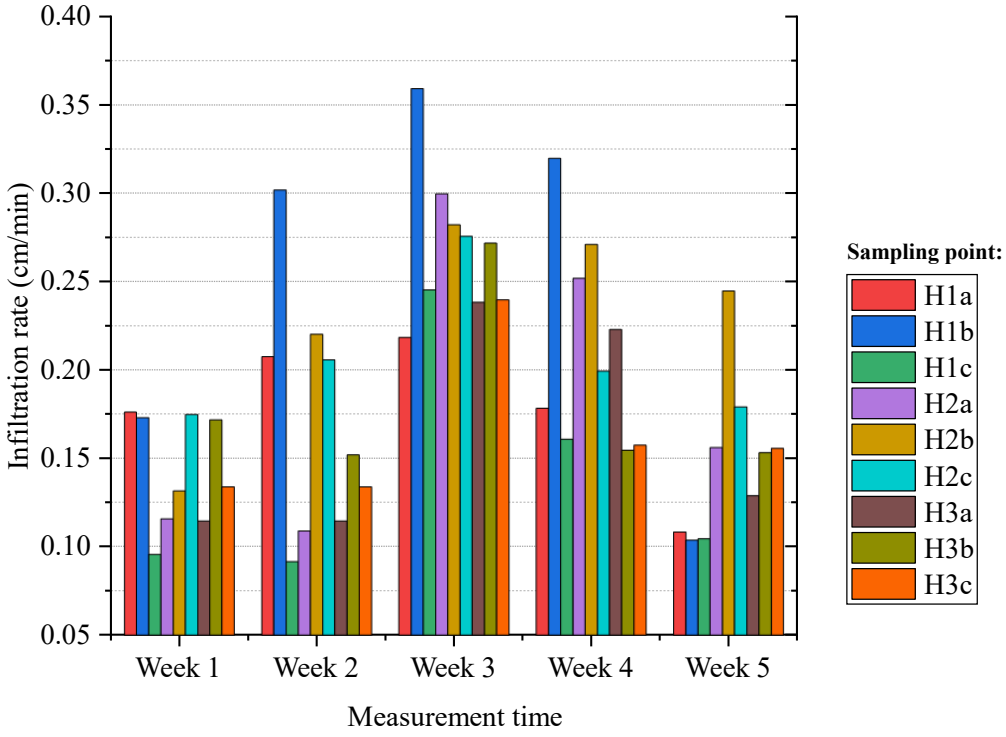


Figure 3. Infiltration rate at location 1

As shown in Figure 3, the infiltration rate at location 1 generally increased from the beginning of the observation period and reached its peak in Week 3 before declining in Weeks 4 and 5. Overall, the infiltration values at this site ranged from 0.092 to 0.359 cm/min. The highest value was recorded at sampling point H1b in Week 3 (0.359 cm/min), followed by H2a (0.300 cm/min), H2b (0.282 cm/min), and H2c (0.276 cm/min). After this peak period, infiltration decreased across all sampling points, although some treatments, such as H1b and H2b, maintained relatively high values in Week 4. By Week 5, the decline continued, indicating that the infiltration response at location 1 was strongly influenced by the temporal field conditions.

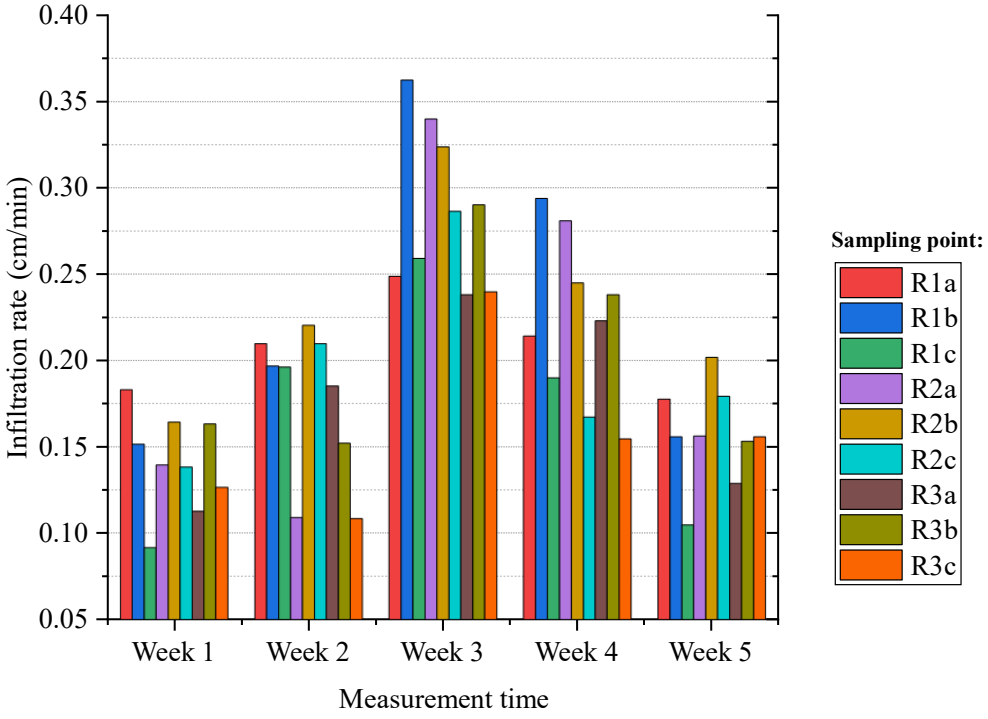


Figure 4. Infiltration rate at location 2

A similar temporal pattern was observed at location 2 (Figure 4). Infiltration rates also increased from week 1 to week 3, followed by a decline in weeks 4 and 5. At this site, the infiltration values ranged from 0.092 to 0.362 cm/min, with the highest value recorded at R1b in Week 3 (0.362 cm/min). Other relatively high values in the same week were observed for R2a (0.340 cm/min) and R2b (0.324 cm/min). Although infiltration decreased after Week 3, several sampling points at location 2 tended to retain slightly higher values during the post-peak period.

3.2 Effect of Hole Depth on Infiltration Performance

The hole depth was treated as one of the main experimental factors to evaluate its influence on the infiltration performance. Conceptually, increasing the depth of a biopore infiltration hole is expected to create a longer vertical flow path and enlarge the contact area between water and the surrounding soil, thereby facilitating the downward movement of water. However, the statistical results of this study showed that depth variation did not significantly affect the infiltration rate, as indicated by the Kruskal-Wallis test ($p > 0.05$). Based on Table 4, treatment variation did not produce statistically significant differences in the infiltration rate. The comparison among depth levels yielded a p-value of 0.228 (location 1) and 0.359 (location 2), indicating that the infiltration responses at 100, 75, and 50 cm were not significantly different from each other. Mechanistically, the absence of a significant depth effect may be explained by the presence of a hydraulic bottleneck in the soil surrounding the biopore. In other words, even when the hole was made deeper, infiltration remained controlled by the least permeable soil layer around the hole wall and base. Studies on layered soils have shown that infiltration patterns may be strongly altered by less permeable subsurface layers, and these effects may only become evident through detailed analysis (Prima et al., 2024). Recent studies have also highlighted that infiltration capacity is jointly controlled by bulk density, porosity, and fine particle content, all of which may vary with soil depth (Wang et al., 2024; Al-Ogaidi et al., 2023).

This finding suggests that the effectiveness of increasing the hole depth was constrained by the ability of the surrounding soil to transmit water, rather than by the geometric depth of the hole alone. Similar observations have been reported by Berdouki et al. (2024) and Geleta et al. (2025), who stated that

deeper infiltration structures do not necessarily produce higher infiltration because their performance remains limited by hydraulic conductivity, soil layering, and antecedent moisture conditions. In the present study, the contrast between the two sites supports this interpretation. Although location 2 had slightly more favorable soil properties, including clay loam texture and somewhat higher permeability, the difference between the two sites was relatively small, indicating that soil texture alone could not fully explain the variation in infiltration performance. This is consistent with Sharghi et al. (2025), who emphasized that infiltration variability cannot be explained solely by soil texture but is also controlled by the soil group, land use, and soil structure.

Table 3. Significance analysis of depth variation comparison

Analysis	Location	Statistical Test	p-value	Decision (α=0.05)
Depth Comparison	Location 1	Kruskal-Wallis	0.228	Not significant
	Location 2	Kruskal-Wallis	0.359	Not significant

3.3 Effect of Filling Media on Infiltration Performance

The filling media used in this study consisted of leaf litter, fruit waste, and organic waste. In principle, organic media may influence infiltration by stimulating microbial and soil fauna activity, promoting the formation of additional pores, and improving the soil structure and porosity. Syarof et al., (2025) reported that the application of biopore infiltration holes can increase nutrient availability, indicating active biological processes in the soil surrounding the hole. Simultaneously, the composition of organic media may also produce different responses because decomposed organic matter can improve soil water absorption, whereas undecomposed fractions or fine particulates may reduce infiltration through pore clogging. Thus, the effect of the filling media is indirect and depends on the composting process and the resulting changes in the physical properties of the soil adjacent to the biopore wall. Previous studies have shown that compost and organic matter can improve soil hydrological function by modifying soil structure and porosity, although the magnitude of the effect depends strongly on the type of material, maturity, and application rate (Bondì et al., 2022). Likewise, Fitria et al. (2023) found that organic filling materials in biopore systems may increase soil hydraulic conductivity. Wang et al. (2023) emphasized that hydraulic conductivity and macropore characteristics remain the main controls of infiltration and percolation.

Table 4. Significance analysis of filling media variation comparison

Analysis	Location	Statistical Test	p-value	Decision (α=0.05)
Filling Media Comparison	Location 1	Kruskal-Wallis	0.362	Not significant
	Location 2	Kruskal-Wallis	0.297	Not significant

Despite this strong theoretical basis, the statistical analysis in the present study showed that the effect of the filling media on the infiltration rate was not significant. However, the statistical results of this study showed that filling media variation did not significantly affect the infiltration rate, as indicated by the Kruskal-Wallis test ($p > 0.05$). Based on Table 5, at location 1, the Kruskal-Wallis test showed a non-significant result with a p-value of 0.362, whereas at location 2, the corresponding p-value was 0.297. These findings indicate that under the field conditions of this study, differences in filling media were not strong enough to generate statistically distinguishable infiltration responses.

The empirical results showed a consistent trend across the two sites. The estimated means indicated that fruit waste produced the highest mean infiltration rate, namely 0.208 cm/min at location 1 and 0.213 cm/min at location 2, respectively. Theoretically, fruit waste tends to decompose more readily and provide microbial substrates more rapidly (Kim et al., 2024), potentially accelerating biological and physical changes around the infiltration hole within a relatively short period. The next highest estimated means were observed for leaf litter, amounting to 0.172 cm/min at location 1, and 0.190 cm/min at location 2. In terms of material characteristics, leaf litter generally has a more fibrous structure and therefore decomposes more slowly (Keerthika et al., 2024), meaning that its influence on infiltration is likely to develop more gradually through medium-term improvement in soil structure. Although the heterogeneous nature of mixed media may provide a wider range of organic substrates, it may also generate fine fractions or organic solutions capable of blocking small pores (pore blocking) when decomposition products accumulate within the infiltration zone (Rabbi et al., 2024). The accumulation of organic decomposition products and their contribution to pore clogging have also been reported in soil infiltration studies by Perujo et al. (2019). From a mechanistic perspective, mixed media do not necessarily produce the most favorable infiltration response, and this pattern further indicates that fruit waste tends to be more responsive in supporting infiltration during the observation period. This pattern indicates that certain media can create conditions that favor infiltration, although the differences were not strong enough to be declared statistically significant in the dataset of this study. This is understandable because the effects of organic media are not instantaneous; they require time, responsive soil conditions, and a stable decomposition process before they appear as measurable differences in infiltration rates.

3.4 Recommended Biopore Configuration

The estimated mean analysis was used to identify the most promising treatment trend after considering the combined influence of hole depth, filling media, and measurement time. As shown in Table 6, the 75 cm depth produced the highest mean infiltration values at both sites, namely 0.198 at location 1, and 0.207 at location 2. For the filling media factor, fruit waste also showed the highest values, reaching 0.208 at location 1 and 0.213 at location 2, respectively. In terms of measurement time, the highest values at both sites occurred in Week 3, with 0.268 at location 1 and 0.287 at location 2, respectively. This pattern suggests that the infiltration response developed progressively until the middle of the observation period and then declined in the following weeks. This trend is consistent with the view that field infiltration is not static but evolves with the development of effective pore networks, biological activity around the hole, and changes in soil moisture conditions during the observation period (Guo et al., 2025; Al-Ogaidi et al., 2023).

A more detailed pattern is presented in Table 7, which presents the combinations of hole depth and filling media. At location 1, the highest value was observed for the 100 cm + fruit waste combination, with an estimated mean of 0.244, whereas at location 2, the highest value was recorded for 75 cm + fruit waste, with 0.230. Although the 100 cm depth produced the highest single value at one site, the overall pattern across both locations indicated that the 75 cm depth was more consistently associated with relatively high infiltration values. Therefore, the interpretation should not rely solely on one peak value but also consider the stability of the response across sites and treatment combinations. In this context, the 75 cm depth appears to be a more representative and promising option. This interpretation is in line with studies showing that increasing depth does not necessarily lead to higher infiltration, as water movement remains controlled by surrounding soil properties, including soil structure, less permeable subsurface layers, porosity, and fine particle content (Bondì et al., 2022).

With respect to filling media, fruit waste showed the most favorable tendency under the two different soil conditions. This pattern suggests that certain types of organic material may provide a more supportive environment for pore development and water movement than leaf litter or mixed organic waste. Such a result is plausible because organic materials are closely related to microbial activity, soil

aggregation, and changes in porosity, although the strength of their effect still depends on material characteristics and site-specific soil conditions. Considering the trends observed in both the single-factor and combined-treatment analyses, the configuration of 75 cm depth with fruit waste as filling media can be regarded as the most suitable option recommended by this study. This recommendation is not based solely on the highest value observed at a single point, but rather on a response pattern that appeared relatively more stable and recurrent across the two study sites.

Table 5. Estimated means of depth, filling media, and measurement time

Variable		Estimated Means	
		Location 1	Location 2
Depth	100cm	0.181	0.185
	75cm	0.198	0.207
	50cm	0.167	0.177
Filling media	Leaf litter	0.172	0.190
	Fruit waste	0.208	0.213
	Mixed organic waste	0.167	0.167
Measurement time	Week 1	0.143	0.139
	Week 2	0.166	0.177
	Week 3	0.268	0.287
	Week 4	0.209	0.222
	Week 5	0.148	0.155

Table 6. Estimated means of depth and filling media combinations

Depth	Filling media	Estimated Means	
		Location 1	Location 2
100cm	Leaf litter	0.158	0.220
	Fruit waste	0.244	0.209
	Mixed organic waste	0.152	0.139
75cm	Leaf litter	0.196	0.196
	Fruit waste	0.206	0.230
	Mixed organic waste	0.191	0.197
50cm	Leaf litter	0.164	0.160
	Fruit waste	0.178	0.202
	Mixed organic waste	0.160	0.172

4. Conclusions

The results showed that variations in biopore infiltration hole depth and filling media did not have a statistically significant effect on infiltration rate under the field conditions of this study. This pattern was consistent at both study sites, despite differences in soil characteristics between location 1 (clay) and location 2 (clay loam). Nevertheless, the descriptive pattern and estimated means indicated that the 75 cm depth and fruit waste filling media tended to produce the most favorable infiltration response across the two soil types. Therefore, the combination of 75 cm depth and fruit waste can be considered the most promising biopore configuration in this study, although further verification with longer observation periods and more extensive replication is still required.

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Ethics Statement

This study did not involve human participants, animals, or personal data. Therefore, formal ethical approval was not required.

CRediT Author Statement

Anik Sarminingsih: Conceptualization, Supervision, Validation, Methodology, Review; **Heru Wandra**: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing - original draft; **Budi Prasetyo Samandikun**: Supervision, Validation, Resources, Writing - review & editing; **Surya Prayoga**: Writing - review & editing.

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