

Infiltration Modeling Using Horton's Equation on Longbean (*Vigna sinensis* L.) Cultivation with Organic Fertilizer Treatment

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Abstract

Infiltration is the process by which water enters the soil, generally (but not necessarily) through the surface and vertically. This study aimed to determine the effect of organic fertilizer in chicken and cow manures on soil infiltration in long bean cultivation. This research was conducted in Tunggulo Village, Tilongkabila Sub- District, Bone Bolango Regency, Gorontalo Province, from February to April 2025. This study employed a Randomized Block Design with five treatment levels and three repetitions. Infiltration was measured using a double-ring infiltrometer and analyzed using Horton's model. Based on the analysis, the fertilizer-free treatment (P0) exhibited the highest infiltration capacity with an infiltration rate of 63.37 mm hour⁻¹ and was considered fast according to the Kohnke infiltration classification. Meanwhile, the lowest infiltration capacity was found in the treatment of organic fertilizer in chicken manure with a dose of 10 tons ha⁻¹ (P1), with an infiltration rate of 18.20 mm hour⁻¹ (rather slow). Linear regression analysis revealed a negative relationship between constant infiltration and production, where the constant infiltration factor accounted for only 47.36% of the variation in long bean production, suggesting that excessive infiltration can lead to nutrient leaching from the root zone. The results of the analysis showed that the treatment of organic fertilizer did not have a significant effect on the capacity and rate of infiltration. Based on Horton's model, the highest infiltration capacity was found in the treatment without fertilizer, followed by the treatment with organic fertilizer from chicken manure at a dose of 20 tons ha⁻¹, and the lowest at a dose of 10 tons ha⁻¹ of cow manure.

Keywords: Horton Infiltration, Organic Fertilizer, Long Beans, Water Infiltration



INTRODUCTION

Infiltration is the process of water entering from the soil surface into the layers beneath, playing a crucial role in the hydrological cycle. This process determines the amount of water available for groundwater reserves, reduces surface runoff, and prevents erosion. Part of the infiltrated rainwater is retained in soil pores, while the rest moves vertically due to gravity (David et al., 2016). The infiltration rate is influenced by soil physical properties such as texture, slope, and land use (Arianto et al., 2021), as well as changes in soil storage capacity due to land management (Nita et al., 2024).

In the agricultural sector, optimal infiltration is key to successful production, especially for high-economic-value horticultural crops like long bean (*Vigna sinensis* L.). This plant requires soil conditions that can effectively absorb and store water to support maximum growth and yield. According to Nurmi et al. (2023), water infiltration into the soil is essential to ensure adequate water availability for plant growth. However, agricultural land often experiences physical soil degradation that lowers the infiltration rate. One way to improve this is by applying organic fertilizers, which can increase soil aggregation, improve porosity, and support the formation of an optimal root zone. This aligns with the findings of Saputra et al. (2018) in the Purwosari salak plantation, East Java, which showed that a significant increase in soil organic matter raised the C-organic content, decreased bulk density, increased porosity, and accelerated infiltration.

To study the infiltration process, one of the most widely used models is the Horton equation. This equation can describe the soil infiltration rate by considering time and soil characteristics. By using the Horton equation, accurate infiltration modeling can be performed for various soil treatment conditions, including the use of organic fertilizers.

This study aims to analyze the effect of organic fertilizers from chicken and cow manure on the infiltration rate in long bean plants. Additionally, the research also focuses on determining which fertilizer treatment is most effective in increasing water absorption.

METHOD

The study was carried out from February to April 2025 in Tunggulo Village, Tilongkabila District, Bone Bolango Regency, Gorontalo Province. The analysis of soil and organic fertilizer nutrient content was conducted at the Soil Science Department Laboratory, Faculty of Agriculture, Hasanuddin University.

The research utilized a Randomized Block Design (RBD) with five treatments and three



replications: P0 = control (no fertilizer), P1 = 10 tons ha⁻¹ chicken manure, P2 = 20 tons ha⁻¹ chicken manure, P3 = 10 tons ha⁻¹ cow manure, and P4 = 20 tons ha⁻¹ cow manure. In total, there were 15 experimental units, each measuring 2 x 1.5 meters and planted with 15 long bean plants (*Vigna sinensis* L.). Infiltration was measured using a double ring infiltrometer to minimize lateral seepage.



Figure 1. Double ring infiltrometer

The observed parameters measured in this study included the pod weight of yard long bean, representing the production parameter, and soil infiltration. Further analysis of the soil infiltration rate, obtained from field data collection, was conducted in depth to predict the infiltration rate using the Horton Model approach. The infiltration rate was calculated using: $f(t) = \frac{\Delta H}{\Delta t}$ With, ΔH = The change in height (cm) during the time interval t , Δt = the time required for the water at ΔH to enter the soil (minutes). The results of the field measurements of soil infiltration rate were further analyzed to estimate the soil infiltration rate based on the Horton model. The Horton model can be expressed mathematically as follows:

$$f = f_c + (f_0 - f_c)e^{-kt}$$

Legend:

f = Infiltration rate (cm/hour) or (mm/hour)

f_0 = Initial infiltration rate (cm/hour)

f_c = Final infiltration rate (cm/hour)

e = Napierian logarithm base number (2,71828)

t = Time calculated from the start of rainfall (hours)

k = Soil K value

Based on the main formula, several parameters used in the Horton method were then determined, namely:

- The value of f_c is obtained from the infiltration rate when it reaches a steady/constant state.
- The value of f_0 is obtained from the infiltration rate during the initial condition.
- Based on the main formula above, the formula is then derived into:

$$\log (f - f_c) = \log (f_0 - f_c) e^{-kt}$$

$$\log (f - f_c) = \log (f_0 - f_c) + \log e^{-kt}$$

$$\log (f - f_c) = \log (f_0 - f_c) - kt \log e$$

$$t = \frac{1}{k \log e} \log (f_0 - f_c) - \frac{1}{k \log e} \log (f - f_c)$$

$$Y = a + bx$$

$$Y = t$$

$$a = - \frac{1}{k \log e} \log (f_0 - f_c)$$

$$b = - \frac{1}{k \log e}$$

The classification of infiltration rates follows Kohnke (1980) as cited in Ricardy (2017) (Table 1).

Table 1. Infiltration rate classification, Kohnke, 1980

Description	Infiltration Rate (mm hour ⁻¹)
Very Fast	>250
Fast	125-254
Moderately Fast	63-127
Moderate	20-63
Moderately Slow	5-20
Slow	1-5
Very Slow	<1

RESULTS AND DISCUSSION

Infiltration Capacity in *Vigna sinensis* L.

The infiltration rate data was analyzed using the Horton equation and presented in the form of an infiltration curve (Figure 2). The treatments used included P0 (no fertilizer), P1 (chicken manure 10 tons ha⁻¹), P2 (chicken manure 20 tons ha⁻¹), P3 (cow manure 10 tons

ha⁻¹), and P4 (cow manure 20 tons ha⁻¹).

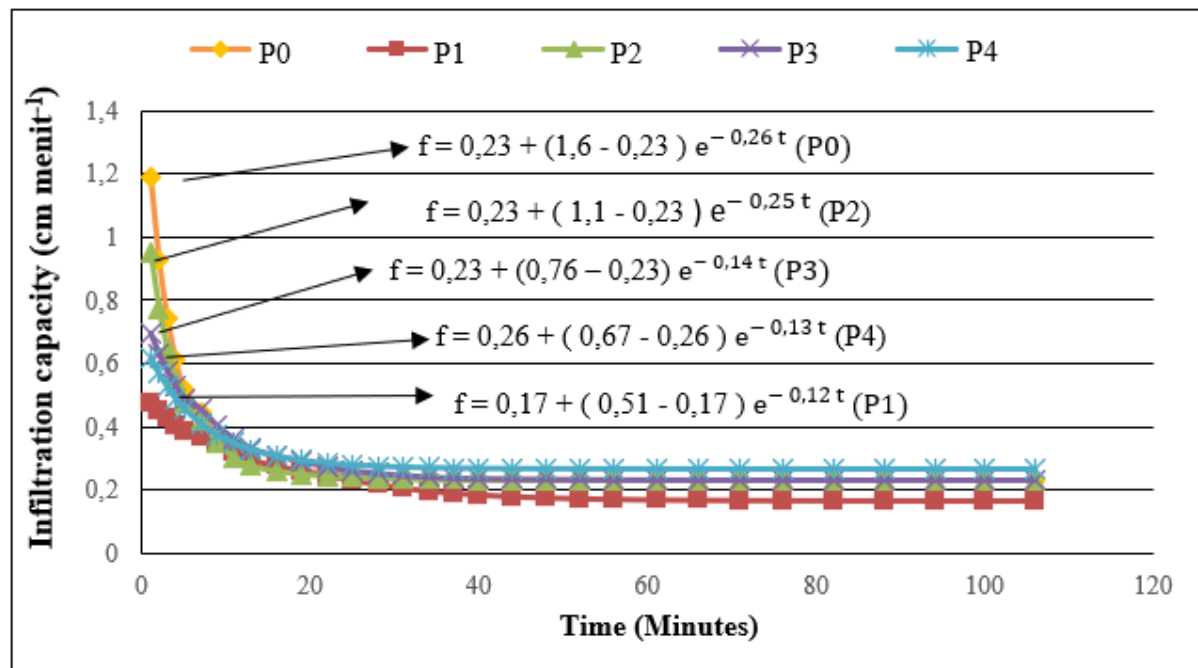


Figure 2. Infiltration Capacity for various organic fertilizer treatments.

Based on Figure 2, the highest infiltration capacity was obtained in the no-fertilizer control treatment (P0), while the lowest value was observed in the 10 ton ha⁻¹ chicken manure treatment (P1). The 20 ton ha⁻¹ chicken manure treatment (P2) demonstrated an increase in infiltration compared to other fertilizer treatments, although it remained below the control (P0). Conversely, the 10 ton ha⁻¹ cow manure treatment (P3) exhibited a higher infiltration capacity than P1 and P4, yet it was still lower than P0 and P2.

Measurement results for porosity showed variation, specifically: P0 (34.6%), P3 (34.0%), P1 (33.4%), P2 (30.8%), and P4 (28.5%). Generally, higher porosity correlated positively with infiltration capacity, as evidenced by P0 having the highest value and P4 the lowest. This finding aligns with Sonora et al. (2022), who reported that soil porosity significantly influences the infiltration rate across various land uses. However, this relationship is not entirely linear, as differences in pore structure, macropore connectivity, and soil surface conditions also affect infiltration efficiency (Antonio Panjaitan et al., 2024).

The highest infiltration capacity in P0 is hypothesized to result from the natural soil structure remaining undisturbed by organic matter addition, which facilitates water movement.

Ariessandi et al. (2022) reported that unamended soil tends to preserve its natural aggregate structure, supporting better infiltration. Conversely, at low fertilizer doses such as P1, incompletely decomposed organic matter may form a dense layer on the soil surface, thereby occluding pores. Mertari et al. (2023) also stated that although 10 ton ha⁻¹ chicken manure can enhance soil moisture and pH, it is not yet effective in improving soil structure. At the higher dose (P2), the increased organic matter content strengthened soil aggregation and formed functional macropores that accelerated water flow.

The use of a cattle-drawn plough in soil preparation also contributed to increased infiltration in the control treatment. This is consistent with Manik et al. (2017), whose results indicated that light tillage using a mouldboard plough can improve soil porosity and decrease bulk density compared to a rotary tiller. Conversely, intensive tillage with a tractor potentially reduces infiltration due to the compaction of the surface layer (Henny & Arsyad, 2022).

The infiltration parameter values indicated that P0 had an initial infiltration rate (f_0) of 1.6 cm min⁻¹, a constant infiltration rate (f_c) 0.23 cm min⁻¹, and a soil constant (k) 0.26. P1 exhibited the lowest values with f_0 0.51 cm min⁻¹, f_c 0.17 cm min⁻¹, and k 0.12. P2 showed an increase (f_0 1.1 cm min⁻¹, f_c 0.23 cm min⁻¹, k 0.25), while P3 (f_0 0.76 cm min⁻¹, f_c 0.23 cm min⁻¹, k 0.13) and P4 (f_0 0.67 cm min⁻¹, f_c 0.26 cm min⁻¹, k 0.12) were in the intermediate range. This variation suggests that organic matter application is capable of improving soil structure and increasing pore space, although it does not invariably result in the maximum infiltration rate (Nurmi et al., 2023).

Overall, the infiltration curves illustrate that the initial capacity is higher due to unsaturated soil conditions, subsequently decreasing until a constant value is reached when the soil becomes saturated. At 15 minutes, the volume of absorbed water reached 16.07 cm (6.428 m³ ha⁻¹ hour⁻¹) in P0 and 4.52 cm (1.808 m³ ha⁻¹ hour⁻¹) in P1. These findings affirm that the effect of organic fertilizer on infiltration is highly influenced by the dosage, type of fertilizer, and the resulting physical condition of the soil after application.

Infiltration Rate in *Vigna sinensis* L. Cultivation

The infiltration rate in long bean cultivation was calculated using the Horton method, which determines the constant infiltration rate using the equation $f = f_c + (f_0 - f_c)e^{-kt}$. The infiltration rate for the long bean cultivation is presented in the following Table 2.

Table 2. Infiltration rate in *Vigna sinensis* L. cultivation.

Treatment	Filtration Rate (mm hour ⁻¹)	Description
P0	63,37	Moderately fast
P1	18,20	Moderately slow
P2	40	Moderate
P3	6,3	Moderately slow
P4	21,76	Moderate

Based on Table 2, the highest infiltration rate was found in the control treatment (P0), with a value of 63.37 mm hour⁻¹, which falls into the "moderately fast" classification according to Kohnke's (1980) soil infiltration rate classification. This result indicates that soil without fertilizer treatment has a more stable and naturally open pore structure, allowing it to absorb water more quickly. It is suspected that the absence of added organic matter prevents the clogging of pores by fine particles or slurry, thus optimizing the infiltration rate. This aligns with the findings of Dewanti et al. (2023), who stated that the control treatment showed higher permeability compared to soil that had been treated with manure because it did not experience structural disturbance from incompletely decomposed organic matter. According to Nurmi et al. (2023), infiltration is directly proportional to soil permeability.

Treatments P2 (20 tons ha⁻¹ chicken manure) and P4 (20 tons ha⁻¹ cow manure) both fall into the "moderate" infiltration rate category, but their values differ, with P2 at 40 mm/hour and P4 at 21.76 mm/hour. This difference is influenced by the physical and chemical properties of the fertilizers. Based on laboratory analysis, chicken manure has a finer texture and higher C (18.70%) and N (1.57%) content compared to cow manure (C 16.67%; N 1.13%), allowing it to decompose faster and improve soil aggregation. However, at high doses, this fertilizer can form a slurry layer that clogs macro pores and decreases infiltration (Ariessandi et al., 2022).

The infiltration value for P4 is lower because of the cow manure's coarse texture and slow decomposition, which can potentially form a compact layer on the soil surface that inhibits water movement. A similar condition was also explained by Ariessandi et al. (2022), who noted that high doses of cow manure can form an impervious layer if not mixed thoroughly.

Treatments P1 (10 tons ha⁻¹ chicken manure) and P3 (10 tons ha⁻¹ cow manure) fall into the "moderately slow" category with values of 18.20 mm/hour and 6.3 mm/hour. At low doses, chicken manure still adds organic matter and microbial activity but is not yet sufficient to significantly improve pore structure; it can even form a fine layer on the surface. Cow manure at the same dose tends to inhibit infiltration more due to its coarse texture and slow

decomposition (Dewanti et al., 2023).

Correlation between Infiltration and *Vigna sinensis* L. Production

Constant infiltration is a physical property of the soil that is influenced by organic matter content and can affect plant yield. The relationship between constant infiltration and long bean yield is shown in Figure 3.

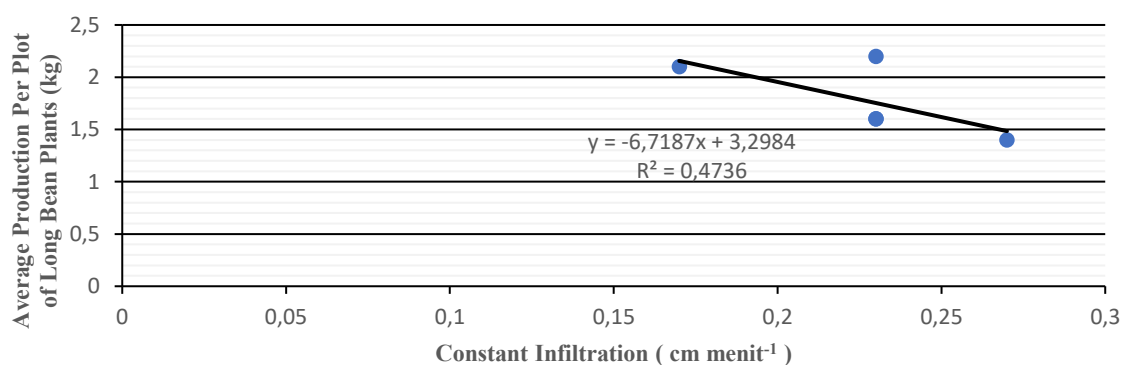


Figure 3. Relationship between constant infiltration and *Vigna sinensis* L. yield

Linear regression analysis showed a fairly strong negative correlation ($R=-0.688$) between constant infiltration and long bean yield, with a regression equation of $y=-6.7187x+3.2984$ and a coefficient of determination (R^2) of 0.4736. This means that each 0.1 cm minute⁻¹ increase in infiltration can reduce yield by approximately 6.72 kg ha⁻¹, where constant infiltration only contributes 47.36% to the variation in yield.

This negative relationship is strongly suspected to be a result of high infiltration rates, which accelerate the leaching of water and nutrients into the lower soil layers, thus reducing the availability of nitrogen and phosphorus in the root zone. This condition has a significant impact on leguminous plants like long beans, which have shallow roots. This finding is consistent with Prakasa et al. (2021), who reported that high infiltration correlates with a reduction of nutrients in the topsoil.

In a study by Agustin et al. (2021) on cowpea (*Vigna unguiculata* L.), it was mentioned that tillage systems also had a significant effect on N absorption. This indicates the importance of maintaining nutrient availability for optimal absorption and long bean yield, especially given that long bean roots are relatively shallow. If infiltration is too high, nutrients can be dissolved and lost from the root zone.

CONCLUSION

Based on the results of the study, it can be concluded that the various organic fertilizer treatments applied to yard long bean (*Vigna sinensis* L.) cultivation did not have a significant effect on either the infiltration capacity or infiltration rate of the soil. The analysis using the Horton Infiltration Model revealed that the highest infiltration capacity occurred in the treatment without fertilizer (P0), followed by the treatment with chicken manure at a rate of 20 tons ha⁻¹ (P2), and cow manure at a rate of 10 tons ha⁻¹ (P3). In contrast, the lowest infiltration capacity was observed in the treatment with chicken manure at a rate of 10 tons ha⁻¹ (P1). These findings suggest that the application of organic fertilizers does not always correspond to an improvement in the soil's water absorption capacity, as other factors such as the natural soil structure, the degree of organic matter decomposition, and the soil's physical condition also play important roles in influencing the infiltration process.

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