



Impact of compost application rates and depths on soil hydrodynamic properties and irrigation efficiency

Prince Irené Sewanou Babadjidé Aguessy¹, Cintia Ahouandogbo¹, Yaovi Aymar Bossa¹,
Maurel Aza-Gnandji², Mariam Ouedraogo¹, Esther Ndjiki³, Cypel Attakoun¹, and Carlos Akpinfa³

¹Laboratory of Hydraulics and Water Management (LHME),
University of Abomey-Calavi, Abomey-Calavi, Benin

²School of Rural Engineering, National University of Agriculture, Ketou, Benin

³Laboratory of Applied Hydrology, University of Abomey-Calavi, Abomey-Calavi, Benin

Correspondence: Prince Irené Sewanou Babadjidé Aguessy (aguessyprince@gmail.com)

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Abstract. Optimal water management in irrigation relies, among other things, on soil properties, which can be modified by agronomic interventions such as composting. It is in this context that the present study was carried out in 2024 at the experimental site of the Institut National de l'Eau to determine the optimal compost dose and burial depth with an effect on soil hydrodynamic properties. A completely randomized experimental block design was used, comprising control plots (without compost) and plots treated with three doses of compost ($T1 = 3 \text{ kg m}^{-2}$, $T2 = 4 \text{ kg m}^{-2}$, $T3 = 5 \text{ kg m}^{-2}$), each incorporated at three depths (10, 20 and 30 cm). Statistical analyses were carried out using R.4.4.1 software. Results showed that the application of 5 kg compost at 10 cm ($T3 P10$) improved water retention (0.466 vs. $0.210 \text{ cm}^3 \text{ cm}^{-3}$ for the control), improved hydraulic conductivity (52.62 cm h^{-1} vs. 30.35 cm h^{-1}) and reduced bulk density (1.06 g cm^{-3} vs. 1.88 g cm^{-3} for the control). In conclusion, burying compost at a depth of 10 cm, particularly at a rate of 5 kg m^{-2} , optimizes soil hydrodynamic properties, contributing to more efficient water management during irrigation under natural conditions for a sandy-loam soil type.

1 Introduction

In a context of population growth and increasing scarcity of natural resources, efficient water management in agriculture is becoming a major challenge, particularly in the face of climatic fluctuations and decreasing soil moisture stability. In West Africa, reduced rainfall since the 1970s has had a major impact on agricultural production, making irrigation essential to offset water deficits and improve yields (Agbossou and Sintondji, 2000). However, irrigation remains a major water consumer, accounting for around 70 % of the world's freshwater withdrawals and nearly 90 % of water resources consumed in some regions. In this context, optimizing the use of irrigation water by reducing losses through deep infiltration and evaporation is a priority to ensure the sustainability of agricultural systems (Waller and Yitayew, 2015). Improving the hydrodynamic properties of soils through adapted

agricultural practices is a promising approach to more efficient water management. Composting is one such strategy, influencing soil water retention and limiting water losses. Organic amendments such as compost increase soil water retention capacity (Guevarra et al., 2024) and improve water availability for crops (Kumar et al., 2024). Agronomic recommendations suggest limiting compost inputs to around 50 t ha^{-1} in order to ensure uniform incorporation into the topsoil (U.S. Environmental Protection Agency, 2025). However, the quantity and depth of compost application play a decisive role in these effects. Excessive application could alter soil moisture dynamics, leading to undesirable fluctuations, while insufficient application would limit its effectiveness. The aim of this study is therefore to analyze the impact of compost application rates and depths on soil hydrodynamic properties and irrigation efficiency. The aim is to assess how these parameters influence water retention and the reduction

of water losses, in order to identify the best practices for optimizing water use in irrigated agriculture.

2 Methodology

The study was carried out on the experimental site of the Institut National de l'Eau, located within the Université d'Abomey-Calavi, in the commune of Abomey-Calavi, southern Benin. The site (Fig. 1), covering an area of 650 m², is located between latitudes 6°24'46" and 6°24'47" N and longitudes 2°20'24" and 2°20'25" E, with an altitude of around 14.44 m above sea level. The commune of Abomey-Calavi covers an area of 539 km² and is characterized by a sub-equatorial climate average annual rainfall is around 1200 mm, based on data from 1994 to 2023 and the soil is ferrallitic. The study was carried out in various phases, detailed in the methodology below.

2.1 Compost production

In this experiment, several biodegradable materials were selected and collected to produce a balanced, nutritious compost. Materials included green leaves kept in the shade to prevent drying out, poultry droppings stored in airtight bags to limit ammoniacal nitrogen losses, sawdust stored in a dry place to prevent compaction, urine stored in closed drums to prevent nitrogen volatilization, and ash. These choices aim to provide essential elements such as nitrogen, phosphorus, potassium and other minerals needed to enrich soils and improve their fertility (Gajalakshmi and Abbasi, 2008). The compost used is characterized by a slightly acidic to neutral pH (6.82), a high organic carbon content (16.063 %), moderate total nitrogen (0.630 %), and significant levels of available phosphorus (140.226 ppm), total phosphorus (1897.05 ppm), and potassium (3.518 m eq. per 100 g).

2.2 Experimental system

The experimental set-up used a split-plot design to study the cross-effects of two main factors: compost dose and depth of application. Our experimental plot (Fig. 2) was divided into two main compartments. The first compartment, serving as a control, was subdivided into small plots 3 m long by 1 m wide, i.e. plots of 3 m² each, on which no compost was applied. The second compartment was subdivided into several 3 m² beds, on which three doses of compost T1 (3 kg m⁻²), T2 (4 kg m⁻²) and T3 (5 kg m⁻²) i.e. 9, 12 and 15 kg per bed – were applied at three distinct depths: 10, 20 and 30 cm. To apply the amendments, the soil was cleaned by removing obstacles and waste, followed by manual weeding to eliminate weeds and debris. The experimental layout was then laid out using ropes, a decimeter, stakes and a machete.

2.3 Sampling and analysis of soil properties

Samples were taken from the soil profile at depths of 0–15, 15–30, and 30–45 cm, as well as from each of the plots where treatments were applied.

- Bulk Density: Soil bulk density, an indicator of soil compaction, is obtained by dividing the dry mass (M_S) by the total volume of the sample (V_t). Samples taken with a Kopecky cylinder were dried at 105 °C for 72 h, then weighed. The volume of the cylinder, 98.125 cm³, was used for the calculation. This procedure was applied to each sample, using the following formula.

$$D_a = \frac{M_S}{V_t} \quad (1)$$

- Volumetric water content Θ : Volumetric water content (cm³ cm⁻³) represents the volume of water in relation to the volume of soil. It is determined by weighing and suction measurements. The sample is pre-saturated, then weighed to obtain the wet mass. After 72 h drying in an oven, the dry mass is measured. The mass of the ring, fabric and elastic is also weighed using a precision balance. This procedure was applied to each sample, using the following formula

$$\Theta_v = \Theta_g \times d_a \quad (2)$$

With: Θ_v : Volumetric water content (cm³.cm⁻³); Θ_g : Gravimetric water content(g g⁻¹); d_a : Apparent density (g cm⁻³)

- Saturated hydraulic conductivity K_S : Saturated hydraulic conductivity (cm s⁻¹) measures the soil's capacity to transmit saturated water. It can be determined by various methods, such as KES or the constant-load permeameter. To measure it, the sample is inserted into a cartridge placed in the permeameter. The load levels (h_1 and h_2) and operation time are recorded. Finally, the volume of water passing through the sample is measured in a graduated burette. This procedure was applied to each sample, using the following formula

$$K_S = \frac{v \times l}{s \times t \times h} \quad (3)$$

Where v : volume of water (cm³), l : length of sample (cm), s : cross-sectional area of cylinder (cm²), t : operation time (s) and h : change in load (cm)

Data were processed with Excel (2013) to create tables and graphs. Statistical analyses were performed in R (version 4.2.1) to assess the effect of compost incorporation rates and depths. Prior to ANOVA, normality (Shapiro-Wilk test) and homogeneity of variances (Bartlett test) were checked. Two-factor ANOVA, via the aov function, was applied with a significance level of 5 % ($p < 0.05$) to test treatment effects and interactions. The assumptions used for these tests are listed in Table 1.

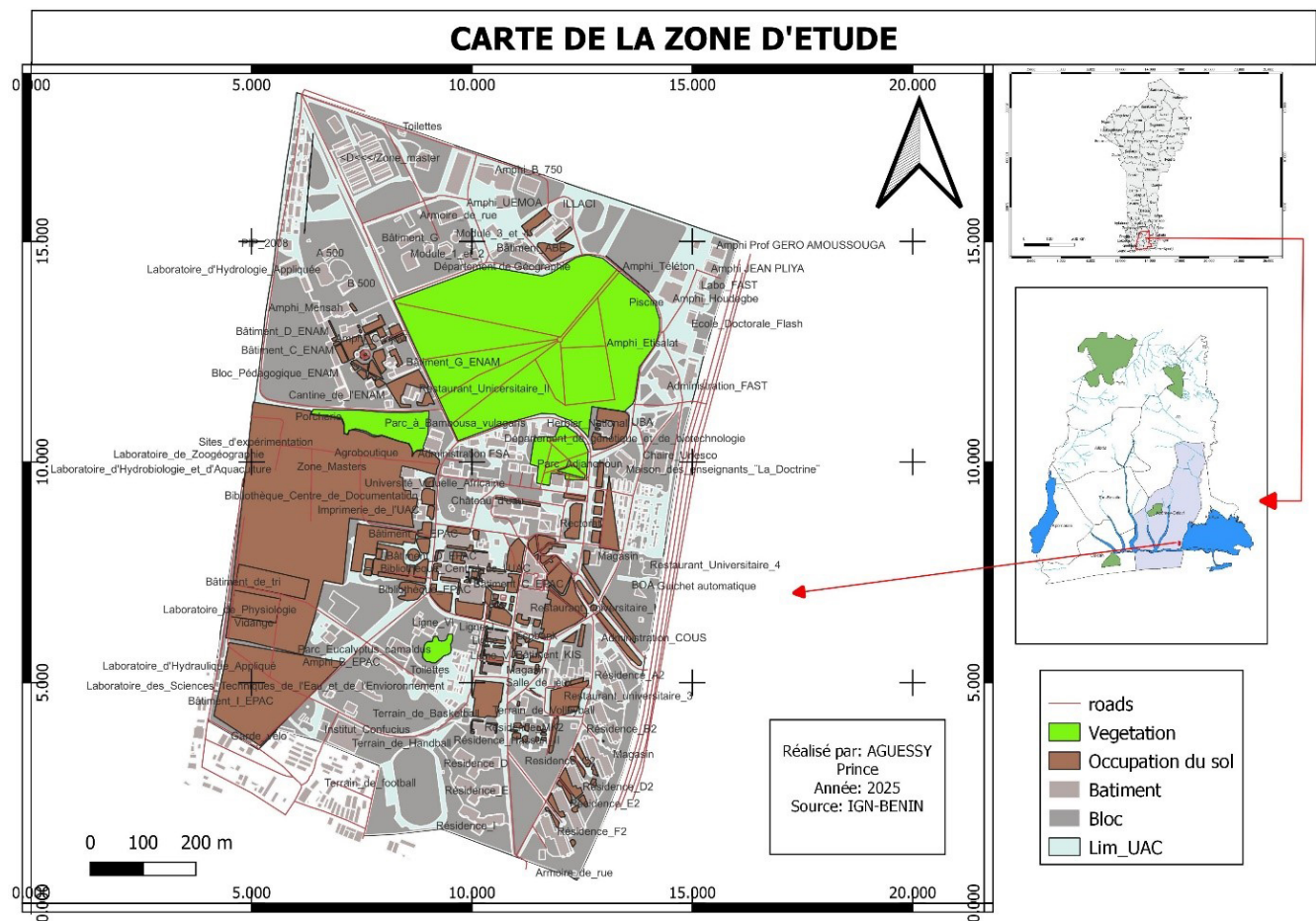


Figure 1. Location of study area. Source: Prince Irené Sewanou Babadjidé Aguessy, 2024.

Table 1. Two-factor ANOVA assumptions.

Facteurs	Non-null hypothesis (H0)	Alternative assumptions (H1)
Effect of compost dose	The dose of compost has no significant effect on the parameters measured.	Compost dose has a significant effect on the parameters measured.
Effect of application depth	Depth of application has no significant effect on measured parameters.	The depth of application has a significant effect on the parameters measured.
Interaction between compost dose and depth of application	There was no significant interaction between compost dose and depth of application on the parameters measured.	There is a significant interaction between compost dose and depth of application on the parameters measured.

Source: Prince Irené Sewanou Babadjidé Aguessy, 2024.

3 Result and discussion

3.1 Result

3.1.1 Measured bulk density

Figure 3 below shows the variation in bulk density as a function of compost treatments applied and depths compared with soil without compost (SC).

Analysis of the results shows that soil bulk density is highest without compost, indicating a more compact soil. At a depth of 10 cm, it reaches 1.5429 g cm⁻³ without compost, while the 4 kg compost treatment (1.0588 g cm⁻³) significantly reduces compaction. The 3 kg and 5 kg treatments show intermediate effects. At 20 cm, the highest density (1.88 g cm⁻³) was observed without compost, while the 5 kg treatment (1.4492 g cm⁻³) improved soil structure the most.

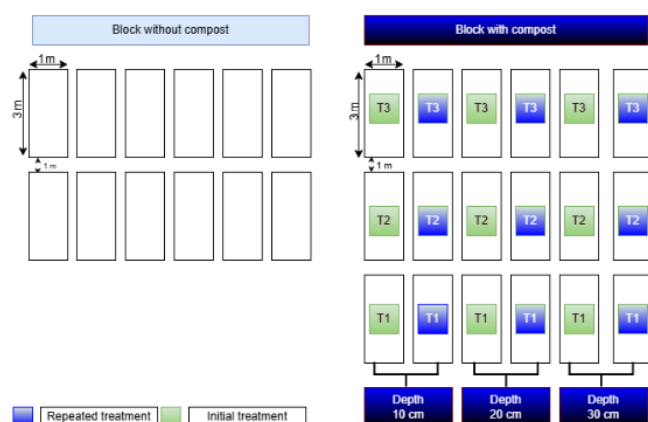


Figure 2. Experimental setup.

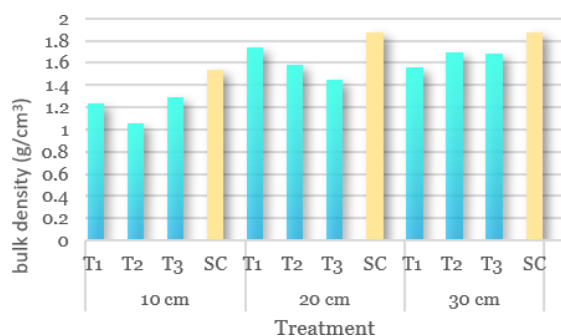


Figure 3. Effects of treatments on bulk density.

At 30 cm, the lowest density (1.5582 g cm^{-3}) was obtained with 3 kg of compost, compared with 1.87 g cm^{-3} without compost. Overall, the addition of compost lightens the soil, encouraging water infiltration and root growth, with variable effectiveness depending on dose and depth

- Statistical analysis: The two-factor analysis of variance (ANOVA) carried out to assess the influence of compost application depth. The two-factor analysis of variance (ANOVA) performed to assess the effect of depth and treatment on soil bulk density showed that depth had a significant effect on water content ($p = 0.0303$), indicating that depth variations significantly influence bulk density. On the other hand, the effect of treatment ($p = 0.2614$) and the interaction between depth and treatment ($p = 0.8082$) were not significant. These results suggest that, although depth plays a decisive role in water content, the different treatments applied and their interaction with depth have no significant impact. Consequently, the variations in water content observed can be attributed primarily to depth, with no significant effect of the treatments used or their interaction with depth.

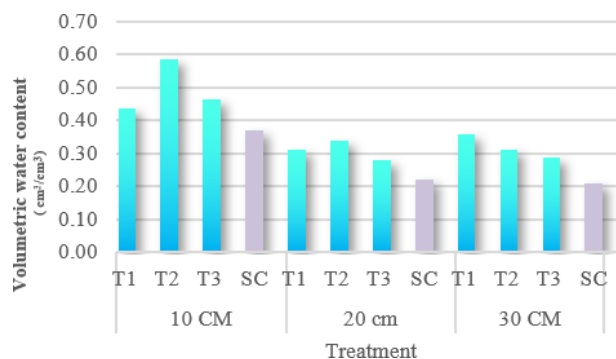


Figure 4. Effects of treatments on Saturated Volumic Water Content θ_{sat} .

3.1.2 Water content by volume at saturation

Water contents were measured at different depths for each treatment. Figure 4 illustrates these variations.

Analysis of Fig. 4 shows that the application of compost influences the saturated volumic water content of the soil according to depth. At 10 cm, treatment T2 (4 kg) showed the best water retention ($0.59 \text{ cm}^3 \text{ cm}^{-3}$), while the soil without compost had the lowest value ($0.37 \text{ cm}^3 \text{ cm}^{-3}$). At 20 cm, the beneficial effect of compost is also observed, with T2 (4 kg) reaching $0.34 \text{ cm}^3 \text{ cm}^{-3}$, compared with $0.22 \text{ cm}^3 \text{ cm}^{-3}$ for the soil without compost. However, beyond 4 kg, no further significant gain was noted. At 30 cm, T1 (3 kg) offers the best retention ($0.36 \text{ cm}^3 \text{ cm}^{-3}$), followed by T2 (4 kg) and T3 (5 kg). Unlike at other depths, water retention did not follow a linear trend with increasing dose, suggesting a negative impact on soil structure. Thus, 4 kg seems optimal at 10 and 20 cm, while 3 kg is more effective at 30 cm.

- Statistical analysis: A two-factor analysis of variance (ANOVA) was carried out to assess the influence of compost application depth, compost quantity and their interaction on soil water retention. The results show that compost application depth has a significant effect on water retention ($p = 0.0345$). On the other hand, the effect of treatment alone was not significant ($p = 0.2831$), indicating that the different quantities of compost applied did not significantly modify soil water retention. Furthermore, the interaction between depth and amount of compost applied was not significant ($p = 0.6753$), suggesting that the effect of depth is independent of the amount of compost applied. These results indicate that compost application depth influences soil water retention, but that increasing the compost dose does not appear to have a significant effect on this variable.

3.1.3 Hydraulic conductivity at saturation K_s

Figure 5 shows the variation in saturated Hydraulic Conductivity K_s as a function of the treatments applied and the depth of application, compared with soil without compost (SC).

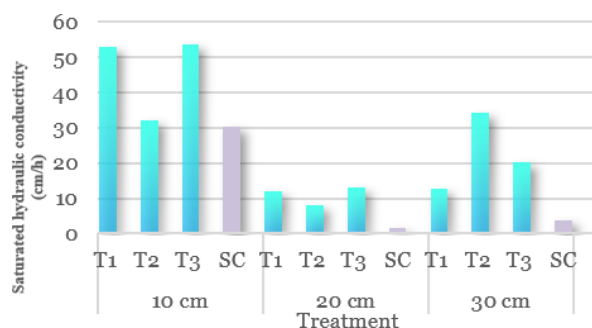


Figure 5. Effects of treatments on saturation hydraulic conductivity.

Analysis shows that hydraulic conductivity at saturation varies with depth and treatments applied. At 10 cm, it is highest with 3 and 5 kg of compost (52.795 and 53.622 cm h^{-1}), while 4 kg reduces conductivity (32.020 cm h^{-1}), close to the soil without compost (30.359 cm h^{-1}), probably due to a change in porosity. At 20 cm, the addition of compost improves infiltration compared with soil without compost (1.75 cm h^{-1}), with maximum values for 5 kg (13.19 cm h^{-1}) and 3 kg (12 cm h^{-1}), while 4 kg (8.14 cm h^{-1}) shows less efficiency, suggesting a non-linear effect. At 30 cm, conductivity also increases compared to the soil without compost (3.7 cm h^{-1}), but here 4 kg (34.3 cm h^{-1}) has the highest value, followed by 5 kg (20.1 cm h^{-1}) and 3 kg (12.71 cm h^{-1}), indicating a variable influence of compost dose according to depth. Higher conductivity promotes better infiltration and optimal drainage.

- Statistical analysis: The two-factor analysis of variance (ANOVA) carried out to assess the effect of depth and treatment on saturated soil hydraulic conductivity showed that none of the factors studied had a significant effect on saturated hydraulic conductivity. Indeed, the main effect of depth ($p = 0.120$) and treatment application ($p = 0.675$) were not statistically significant, with p values above the 0.05 threshold. Nor did the interaction between depth and treatment ($p = 0.666$) reveal any significant effect. These results suggest that neither the depth of application, nor the different compost treatments, nor their interaction have any significant impact on saturated soil hydraulic conductivity under the experimental conditions of this study.

3.2 Discussion

The results show that compost application improves hydraulic conductivity, bulk density and water retention, with maximum levels at 10 cm depth for the 5 kg compost treatment (T3). Conversely, unamended soils showed lower water retention, confirming the effectiveness of compost in improving water availability, in line with the work of Wright et al. (2023) and Jiahao et al. (2023). This finding is also in line

with studies by Logsdon and Malone (2015), who showed that volumetric water content increases after compost application. The increase in hydraulic conductivity at saturation in amended soils (52.62 cm h^{-1} for T3 versus 1.75 cm h^{-1} without compost) corroborates the studies by Kranz et al. (2020) and Fitria et al. (2023), who showed that compost significantly improves infiltration, particularly in compacted soils. With regard to bulk density, compost improves porosity and reduces compaction, with a minimum density at 10 cm for treatment T2 (4 kg compost) and a maximum at 20 cm in unamended soil.

However, only depth had a significant influence on this property ($p = 0.0303$), while compost quantity had no significant effect ($p = 0.2614$). These results corroborate previous studies of Burg et al. (2019) and Belyuchenko (2013) demonstrating that compost application lowers soil bulk density and density and enhances soil aeration and root development.

4 Conclusion

The aim of this work was to assess the impact of compost application rates and depths on soil hydrodynamic properties. The results of this study confirm the significant influence of compost application on soil hydrodynamic properties and irrigation efficiency. Optimization of application rates and depths enabled us to identify the most effective combination: incorporating 5 kg of compost at a depth of 10 cm (T3P10). This configuration improved water retention, increased hydraulic conductivity at saturation and reduced soil bulk density, thereby improving soil structure and infiltration capacity. These results underline the importance of organic amendments in managing water resources and optimizing cultivation practices. The targeted application of compost represents a promising strategy for improving the sustainability of agricultural systems, notably by reducing water losses through percolation and optimizing the use of irrigation water. However, further studies, including long-term monitoring and analysis of agronomic impacts on the crop, would be required to refine recommendations and ensure optimal compost application according to soil and crop specificities. However, it should be noted that the results obtained are specific to the soil and climate conditions and farming practices of the site studied, which may limit their generalizability to other contexts.

Data availability. No data sets were used in this article.

Author contributions. PISBA designed the study, conducted the analyses, performed the simulations, and wrote the manuscript. CaA and MAG developed the data collection system. PISBA, CaA, CyA, MO, and EN carried out the field experiments, including sensor installation, data collection, compost preparation, and site maintenance. AB coordinated all the work, secured funding, and contributed to the scientific direction and manuscript revision. CiA supervised the fieldwork and contributed to operational coordination. CiA, AB, and MAG also contributed to the manuscript revision.

Competing interests. At least one of the (co-)authors is a guest member of the editorial board of *Proceedings of the International Association of Hydrological Sciences* for the special issue “Circular Economy and Technological Innovations for Resilient Water and Sanitation Systems in Africa”. The peer-review process was guided by an independent editor, and the authors also have no other competing interests to declare.

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