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In-situ measuring and predicting dynamics of soil bulk density in a non-rigid soil as affected by tillage practices: Effects of soil subsidence and shrinkage

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ABSTRACT

Non-rigid soils (e.g., Vertisols) present dynamics of bulk density (ρ_b) due to high shrinkage and swelling. However, the in-situ measurement and prediction of the dynamic of ρ_b in non-rigid soils are still great challenges. The objectives were to (1) evaluate the performance of the combined soil moisture and thermal property sensors in estimating in-situ ρ_b dynamics under different tillage practices, (2) and establish mathematic equations to predict the ρ_b dynamics associated with soil subsidence and shrink-swelling processes during wetting and drying cycles. The in-situ ρ_b monitoring and periodical intact soil core sampling were conducted in the 0–10 cm and 10–20 cm layers in a Vertisol under three tillage treatments, containing no-tillage (NT), rotary tillage (RT) and deep ploughing (DP). Our results showed that the dual-sensor combination provided accurate ρ_b estimates in the field over 2021–2022 year ($R^2 > 0.487$, RMSE < 0.177 g cm^{-3}), except for the early stage after deep tillage. The ρ_b dynamics in the 0–20 cm in the NT and the 10–20 cm layer in RT treatment were mainly caused by shrink-swelling. Whereas the ρ_b dynamics in the 0–10 cm and 10–20 cm in the DP and the 0–10 cm layer in RT treatment were predominantly determined by soil subsidence first and then shrink-swelling when the accumulative rainfall (P_t) reached 131.8 mm, 186.1 mm, and 79.3 mm, respectively. The ρ_b dynamics during soil subsidence were well-fitted by an exponential equation related to accumulative rainfall ($R^2 > 699$, $P < 0.01$), while the ρ_b dynamics during shrink-swelling were well-fitted by a newly proposed $SSC_{\rho b}$ equation derived from the Peng and Horn soil shrinkage model ($R^2 > 589$, $P < 0.05$). Combined with the long-term monitored rainfall and soil moisture, The $SSC_{\rho b}$ equation and the two-stage equation involving subsidence and $SSC_{\rho b}$ exhibited good prediction of ρ_b dynamic from 2017 to 2022 ($R^2 > 0.453$, RMSE < 0.070 g cm^{-3}). The soil subsidence and shrink-swelling process accounted for 3.32%– 12.5% and 2.84%– 14.8% of the ρ_b variation in tilled non-rigid soils, respectively. Our results demonstrated that the dual-sensor combination can be applied for field ρ_b monitoring in non-rigid soil. The proposed two-stage equation has great potential for predicting the field dynamics of ρ_b.

1. Introduction

Soil bulk density (ρ_b) is one of the most frequently used indicators to evaluate soil structure, which can be used to characterize soil's ability in water retention, gaseous exchanges, and crop growth (Passioura, 1991; Rabot et al., 2018). For non-rigid soils with high shrinkage and swelling capacity (Soil survey staff, 2015), ρ_b is a highly dynamic property as affected by wetting and drying (WD) cycles under hydraulic stresses (Wang et al., 2022a). However, tillage management also had a strong influence on the ρ_b dynamic in the field (Alletto and Coquet, 2009; Geris et al., 2021; Strudley et al., 2008). The hydraulic- and tillage-related factors interact with each other, making the structure dynamic more complicated in the field (Bodner et al., 2013; Dörner et al., 2012). To better explore the dynamic relations between soil physical processes and crop growth in non-rigid soils, in-situ measurements of ρ_b dynamics as affected by tillage and WD cycles in field conditions are acquired.

Tillage is one of the most prominent practices in altering soil structure (Green et al., 2003). However, the loose soil structure induced by

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