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Soil loss due to root crop harvesting increases with tillage operations

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ABSTRACT

Variations in soil conditions and root crop parameters have significant impact on soil loss due to root crop harvesting (SLCH). Tillage operation may alter soil properties and root crop performance and consequently influence SLCH. The objective of this study was to determine the best tillage practice that can reduce SLCH with optimum crop yield and to understand the mechanism of tillage practices on SLCH. A 3-year field investigations were conducted with four different tillage practices: no-till (NT), traditional tillage (TT), minimum tillage (MT) and conventional tillage (CT), planted with two yam cultivars. Annual SLCH increased with increases in tillage operations. Mean annual SLCH value was highest under mechanized tillage (CT and MT) (346.29 kg ha^{-1} $harvest^{-1}$ yr^{-1}), followed by TT (106.50 kg ha^{-1} $harvest^{-1}$ yr^{-1}) and least by NT (50.27 kg ha^{-1} $harvest^{-1}$ yr^{-1}). Also, MT significantly ($p < 0.05$) reduced SLCH compared to CT by 39.4%. Root hair density and root crop yields increased but soil bulk density decreased with tillage operations. SLCH was significantly linearly related to root hair density ($r^2 = 0.85–0.93$; $p < 0.01$) and root crop yields ($r^2 = 0.59–0.81$; $p < 0.01$), and inversely related to soil bulk density ($r^2 = -0.45 - -0.65$; $p < 0.05$) for all tillage management practices investigated. Tillage impacts SLCH by two mechanisms: one is direct impact on SLCH by enhancing root hairs and root crop yields, and another is indirect impact on SLCH by reducing soil bulk density to create good soil conditions for root growth and development. Mechanized tillage had highest root crop yield (11.12 t ha^{-1}), followed by TT (6.08 t ha^{-1}) and least by NT (3.43 t ha^{-1}). However, root crop yields from both CT (11.26 t ha^{-1}) and MT (10.97 t ha^{-1}) were not significantly different. Our study suggests that minimum tillage system of farming could be a viable alternative for a large scale farming to obtain optimum root crop yields as well as mitigating SLCH.

1. Introduction

Soil loss due to root crop harvesting (SLCH) has been identified as an important land degradation process (Dada et al., 2016; Faraji et al., 2017; Mwango et al., 2015a; Oshunsanya, 2016a; Parlak and Blano-Canqui, 2015; Parlak et al., 2016; Parlak et al., 2018). Some of these studies have attributed this soil loss from harvesting of root crops such as sugar beet, potatoes, chicory roots, cocoyam, cassava and yam to agricultural soil mechanization (Parlak and Blano-Canqui, 2015; Parlak et al., 2016). Although SLCH has not been given recognition as water erosion, some published works on potato, sugar beet and cassava indicated that SLCH could be of the same order of magnitude as soil losses caused by water erosion. For example, measured sheet and rill erosion (6.9 t ha^{-1} $year^{-1}$) and ephemeral gully erosion (5.4 t ha^{-1} $year^{-1}$) in central Belgium (Poesen et al., 2001) versus SLCH values of 12.9 Mg ha^{-1} $harvest^{-1}$ caused by the potato harvest in Turkey (Parlak and Blano-Canqui, 2015), and 4.6 Mg ha^{-1} $harvest^{-1}$ caused by the red cocoyam harvest in Nigeria (Oshunsanya, 2016a). Continuous removal of soils from the field coupled with nutrient uptake by the crops could result to land degradation by lowering the depth of top soil (Mwango et al., 2015b; Oshunsanya, 2016b). In addition, SLCH has economic and environmental consequences attributed to soil transport, cleaning of crop-root and storage and disposal of soils into the streams (Oztas et al., 2002; Yu et al., 2016).

In order to solve the problems associating with SLCH, the factors controlling SLCH have been investigated by many studies (Parlak et al., 2018; Parlak and Blano-Canqui, 2015; Ruysschaert et al., 2006). They are soil properties (soil texture, soil moisture content, organic matter content, soil structure, $CaCO_3$), crop-root characteristics (root shape, skin roughness, root-size, root grooves, rootlets, root density) and harvest technique (type and shape of harvesting machine, harvesting depth, harvesting speed). Among these factors, soil properties were indicated as the major determinant of SLCH (Parlak et al., 2018; Sumithra et al., 2013). For instance, clay, lime, organic matter and soil

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moisture content were found to account for 35% variation in SLCH (Parlak et al., 2018). Similarly, clay and soil moisture contents were reported as the major predictors of SLCH in manual and mechanized harvests respectively in Turkey. Sumithra et al. (2013) reported that soil moisture content at harvesting time was a significant factor that explained the variations in soil loss due to cassava harvesting. They also found that soil moisture was linearly and positively related to average soil loss per unit root crop yield. Soil properties can be influenced by tillage practices to a large extent. Yet, tillage practices have not been considered as part of factors influencing SLCH.

Tillage is defined as the mechanical manipulation of soil to increase crop yields by altering the soil physical characteristics such as bulk density, saturated hydraulic conduction, soil water conservation, soil temperature, infiltration, aggregate stability and soil physical quality (Buchi et al., 2017; Crittenden et al., 2015; de-Almeida et al., 2018). Soil physical environment can be modified by tillage through cutting, mixing, overturning and loosening processes (Duiker and Beegle, 2006; Nunes et al., 2015; Zhang et al., 2014). The extent to which tillage alters soil physical properties depends on the types of tillage. For instance, conventional tillage involves ploughing (overturning) followed by harrowing (mixing, loosening, smoothing) of the soil while minimum tillage reduces soil manipulation operation to ploughing (Buchi et al., 2017; Kaurin et al., 2015; Nunes et al., 2015). However, traditional tillage involves surface scraping and piling up the soil into ridges or mounds while no tillage involves land cultivation with little or no soil surface disturbance (Didone et al., 2014; Schneider et al., 2017). Effects of tillage practices on soil properties have been documented over the years (Carvalho et al., 2015; de-Almeida et al., 2018). For example, research studies conducted at various locations showed that tillage reduced soil aggregate size and increased pore size, resulting into lower moisture content in tilled soil compared to non-tilled soil (Buchi et al., 2017; de-Almeida et al., 2018; Kaurin et al., 2015). In Brazil, a newly imposed conventional tillage caused an increase in soil porosity and water infiltration compared to no-tillage. However, surface sealing occurred after a few days of tillage due to the direct impacts of rain drops that resulted to an increase in bulk density (Carvalho et al., 2015). Similarly, Ruysschaert et al. (2006) noticed different relationships between bulk density and SLCH under different soil conditions. They found a negatively significant correlation between ridge bulk density and adhering SLCH. However, no significant relationship was found between inter-ridge bulk density and the SLCH, ascribed to soil compaction caused by the wheels of the harvesting machine in-between the ridges.

Moreover, tillage could modify root morphological characteristics which in turn influence soil properties. For instance, Guan et al. (2015) found that root weight density, root length density and root surface density of winter wheat were greater in plow-land compared to no-tillage in the North China Plain. Ji et al. (2013) and Twum and Nii-Annang (2015) also found that root elongation, root development and proliferation as well as root distribution were drastically reduced under higher soil bulk density condition. Modification of soil structure, soil moisture content and bulk density by tillage operations may alter or modify the root hairs of root crops. Such enhanced root hairs by tillage can fix large volume of soil particles due to harvesting of root crops. But gap in knowledge with respect to influence of tillage on the relationship between SLCH and soil properties as well as root hairs of root crops still remain unclear. Thus, we conducted a 3-year field experiment to evaluate the relationships between SLCH and soil properties as well as root hairs in response to tillage operations. The specific objectives are to: i) determine the best tillage practice that can reduce SLCH with optimum crop yield, and ii) understand the mechanism of tillage practices on SLCH. The expected results will enhance our understanding of the contribution of tillage to SLCH. It can also provide farmers with tillage practices that will mitigate SLCH with optimum crop yield.

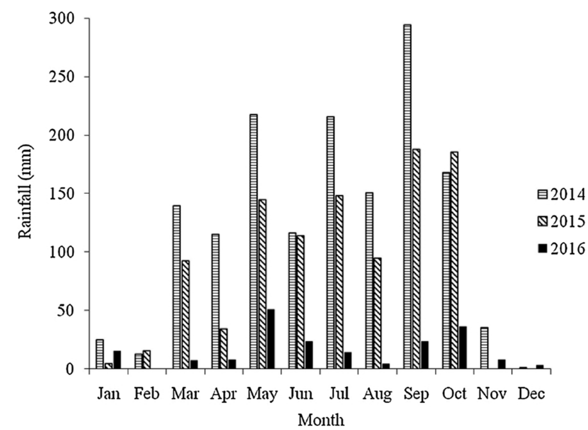

Fig. 1. Rainfall amount for 2014, 2015 and 2016 during the study.

2. Materials and methods

2.1. Study area

The field experiments were conducted over a three-year duration between 2014 (Year 1) and 2016 (Year 3) at the Teaching and Research Farm, University of Ibadan (Latitude 07° 27′ 05.4″ N and Longitude 03° 53′ 30.7″ E), Nigeria. The soil of the area is an Alfisol classified as Typic Kandiustalf and formed from basement complex rock. Locally, it is classified as Iwo series (Smyth and Montgomery, 1962) on an undulating topography with an average slope of 1%. The farmland texture is sandy loam with a bulk density of 1.51 Mg m^{-3}, a saturated hydraulic conductivity of 41.16 cm hr^{-1} and a mean weight diameter of 1.51 mm. The surface layer (0–15 cm) of the site had 24.80 g kg^{-1} org. C, 1.61 g kg^{-1} total N, 11.82 mg kg^{-1} P, 1.59 mg kg^{-1} K, 3.03 mg kg^{-1} Ca and 4.02 mg kg^{-1} Mg as base-line chemical properties. The site has mean annual temperature of 26.3 °C. The cumulative rainfall obtained for years 1, 2 and 3 were 1491, 1022 and 194 mm, respectively. The monthly distribution of this rainfall is depicted in Fig. 1.

2.2. Experimental design

The farmland was mapped out into 2 × 4 factorial experiment in a randomized complete block design, involving two cultivars: Tropical *Dioscorea alata* 00/00194 (cultivar[A]) and (Tropical *Dioscorea alata* 00/00006 (cultivar[B]) and four tillage practices: No tillage (NT), Traditional tillage (TT), Minimum tillage (MT) and Conventional tillage (CT), replicated four times. Each plot occupied a size of 20 m × 10 m. The details of the tillage and planting operations for tillage treatments were presented in Table 1. The yam plants were not fertilized throughout the study period. The usual African cultural management practices for yam crops were followed. Staking of yam vines started at 3 weeks after sprouting when vines were long enough to entwine the pole. Yam crop was grown under complete rain-fed agriculture without any supplementary irrigation. Manual weeding was adopted where hoe and machete were used to get rid of weeds on the field. No pest management was involved throughout the study period. It must be noted that only NT plot had surface soil covered with crop residue at the commencement of the experiment (Table 1).

2.3. Soil sampling and analysis

Pre-planting soil samples were collected from the field before imposing tillage practices (5 March 2014) to ascertain the base-line soil properties. Subsequent samples were taken at the end of the first (24 November 2014), second (11 November 2015) and third (28 November 2016) growing cycles respectively. Collected samples were analyzed for nutrient concentration after air-drying and sieving. Soil organic carbon