Potential, quality and quantity assessment of sesame plant residue in dry land vertisols of Tigrai, Ethiopia; Approach for sustainability of dry-land farming

Yohannes Desta*, Mitiku Haile, Girmay Gebresamuel, Mulugeta Sibhatleab

Mekelle University, College of Dryland Agriculture and Natural Resources, Ethiopia

ARTICLE INFO

Keywords:
- Sesame residue
- Timing
- Elevation
- Nutrient potential
- Dry land farming
- Agricultural soil science
- Agronomy
- Organic farming
- Soil science
- Environmental assessment
- Environmental impact assessment
- Agriculture
- Environmental science

ABSTRACT

In dryland areas, the increasing demand for sustainable production needs to effectively utilize and manage residue. The aim of this study was to evaluate the potential, quality, and quantity assessment of sesame residue in dryland areas. Quantification of residue potential was performed at <650, 650–850, 850–1050, and >1050 m elevation by summing the weight of stack, standing residue, and straw. Whereas, assessment in the residues nutrient content was performed at <650, 650–850, 850–1050, and >1050 m elevation and age of residue (fresh and old). The TN, S and P in the residue were determined by Kjeldahl digestion Method, wet acid digestion Method, and two percent acetic acid (CH3COOH) as extracting to extract PO4 respectively. Atomic absorption spectrophotometer was used to determine micronutrient cations such as Fe, Zn, and Cu. B was determined by extraction using a mixture of hydrochloric (HCl) and hydrofluoric (HF) acids to plant tissue digestes. The nutrient potential was calculated by multiplying nutrient content in residue with the amount of residue estimated ha−1. R software (R version 3.5.2) was used to analyze the data. The result indicates that during the last 20 years, the total cultivated land size covered by sesame was 170,000 (ha) and total grain yield of 0.09 Mt. This implies that the size of cultivated land put under sesame cultivation has increased by 79.5%. On average 2.01 t ha−1 of residue was produced annually and about 0.34 Mt yr−1 of residue was harvested from sesame production. The age of residue differed significantly (p < 0.05) on TN, S, P, Zn, Fe, Cu, and B content of sesame residue. Nutrient content in residue was ranged from 34.55–24.53 g TN/kg, 9.6–4.2 g S/kg, 5.2–4.3 g P/kg, 23–14.6 mg Zn/kg, 130.23–94.78 mg Fe/kg, 17–6.2 mg Cu/kg and 10.67–9.12 mg B/kg during fresh and old residue analysis respectively. Elevation differed significantly (p < 0.05) for TN, S, P, Zn, and Fe. Nutrient content in residue was ranged from 27.1–32.2 g TN/kg, 6.8–5.5 g S/kg, 6.6–4.1 g P/kg, 20.8–17 mg Zn/kg, 109–116 mg Fe/kg, 129–10.4 mg Cu/kg and 10.1–9.6 mg B/kg for the elevation range of <650 m and >1050 m respectively. The TN, S, P, Zn, Fe, Cu, and B potentially produced from sesame residue were in the range of 49.4–5.0 kg N ha−1, 8.5–19.3 kg S ha−1, 8.7–10.5 kg P ha−1, 294–463 mg Zn ha−1, 1.99–2.62 g Fe ha−1, 1.25–342 mg Cu ha−1 and 183–214 mg B ha−1 respectively. This study clearly concludes that fresh and old residue as well as elevation are critical factors that need to be considered for exploring crop residue and its nutrient potential, quality, and quantity aspects in dryland farming systems.

1. Introduction

The ecosystems over drylands are fragile and sensitive to many changes such as climate, agricultural, farming, and cropping practices (Reynolds et al., 2007; Reed et al., 2012). Expansion of dry-lands associated with an increase in aridity has a direct consequence on desertification and farming (i.e., land degradation in arid, semi-arid, and dry sub-humid areas), and is a central issue for sustainable development, especially in the face of population growth (Reynolds et al., 2007). Arid and semi-arid regions comprise almost 41% of the world’s land area and are inhabited by some 700 million people and approximately 60% of these dry-lands are in developing countries (Parr et al., 1990; Feng et al., 2013).

Agriculture has undergone drastic changes over the last few decades, and farms have increasingly become more specialized and more intensive, with arable production often being concentrated in different regions of a country (McNeill et al., 2005). Agricultural activities (e.g.,

* Corresponding author.
E-mail address: yohannes7@yahoo.com (Y. Desta).

https://doi.org/10.1016/j.heliyon.2020.e05234
Received 18 July 2020; Received in revised form 10 August 2020; Accepted 8 October 2020
2405-8440/© 2020 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
destruction, burning, plowing, and intensive grazing) and expansions contribute substantially to the carbon pool (Lal and Kimble, 1997).

Agricultural production generates a large number of crop residues approximately 4 billion metric tons per year globally (Lal, 2005), and 1 billion tons of carbon in the form of crop residues may be available (Metzger and Benford, 2001). Crop residues are often mistakenly regarded as “agricultural waste” or something of little or no value, but they are not a “waste” (Lal, 2004). Restoring soil carbon is essential to enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing atmospheric CO2 (Lal et al., 2004). Some general effects of crop residues left on the soil surface are protected from erosion forces, maintains soil organic matter, addition to the available pool of nutrients, and improve crop yield (Pimentel et al., 1995; Clapp et al., 2000; Beri et al., 1995; Karlen et al., 1994; Linden et al., 2000).

Crop residue provides food and habitat for soil fauna (earthworms), recycles plant nutrients, improves crop production, biofuel production, and enhances biodiversity (Lal, 2004; Vinator et al., 2005; Bahadur et al., 2015). Some view the use of crop residues for biofuel production as an opportunity to give these “agricultural wastes” an economic value while reducing the over-dependence on fossil fuels without consideration of maintaining soil carbon, and they are valuable assets when returned to the soil (Wilhelm et al., 2007). The amount and nutrient content of the residue is hard to approximate and depends on factors such as time, tillage, grazing, elevation, temperature, precipitation, and practices (Gelderman, 2009). Burning of crop residue results a loss of 98–100% of N, 75% of S, 21% of P, and 35% of K (Gelderman, 2009).

The amount of total residue produced varies from year to year depending on variations in inter alia weather, water availability, soil fertility, and farming practices (Bahadur et al., 2015). The potential of crop residue of major cereals, pulses, oilseeds, and commercial crops for recycling of valuable plant nutrients for sustained crop production is enormous (Bahadur et al., 2015). The amount of nutrients in post-harvest crop residues is highly variable because it is determined by differences between individual plant species (Torma et al., 2018). Determination of nutrient content in residue has to be taken into account when calculating the fertilizer requirement of the subsequent crop in order to achieve better resource utilization, thereby reducing the risk of eutrophication and improving farm profits by reducing expenditure on fertilizer (Bahadur et al., 2015).

Knowledge of the amount and nutrient contents of sesame plant residues and their potential in terms of plant nutrition regarding the age of crop residue and elevation is critically important, particularly in dryland farming. However, virtually no studies have explored the potential, quality, and quantification assessment of sesame crop residue in dry land ‘vertisol’ where sesame cropping has continuously practiced. Therefore, the aim of this study was to explore the potential, quality, and quantity of sesame crop residue regarding the age of residue and elevation differences.

2. Methodology

2.1. Description of the study area

‘Kafta-Humera’ (Figure 1a) is located between 13°45’ to 14°28’ north latitude and 36°20’ to 37°31’ east longitude in ‘Tigrai’ regional state of Ethiopia. It is bordered by Eritrea and the Sudan Republic in the north and west, respectively. Most of the area is flat topography with an altitude that ranges between 510–1863 m (Figure 1b) above sea level (m.a.s.l) and sesame is potentially grown from 500 to 1600 m.a.s.l (Terefe et al., 2012). The study area has agroecological classes such as warm moist, warm semi-arid, and warm sub moist low lands (Figure 1a). It is generally characterized by arid climatic conditions with a mean annual temperature of 28.3 °C and a mean annual rainfall of 615.5 mm, which ranges from 300 mm to 800 mm (Figure 2). The rainy season is limited from June to September.

2.2. Experimental design

Age of residues (Fresh and old) and elevation differences were considered for the estimation of sesame residue and its nutrient potential. The age of residue referred herewith as the fresh residue and old residue to indicate 5 and 200 days old sesame residue left over the surface after harvest. Whereas, the elevation was classified as <650, 650–850, 850–1050 and >1050 m. This study was carried out in a homogeneous soil type of ‘vertisol’.

2.3. Crop residue estimation

A 20 years data on sesame cultivation were taken from ‘Kafta-Humera’ Office of Agriculture towards understanding the total cultivated land that falls under sesame cultivation and the grain yield obtained in those years. A total of 200 sesame residue samples were used for crop residue estimation and nutrient analysis. In order to quantify the mass of sesame residue, 50 samples of the stack and standing residues as well as straw were taken from each elevation ranges of <650 m, 650–850 m, 850–1050 m and >1050 m. Moreover, the analysis of nutrient content and potential in sesame residue were taken from 100 residue samples for each age of residue and 50 residue samples for each elevation difference. The residue samples were stored in cloth bags. The mass of stack residue and straw was calculated from the stack remained above the surface in a unit hectare of selected sesame cultivated land. Whereas, the mass of standing residue were determined from a plot area 20 (5 × 4) m² of each
selected sesame cultivated land. Collectively, the total mass of sesame residue was calculated as a sum of the mass of stack, standing residue, and straw. Stack residues are interpreted as residue gathered in one place during isolating grain from the residue. Whereas, standing residues are the bottom parts of the crop that did not cut and remains raised on the surface after harvest. The mass of sesame residue was calculated according to the formula of Bahadur et al. (2015).

\[
\text{Mass of sesame residue} = \text{Mass of stack} + \text{Mass of standing residue} + \text{Straw}
\]

(1)

3. Results and discussion

3.1. Nutrient composition of vertisols of the study sites

The soil laboratory analysis conducted for the composite soil samples taken from a depth of 0–20 cm results indicated that the proportions of soil particle size distribution were 47.7, 47.4, 46.6, and 45.7 for clay, 25.7, 30.1, 27.9, and 29.1 for silt and 22, 17.3, 18.7, and 16.6 for sand at the altitude of <650, 650–850, 850–1050 and >1050 respectively (Table 1). TN were 0.12%, 0.12%, 0.11% and 0.11% on <650, 650–850, 850–1050 and >1050 respectively (Table 1) and rated moderate as per Tekalign et al. (1991). Available P content of the soil on <650, 650–850, 850–1050 and >1050 were 10.5, 10.7, 11.0, and 11.5 mg/kg respectively (Table 1) and rated as low for plant growth and it is indicative of soil capable of significant yield responses to application of the appropriate level of the nutrient.

Similarly, Olsen and Dean (1965) stated as the P content of less than 12 P kg ha\(^{-1}\) in soil indicates a crop response to P fertilizers, between 12 and 24 kg P ha\(^{-1}\) indicates a probable response. The available S nutrient content of the soil at <650, 650–850, 850–1050 and >1050 were 12.92, 13.42, 14.17 and 15.39 mg/kg respectively (Table 1). Moreover, Zn nutrient content of soil at <650, 650–850, 850–1050 and >1050 were 39.9, 39.6, 38.0 and 36.0 mg/kg respectively (Table 1). Kiekens (1995) reported a typical range of zinc in soils of 10–300 mg kg\(^{-1}\) with a mean of 50 mg Zn kg\(^{-1}\). Finer texture soils like clay have higher CEC values and therefore have highly reactive sites and can retain more Zn than lighter textured soils (Shukla and Mittal, 1980). Furthermore, B content of the soil at <650, 650–850, 850–1050 and >1050 were 10, 9.8, 9.8 and 8.7 mg/kg respectively (Table 1). As a general rule, B toxicity occurs when soils contain concentrations greater than 12 mg/kg B (Hall, 2010). Cu content of the soil at <650, 650–850, 850–1050 and >1050 were 12, 11.4, 10.9 and 10.9 mg/kg respectively (Table 1). In addition, Fe content of the soil at <650, 650–850, 850–1050 and >1050 were 111.1, 110.9, 110.9 and 110.1 mg/kg respectively (Table 1).

3.2. Sesame area coverage, grain yield, and residue potential

Based on the 20 years data, the result shows that the total average cultivated land covered by sesame was 170,000 ha which accounts for 44 % of the total cultivated land of 386,364 ha (Figure 3). Accordingly, the size of sesame cultivated land during 1999 and 2018 was observed 45,918 ha and 223,825 ha respectively. This indicates that the currently cultivated land covered by sesame has increased by 79.5 % compared with the cultivated land covered by sesame before 20 years ago showing that more than the double land size has been brought into sesame cultivation during this period of time. This result agrees with the report of Ayana (2015) which stated that the total production area of sesame in Ethiopia has increased by 61.23 %.
The total annual grain production of sesame was calculated to be 0.09 Mt (Figure 3). The ratio between grain yield and size of cultivated land covered by sesame was about 5.1. This implies that the annual average grain yield was 5.1 times greater than the area being covered by sesame. The increment in the size of cultivated land by sesame and annual variability in grain yield of sesame may be related to land-use change and expansion of cultivated land, inconsistency in the use of fertilizer, crop rotation, and climate variability. A study by Deininger and Byerlee (2011) revealed that within only 5 years (2004–2009) around 1.2 million ha of land was converted into arable land in Ethiopia. It was also reported that during the last 300 years, >50% of the land surface has been affected by land-use change activities, >25% of forests have been permanently cleared, agriculture occupies >30% of the land surface (Vitousek et al., 1997; Hurtt et al., 2006, 2011).

Elevation difference showed a significant (p < 0.05) influence on the average mass of sesame residue. The average sesame residue obtained at <650 m, 650–850 m, 850–1050 m, and >1050 m elevation were 26.8, 21.2, 17.5, and 15 qt/ha respectively (Figure 3). Moreover, the highest (26.8 qt/ha) and lowest (15 qt/ha) values for the average mass of sesame residue were perceived in the lowest (<650 m) and highest (>1050 m) elevation respectively. This study revealed that the amount of sesame residue production increases as elevation decreases due to the accumulation of nutrients in low elevated areas through leaching down and erosion conditions from the high elevated area that results in high biomass production and cropping practices such as shifting cultivation, intercropping and crop rotation. Moreover, due to elevations of great variability and its influence on microclimate; the production of sesame crop residue had greatly affected. Charan et al. (2013) has similarly reported that elevation had shown a great variability and its influence on microclimate that leads to producing different amount of residue. Jain et al. (2014) has also reported that there was a large variation in plant residues generation in India due to their cropping intensity, and biomass productivity (see Figure 4).

Generally, the average mass of sesame residue produced was 20.13 qt/ha. Considering this and the total area of sesame cultivated land, a total mass of 0.34 Mt of sesame residue were produced. The estimated sesame residue to grain yield ratio is around 3.7. In reports by Jain et al. (2014) plant residue to grain ratio varied between 2.0–3.0 for oilseed crops whereas our result show higher by 0.7 considering the maximum ratio. The possible reasons for the variation could be due to crop-specific residue estimation, environmental, social, and climatic issues. The estimates of Jain et al. (2014) were also in line with other reports in literature stated by Pathak et al. (2006, 2010) have estimated 253 Mt of plant residue generation in India by the year 2010.

### 3.3. Nutrient concentration and potential in sesame residue

Macro and micronutrient concentration analysis for the type of sesame residue and elevation were performed. The selected elemental concentration in sesame residue that was analyzed based on the weight of dry matter includes TN, S, P, Zn, Fe, Cu, and B.

#### 3.3.1. Total nitrogen, sulfur, and phosphorous concentration

TN concentration differed significantly (p < 0.05) with the type of sesame residue (Table 3). A higher TN concentration was observed in the fresh residue (34.55 g/kg) than old residue (24.53 g/kg). Similarly, TN potential of 49.4 kg N ha\(^{-1}\) and 69.6 kg N ha\(^{-1}\) were produced during old and fresh residue respectively. Moreover, TN concentration at >1050 m elevation differed significantly (p < 0.05) with <650 m and 650–850 m elevation (Table 2). However, there was no significant differences in the TN concentration of sesame among <650 m, 650–850 m, and 850–1050 m elevation. As shown in Table 2; the TN concentration in sesame residue on <650 m, 650–850 m, 850–1050 m, and >1050 m elevation was 27.1, 28.4, 30.6, and 32.2 g/kg respectively. In this case; the highest (32.2 g/
kg) and lowest (27.1) values of TN were observed on the highest (>1050 m) and lowest (<650 m) elevation respectively. Collectively, from this study, it is understood that TN concentration decreased in old residues and decreased as elevation decreases and increased in fresh residues and increased as elevation increases (Table 4). The variation for TN concentration in sesame residue could be resulted due to the variability on the loss of substantial amounts of nitrogen (N) in the forms of ammonia and leaching in the form of nitrate. De Ruijter et al. (2010) has reported ammonia volatilization was 5–16 percent of the N content of residues when placed on top of the soil. McNell et al. (2005) has indicated that besides leaching of N in the form of nitrate from elevated areas of land, substantial emissions of N as ammonia are also associated with land spreading of residues and manures. It was also stated that nitrogenous fertilizers are the largest single source of GHG emissions from arable agriculture (Galloway et al., 2008; Smith et al., 2008). Furthermore, there are reports of the potential loss of N by volatilization during spring was greater than in years with normal rainfall amounts and represented a significant portion of aboveground plant N mass (Turner et al., 1997). As reported in Table 3, the varying age of residue significantly (p < 0.05) influenced S concentration in sesame residue. The highest (9.7 g/kg) and lowest (4.2 g/kg) values of S concentration in sesame residue were perceived during fresh and old residue analysis respectively. Perhaps fresh residue increased S concentration by more than double compared with the old residue. The S potentially produced from sesame residue was recorded 8.5 kg S ha⁻¹ to 19.3 kg S ha⁻¹ during old and fresh residue analysis respectively. This implied that old residues decreased S concentration by 5.4 g/kg (56.25%) compared with fresh residues (Table 3). Furthermore, elevation difference significantly (p < 0.05) influenced S concentration in sesame residue (Table 2 and Figure 5b). The S concentration has notably recorded as 6.0, 6.1, 7 and 8.5 g/kg for <650 m, 650–850 m, 850–1050 m and >1050 m elevation respectively (Table 2). Similarly, the highest elevation (>1050 m) resulted in higher S concentration and potential than the lowest elevation (<650 m). This result indicated that the S concentration of sesame residue increases substantially with increase in elevation and vice versa. In literature, it was reported that the factors which affect the rate of S emission from plants include temperature, light intensity, plant age, and plant injury (Grundon and Asher, 1988; Trust and Fry, 1992). It was also reported that the S emission from plants in agroecosystems may range from about 0.1 to 3 kg S ha⁻¹ yr⁻¹ (Aneja et al., 1991). However, our study shows a higher S emission than what was reported by Aneja et al. (1991) and this may be resulted due to a specific type of plant residue and climate variability. Plants may release measurable amounts of volatile S into the atmosphere (Rennenberg, 1984) as well as the emission of H₂S and other volatile S compounds have been proposed as a mechanism for removing excess inorganic S in plant tissues (Rennenberg, 1984; McNeill et al., 2005).

Age of residue significantly (p < 0.05) influenced P concentrations in sesame residue (Table 3). P concentration of 5.2 and 4.3 g/kg in sesame residue were observed during fresh and old residue respectively. Moreover, potential ranges of 8.7–10.5 kg P ha⁻¹ were produced from sesame residue. However, the highest (10.5 kg P ha⁻¹) and lowest (8.7 kg P ha⁻¹) P potential were perceived during fresh and old residue respectively. This result indicated that old sesame residues decreased the P concentration and potential by 17% compared to fresh residues (Table 3). This study agreed with the reports of Losier et al. (2017) which reported that water-extractable P concentrations in vegetation increased with plant decomposition and decreased following runoff events indicating that the plant P was removed by runoff. But, the P concentration of sesame residue differed significantly (p < 0.05) with elevation (Table 2 and Figure 5c). The P concentration of sesame residue was recorded as 6.6, 5.5, 4.2, and 4.1 g/kg for <650 m, 650–850 m, 850–1050 m, and >1050 m elevation categories respectively (Table 2). Moreover, 8.3 kg P ha⁻¹, 8.5 kg P ha⁻¹, 11.1 kg P ha⁻¹ and 13.4 kg P ha⁻¹ P potential were produced in <650 m, 650–850 m, 850–1050 m and >1050 m elevation respectively. This result revealed that as elevation increases, the P concentration of sesame residue decreases, and vice versa. This kind of variation could be brought due to high biomass production in low elevated areas and less P uptake by plants due to low biomass production in high elevated areas (Liu, 2013). Furthermore, runoff removes a substantial amount of P from soils of high elevation that may have an impact on the P uptake by plants. However, as reported by McDowell et al. (2011); P concentrations in crops tended to increase with soil P availability, as measured by Mehlich-3 extractable soil P concentration. This difference agrees with studies of forage harvested on a monthly basis in New Zealand by Crush et al. (1989) and on an annual basis in the U.S. by Pederson et al. (2002).

### 3.3.2. Zinc, iron, copper, and boron concentrations

The age of residue significantly (p < 0.05) influenced the Zn concentration of sesame residue (Table 3). Zn concentration of sesame residue recorded in fresh and old residues was 23 mg Zn kg⁻¹ and 14.6 mg Zn kg⁻¹ respectively. Furthermore, Zn potential of 463.5 mg Zn ha⁻¹ and 294.3 mg Zn ha⁻¹ were produced during fresh and old residue

---

**Table 2. Mean and standard error of elemental concentration with elevation difference (n = 100).**

| Elevation (m) | Dry matter (%) | Macronutrient concentration in crop residue on a dry weight basis |
|---------------|----------------|---------------------------------------------------------------|
|               | TN (g/kg)      | S (g/kg)           | P (g/kg)           | Zn (mg/kg)          | B (mg/kg)       | Fe (mg/kg)       | Cu (mg/kg)       |
| <650          | 80.9± 2.06    | 27.1± 0.76        | 6.05± 0.08        | 6.15± 0.08         | 20.8± 1.80      | 10.1± 0.23      | 109± 0.80        | 12.9± 0.50       |
| 650–850       | 84.8± 4.25    | 28.39± 0.98       | 6.05± 0.11        | 5.06± 0.11         | 18.4± 1.38      | 10.1± 0.23      | 112± 0.38        | 12.0± 0.45       |
| 850–1050      | 85.0± 2.08    | 30.55± 1.55       | 7.09± 0.17        | 3.86± 0.17         | 18.85± 2.84     | 9.8± 0.30       | 113± 0.84        | 11.1± 0.59       |
| >1050         | 85.3± 2.68    | 32.15± 0.75       | 8.5± 0.08         | 3.8± 0.08          | 16.95± 1.39     | 9.6± 0.50       | 116± 0.39        | 10.4± 0.93       |

Note: Margins sharing a letter in the group label are not significantly different at the 5% level.

---

**Table 3. Mean and standard error of elemental concentration in fresh and old residue (n = 100).**

| Type of residue | Dry matter (%) | Macronutrient concentration in crop residue on a dry weight basis |
|----------------|----------------|---------------------------------------------------------------|
|                | TN (g/kg)      | S (g/kg)           | P (g/kg)           | Zn (mg/kg)          | B (mg/kg)       | Fe (mg/kg)       | Cu (mg/kg)       |
| Fresh residue  | 78.5± 1.87    | 34.53± 0.68       | 8.5± 0.08         | 5.2± 0.08          | 22.93± 1.25     | 10.67± 0.20     | 130.23± 1.25     | 17.0± 0.41       |
| Old residue    | 89.5± 1.99    | 24.53± 0.73       | 7.15± 0.08        | 4.3± 0.08          | 14.58± 1.34     | 9.12± 0.22      | 94.78± 1.34      | 6.2± 0.43        |

Note: Margins sharing a letter in the group label are not significantly different at the 5% level.
respectively. In comparison, the fresh residue has resulted in higher Zn concentration and potential than old residue. This result revealed that Zn concentration in the fresh residue was 63.5% higher than Zn concentration in old residues. In addition, varying elevation differed significantly (p < 0.05) Zn concentration in sesame residue (Table 2). Zn concentration of 20.8 mg Zn kg⁻¹, 18.4 mg Zn kg⁻¹, 18.8 mg Zn kg⁻¹ and 17 mg Zn kg⁻¹ in sesame residue were observed on <650 m, 650–850 m, 850–1050 m and >1050 m elevation respectively (Table 2 and Figure 6a). Moreover, Zn potential of 419.2 mg Zn ha⁻¹, 370.9 mg Zn ha⁻¹, 378.9 mg Zn ha⁻¹ and 342.6 mg Zn ha⁻¹ were produced due to <650 m, 650–850 m, 850–1050 m, and >1050 m elevation respectively. Therefore, the highest Zn concentration (20.8 mg Zn kg⁻¹) and potential...
Fe and Zn cations are either incorporated into enzyme proteins or complexes with low-molecular-weight organic compounds (Frossard et al., 2000). Moreover, Boron is readily soluble in water and should accumulate in the lower slope positions (Knight and Farrell, 2000). Zn enzyme proteins are involved in many physiological activities and growth processes. High Zn contents are therefore found in meristematic tissues. Zn is therefore important in plant tissues which are subjected to oxidative stress (Frossard et al., 2000; Cakmak and Marschner, 1988).

Table 4. Average elemental concentration for both type of residue (fresh and old) and elevation.

| Elevation (m) | Fresh residue (n = 100) | Old residue (n = 100) |
|--------------|-------------------------|-----------------------|
|              | TN (g/kg) | P (g/kg) | S (g/kg) | Zn (mg/kg) | B (mg/kg) | Fe (mg/kg) | Cu (mg/kg) | TN (g/kg) | P (g/kg) | S (g/kg) | Zn (mg/kg) | B (mg/kg) | Fe (mg/kg) | Cu (mg/kg) |
| <650         | 35.3     | 6.8      | 9.7      | 2.9      | 11.35     | 149.4     | 16.8       | 18.9      | 5.5      | 2.4      | 13.7      | 8.78      | 68.6       | 9.0       |
| 650–850      | 34.2     | 5.4      | 8.3      | 2.4      | 11.11     | 132.5     | 18.6       | 22.5      | 4.6      | 3.8      | 12.4      | 9.05      | 91.5       | 5.4       |
| 850–1050     | 34.4     | 4.3      | 9.4      | 2.1      | 10.15     | 117.0     | 16.8       | 26.7      | 3.5      | 4.6      | 16.2      | 9.15      | 109.0      | 5.4       |
| >1050        | 34.3     | 3.2      | 11.2     | 1.2      | 10.11     | 122.0     | 15.8       | 30.0      | 3.4      | 5.8      | 16.0      | 9.21      | 110.0      | 5.0       |

Table 5. Pearson correlation for elemental concentration in sesame residue.

| Variables | Cu | Zn | TN | Fe  | B   | P   | S   |
|-----------|----|----|----|-----|-----|-----|-----|
| Cu        | 1.00 | -0.65* | 0.76** | 0.81** | 0.89** | 0.22 | 0.50 |
| Zn        | 1.00 | 0.73** | -0.76** | 0.86** | -0.67* | 0.81** |     |
| TN        | 1.00 | 0.78** | 0.74** | 0.53 |     | 0.86** |     |
| Fe        | 1.00 | -0.88** | -0.30 | 0.72** |     |     |     |
| B         | 1.00 | 0.14 | 0.70* |     |     |     |     |
| P         | 1.00 |     | 0.50 |     |     |     |     |
| S         | 1.00 |     |     |     |     |     |     |

* and ** indicates significance level at p < 0.01 and 0.05 respectively.
The increase in B may be resulted due to less volatilization and decomposition processes during fresh residue and the residue accumulated in higher elevated areas. The chance of B availability under drought conditions or low organic matter content reduced because of organic matter breakdown (Shorrocks, 1997).

3.4. Correlation among elemental concentrations in sesame residue

The correlation among elemental concentration in sesame residue for TN, S, P, Zn, Fe, Cu, and B were performed using correlation analysis.

The result revealed that Cu highly significantly \( r < 0.01 \) correlated with TN, Fe and B with the value of \( r = 0.76 \) and \( r = 0.81 \) and \( r = 0.89 \) respectively (Table 5). Similarly, Zn highly significantly \( r < 0.01 \) correlated with TN, Fe, and B and with the value of \( r = 0.73 \), \( r = 0.86 \), and \( r = 0.81 \) respectively. Furthermore, TN highly significantly \( r < 0.01 \) correlated with Fe, B, and S with the value of \( r = 0.78 \) and \( r = 0.74 \) and \( r = 0.86 \) respectively (Table 5). In addition, Fe highly significantly \( r < 0.01 \) correlated with B and S with the value of \( r = 0.88 \) and \( r = 0.72 \) respectively (Table 5). Some micronutrients reveal synergism with macronutrients for example the addition of macronutrients resulted in a higher yield of wheat on calcareous soil and the increase due to Zn was largest at the highest addition of macronutrients (Sakal, Singh, and Sinha, 1988). Nitrogen and S fertilization also may catalyze higher production of phytosiderophores and have been reported in soil and field experiments to increase Zn and Fe content in wheat (Kutman et al., 2011; Shi et al., 2010). Whereas, B with S, Cu with Zn and Zn with P significantly \( r < 0.05 \) correlated with the value of \( r = 0.70 \), \( r = 0.65 \) and \( r = 0.67 \) respectively (Table 5). In the absence or low concentrations of zinc, phosphorus uptake and transport increased in the shoot and its concentration increased in the leaves, as a result, can cause toxicity in the plant. Metabolism defect in plant cells that is related to zinc and phosphorus imbalance, so by increasing the phosphorus concentration, zinc tasks are impaired at specific positions in the cells (Das et al., 2005; Alloway, 2008). Imtiaz et al. (2003), reports that the application of Zn had an adverse effect on the Cu concentration in the plant tissue of wheat due to competition for the same sites for absorption into the plant root. Zinc deficiency leads to iron (Fe) deficiency, due to prevent of transfer of Fe from root to shoot in zinc deficiency conditions (Rengel et al., 1998; Rengel and Romheld, 2000). Zinc deficiency decreases plant growth by increasing the concentration of boron in the young leaves and tips of the branches. The application of zinc increased boron uptake by plants in the soils with sufficient stores (Rengel et al., 1998). There is a negative interaction between zinc and copper (Cu) due to effect antagonism and the same membrane transport protein (Moustakas et al., 2011). Several micronutrient contents increased as N fertility increased (Brüns and Ebelhar, 2006). S is also known to interact with almost all essential macronutrients, secondary nutrients, and micronutrients. These interactions can either enhance or reduce the growth and yield of crops by influencing nutrient uptake and utilization (Abdin et al., 2003).

4. Conclusions

This study clearly concludes that the age of residue (fresh and old) and elevation are critical factors that need to be considered for quantifying sesame residue and its nutrient management in dryland farming systems. Lower elevation has a higher amount of sesame residue production, induced due to high biomass production, and cropping practices. Fresh residues had the potential of producing higher TN, S, P, Zn, Cu, Fe, Cu, and B than old residues. Besides potential leaching in highly elevated areas, substantial emissions of N as ammonia and volatile losses of S is higher in old residues than fresh ones. Whereas, higher potential of P in sesame residue occurred on lower elevated areas due to potential runoff removal from higher elevated areas.

Declarations

Author contribution statement

Yohannes Desta: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mitiku Haile, Girmay Gebresamuel, Mulugeta Sibhatleab: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by the MU-NMBU project (phase IV), a cooperative project between Mekelle University (Ethiopia) and Norwegian University of Life Science (Norway).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors have special thanks to the farmers and agricultural officers in the concerned district for the information that provided us and shared their knowledge for the wellbeing of this study.

References

Abdin, M.Z., Ahmad, A., Khan, N., Khan, I., Jamal, A., Iqbal, M., 2003. Sulphur interaction with other nutrients. Sulphur in Plants. Springer, Dordrecht, pp. 359–374.
Alloway, B.J., 2008. Zinc in soils and crop nutrition. published by IZA and IFA, Brussels, Belgium and Paris, France, 139.
Anejia, V.P., Higuchi, T., Osako, M., Nishida, K., et al., 1991. Natural sulfur emissions into the atmosphere. Journal of Environmental Conservation Engineering 20 (4), 256–265.
Ayana, N.G., 2015. Status of production and marketing of Ethiopian sesame seeds (Sesamum indicum L.): a Review. Agric. Biol. Sci. J. 1, 217–223.
Babahur, I., et al., 2015. Crop residue management for improving soil quality and crop productivity in India. Indian J. Agric. Allied Sci. 1 (1), 52–58.
Beri, V., Sisthu, B.S., Balh, G.S., Bhat, A.K., 1995. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. Soil Use Manag. 11 (2), 51–54.
Braudisch, K., R., 1965. The Kjeldahl Method for Organic Nitrogen. Academic Press, New York, NY, and London, UK.
Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen—total 1. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, (methodsofsoilana2), pp. 595–624.
Britat, J.F., Fobis-Loisy, I., Grignon, N., Lobretaux, S., Pascal, N., Savino, G., Van Wuytswinkel, O., 1995. Cellular and molecular aspects of iron metabolism in plants. Biol. Cell. 84 (1-2), 69–81.
Brüns, H.A., Ebelhar, M.W., 2006. Nutrient uptake of maize affected by nitrogen and potassium fertility in a humid subtropical environment. Commun. Soil Sci. Plant Anal. 37 (1-2), 275–293.
Cakmak, I., Marchner, H., 1988. Enhanced superoxide radical production in roots of zinc-deficient plants. J. Exp. Bot. 39 (10), 1449–1460.
Charron, G., Bhati, V., Jadhav, S., Kumar, S., Acharya, S., Kumar, P., Gogoi, D., Srivastava, R., 2013. Altitudinal variations in soil physico-chemical properties at cold desert high altitude. J. Soil Sci. Plant Nutr. 13 (2), 267–277.
Clapp, C.E., Allmaras, R.R., Layese, M.F., Linden, D.R., Dowdy, R.H., 2000. Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 54 (3–4), 127–142.
Crush, J.R., Evans, J.P.M., Coogrove, G.P., 1989. Chemical composition of ryegrass (Lolium perenne L.) and prairie grass (Bromus wildenewii Kunth) pastures. N. Z. J. Agric. Res. 32 (4), 461–468.
Das, K., Dang, R., Shivananda, T.N., Sur, P., 2005. Interaction between phosphorus and zinc on the biomass yield and yield attributes of the medicinal plant stevia (Stevia rebaudiana). Sci. World J. 5, 390–395.
De Ruiter, F.J., Huijmsmans, J.F.M., Rutgers, B., 2010. Ammonia volatilization from crop residues and frozen green manure crops. Atmos. Environ. 44 (28), 3362–3368.
Dreisinger, K., Byerlee, D., 2011. Raising Global Interest in farmland: Can it Yield Sustainable and Equitable Benefits? The World Bank.
