Heliyon 6 (2020) e05234

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

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 PO_4 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 digests. 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 g S/kg, 6.6–4.1 g P/kg, 20.8–17 mg Zn/kg, 109–116 mg Fe/kg, 12.9–10.4 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 49.4–69.6 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}, 125–342 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

deforestation, 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 CO_2 (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; Viator 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 reside and elevation is critically important, particularly in dryland farming. However, virtually no studies have explored the potential, quality, and quantity 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

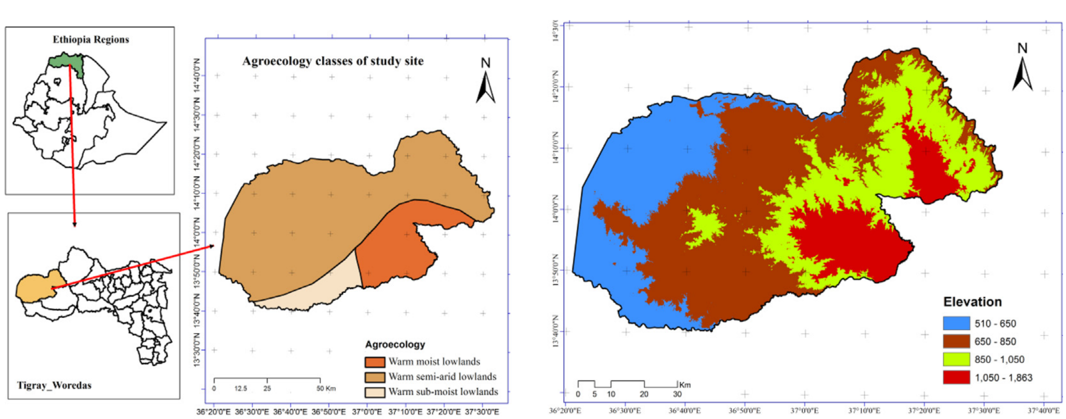
'Kafta-Humera' (Figure 1a) is located between 13°45′ to 14°28′ north latitude and 36°20′ to 37°31′ east longitude in 'Tigrai' regional state of Ethiopia. It is bordered by Eritrea and the Sudan Republic in the north and west, respectively. Most of the area is flat topography with an altitude that ranges 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) m^2 of each



a b

Figure 1. Location (a) and elevation (b) map of the study area.

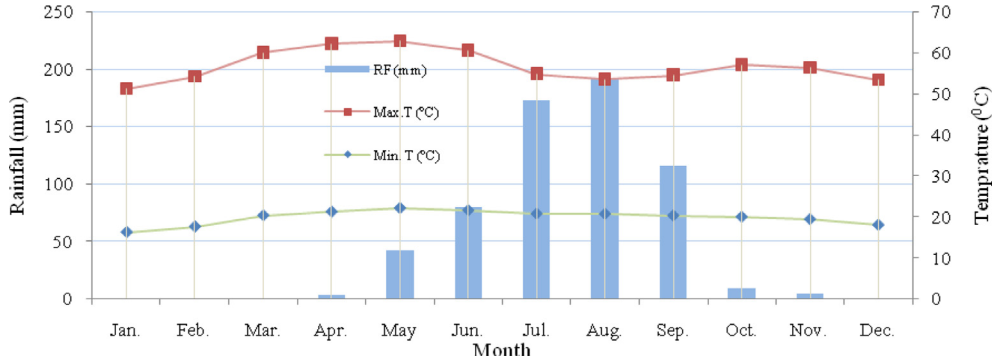


Figure 2. Mean monthly rainfall, maximum and minimum temperature.

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).

$$\text{Mass of sesame residue} = \textit{Mass of stack} + \text{Mass of standing residue} + \text{Straw} \tag{1}$$

2.4. Nutrient analysis

Prior to analysis, fresh and old residue plant samples were dried in a dust-free, forced draft oven at a temperature of 80 °C (176 °F), which is a temperature sufficient to remove moisture without causing appreciable thermal decomposition. The dried plant samples were reduced to pass through a 10-mesh (2-mm) screen to ensure a greater degree of uniformity in sample composition, the tissue was mechanically ground in a ball mill. Elemental concentration analysis in sesame residue was carried out for total nitrogen (TN), phosphorous (P), sulfur (S), zinc (Zn), iron (Fe), copper (Cu) and boron (B). The TN, S, and P in the residue were determined by Kjeldahl digestion Method (Bradstreet, 1965; Bremner and Mulvaney, 1982), wet acid digestion Method (Pritchard and Lee, 1984) and using two percent acetic acid (CH3COOH) as extracting to extract PO_4 as described by Ulrich et al. (1959) respectively.

The procedure outlined by Lindsay and Norvell (1978) was followed for determining micronutrient cations viz., Fe, Zn, and Cu by using atomic absorption spectrophotometer. B was determined by extraction using a mixture of hydrochloric (HCl) and hydrofluoric (HF) acids (van der Lee et al., 1987). The extract is then filtered through a Whatman 42 filter paper on its equivalent for TN, P, S, Zn, Fe, Cu, and B determinations. Finally, nutrient potential per hectare of sesame residue was calculated using Gelderman (2009) formula.

$$\text{Nutrient potential} = \text{Amount of nutrient in residue} * \text{Amount of residue per hectare} \tag{2}$$

2.5. Data analysis

All the field and laboratory data were analyzed using R software (R version 3.5.2). Before analysis, normality and homogeneity checking of the data were performed using the Shapiro-Wilk Test for normality and Levene's Test for Equality of Variances respectively. The mean differences among season and elevation categories were tested using analysis of variance (Two Way ANOVA). Pearson correlation analysis was also done to assess the correlation among nutrients concentrations in sesame residue.

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 %.

Table 1. Initial soil nutrient composition of Vertisols.

Altitude (m a.s.l)	Soil nutrient content							Particle size distribution (%)		
	TN	Av.P	Av.S	Zn	B	Cu	Fe	Clay	Silt	Sand
	%			mg/kg						
<650	0.12	10.5	12.92	39.9	10.0	12.0	111.1	47.7	25.7	22
650–850	0.12	10.7	13.42	39.6	9.8	11.4	110.9	47.4	30.1	17.3
850–1050	0.11	11.0	14.17	38.0	9.8	10.9	110.9	46.6	27.9	18.7
>1050	0.11	11.5	15.39	36.0	8.7	10.9	110.1	45.7	29.1	16.6

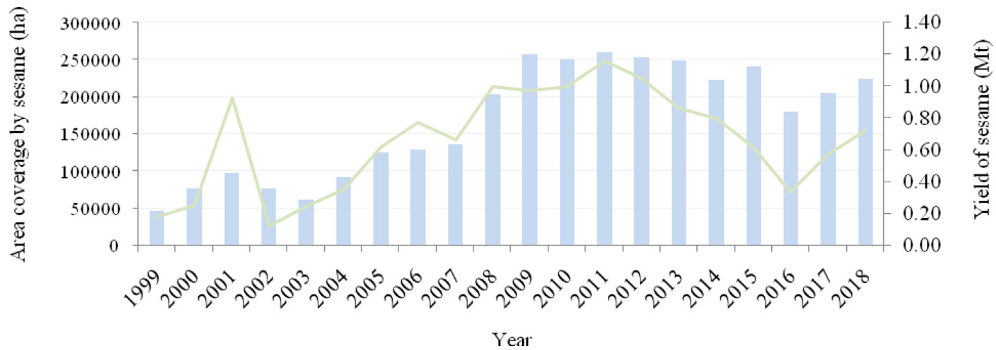


Figure 3. Comparison of area coverage and grain yield of sesame over time.

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 Mts 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.

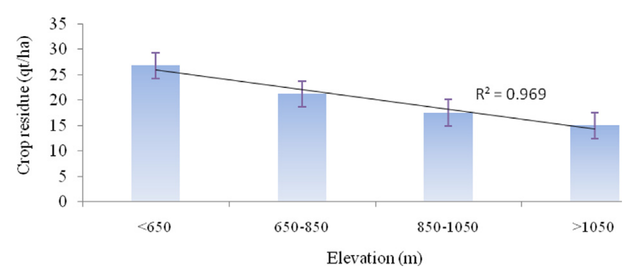


Figure 4. Bar errors showing sesame residue with elevation difference.

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/

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	$80.9^{a} \pm 2.06$	$27.1^{a} \pm 0.76$	$6.05^{a} \pm 0.08$	$6.15^{a} \pm 0.08$	$20.8^{a} \pm 1.80$	$10.1^{a} \pm 0.23$	$109^{a} \pm 0.80$	$12.9^{a} \pm 0.50$
650–850	$84.8^{a} \pm 4.25$	$28.35^{a} \pm 0.98$	$6.05^{ab} \pm 0.11$	$5.0^{ab} \pm 0.11$	$18.4^{ab} \pm 1.38$	$10.1^{a} \pm 0.23$	$112^{ab} \pm 0.38$	$12.0^{a} \pm 0.45$
850–1050	$85.0^{a} \pm 2.08$	$30.55^{ab} \pm 1.55$	$7.0^{ab} \pm 0.17$	$3.9^{ab} \pm 0.17$	$18.85^{ab} \pm 2.84$	$9.8^{a} \pm 0.30$	$113^{ab} \pm 0.84$	$11.1^{a} \pm 0.59$
>1050	$85.3^{a} \pm 2.68$	$32.15^{b} \pm 0.75$	$8.5^{b} \pm 0.08$	$3.8^{b} \pm 0.08$	$16.95^{b} \pm 1.39$	$9.6^{a} \pm 0.50$	$116^{b} \pm 0.39$	$10.4^{a} \pm 0.93$

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

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. McNeill 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 sesame residue significantly *($p < 0.05$)* influenced S concentration in sesame residue. The highest (9.6 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 H_2S 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 Lozier 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, cupper, 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 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	$78.5^{a} \pm 1.87$	$34.55^{b} \pm 0.68$	$8.5^{b} \pm 0.08$	$5.2^{b} \pm 0.08$	$22.93^{a} \pm 1.25$	$10.67^{b} \pm 0.20$	$130.23^{a} \pm 1.25$	$17.0^{b} \pm 0.41$
Old residue	$89.5^{b} \pm 1.99$	$24.53^{a} \pm 0.73$	$7.15^{a} \pm 0.08$	$4.3^{a} \pm 0.08$	$14.58^{b} \pm 1.34$	$9.12^{a} \pm 0.22$	$94.78^{b} \pm 1.34$	$6.2^{a} \pm 0.43$

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

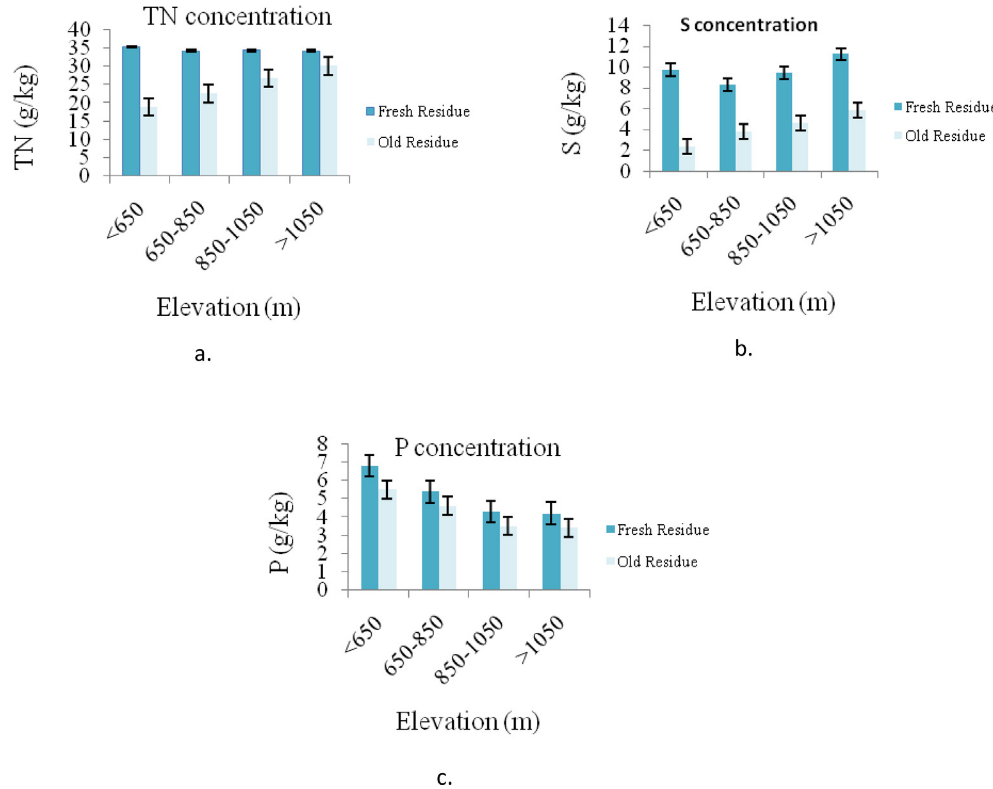


Figure 5. Total nitrogen concentration (a), Sulfur concentration (b) and Phosphorous concentration (c).

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

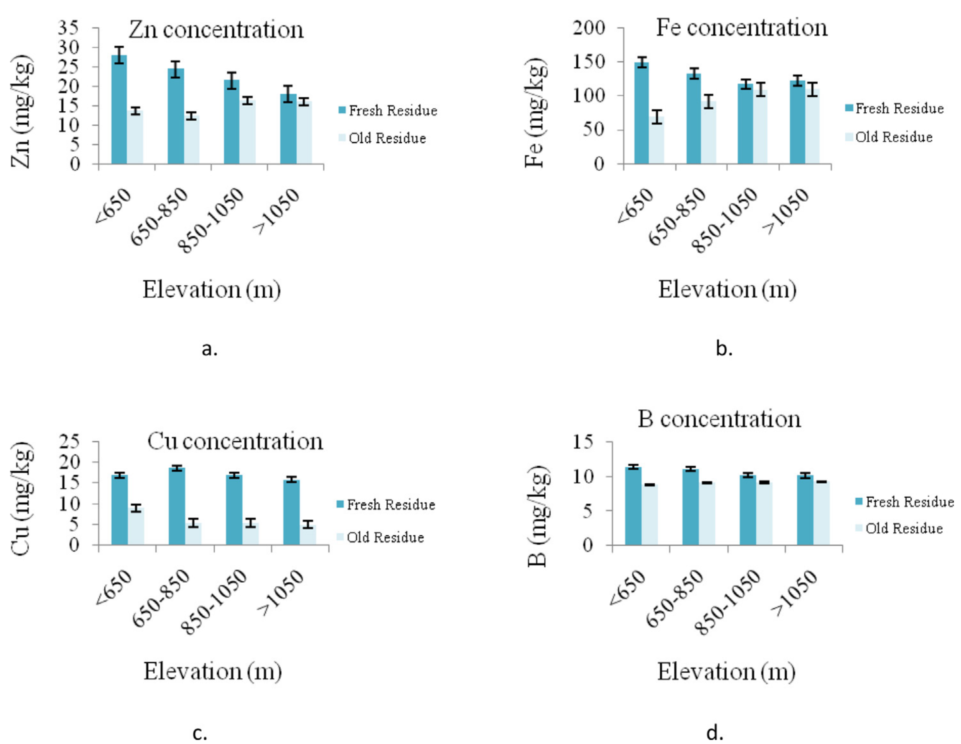


Figure 6. Zinc concentration (a), Iron concentration (b), Copper concentration (c) and Boron concentration (d).

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	27.9	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	24.4	11.1	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	21.5	10.15	117.0	16.8	26.7	3.5	4.6	16.2	9.15	109.0	5.4
>1050	34.3	4.2	11.2	17.9	10.1	122.0	15.8	30.0	3.4	5.8	16.0	9.21	110.0	5.0

(42.1 mg Zn ha^{-1}) were perceived at the lowest elevation (<650 m) than all other elevation categories. This study is in line with the reports of Shah et al. (2013) and Nazir et al. (2015) that shown the permissible limit of zinc in plants is 50 mg/kg. In this study, in the entire analyzed residue samples, Zn concentrations were recorded below the permissible limit. At the same time elevation (Figure 6a), Zn in the residue has shown differences in its concentration levels due to differences in landforms and localized management. Mathew et al. (2016) has reported that plant residue micronutrients have shown in their concentration levels probably be explained by difference in land forms especially in the mountainous areas which associated with localized management.

Fe concentration of sesame residue was differed significantly *($p < 0.05$)* in fresh and old sesame residues (Table 3). Fe concentration in fresh and old residues was 130.23 mg Fe kg^{-1} and 94.78 mg Fe kg^{-1} of sesame residue respectively (Table 3). Sesame residue has a potential of producing Fe that was ranged from 1.99 g Fe ha^{-1} to 2.62 g Fe ha^{-1} as the least one regarded for old residue and highest for fresh residue. This result shows that Fe concentration was higher in fresh residues than old ones and vice versa. Furthermore, Fe concentration differed significantly *($p < 0.05$)* with elevation difference (Table 2 and Figure 6b.). Concentration of 109 mg Fe/kg, 112 mg Fe/kg, 113 mg Fe/kg and 116 mg Fe/kg were analyzed on < 650 m, 650–850 m, 850–1050 m, and >1050 m elevation respectively (Table 2). Sesame crop residue at an elevation of <650 m, 650–850 m, 850–1050 m, and >1050 m were produced Fe potential of 2.3 g Fe ha^{-1}, 2.35 g Fe ha^{-1}, 2.37 g Fe ha^{-1}, and 2.44 g Fe ha^{-1}. The concentration of free Fe^{2+}, Fe^{3+}, and Zn^{2+} in plant tissues is low because Fe and Zn cations are either incorporated into enzyme proteins or complexes with low-molecular-weight organic compounds (Frossard et al., 2000). Fe can be temporarily stored in protein bodies such as phytoferritin (Briat et al., 1995) which is found in seeds, xylem, and phloem and in chloroplasts of leaves (Smith, 1984). Zn enzyme proteins are involved in many physiological activities and growth processes and 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).

Cu concentration of sesame residue differed significantly *($p < 0.05$)* in fresh and old residues (Table 3). Cu concentration in fresh and old residues was recorded as 17.0 mg Cu kg^{-1} and 6.2 mg Cu kg^{-1} respectively showing that fresh residue has 2.74 times higher Cu content than old residue. The permissible limit of copper for plants is 10 mg/kg recommended by WHO (Hassan et al., 2012; Nazir et al., 2015). In this case, all the collected plant samples concentration of copper was recorded above the permissible limit. This implies that sesame residue had the potential to produce Cu in the range of 125–342.1 mg Cu ha^{-1}. The Cu concentration of sesame residue did not differ significantly *($p < 0.05$)* with elevation difference (Table 2 and Figure 6c). However, Cu concentration of 12.9 mg Cu/kg, 12.0 mg Cu/kg, 11.1 mg Cu/kg and 10.4 mg Cu/kg were recorded for <650 m, 650–850 m, 850–1050 m and >1050 m elevation respectively (Table 2). Moreover, sesame residue had the potential of producing around 260 mg Cu/ha, 241.9 mg Cu/ha, 223.8 mg Cu/ha, and 209.7 mg Cu/ha at <650 m, 650–850 m, 850–1050 m and >1050 m elevation categories respectively. In comparison, the highest Cu concentration (12.9 mg Cu/kg) and potential (260 mg Cu/ha) was observed at the lowest elevation (<650 m) than all other elevation categories. In addition, Cu in the residue due to elevation (Figure 6c) have shown a difference in its concentration levels due to the difference in landforms and localized management. Mathew et al. (2016) has reported that plant residue micronutrients have shown in their concentration levels probably be explained by the difference in landforms especially in the mountainous areas which associated with local management.

B concentration in sesame residue differed significantly *($p < 0.05$)* for fresh and old residues (Table 3). B concentration in the fresh and old residue was 10.67 mg B kg^{-1} and 9.12 mg B kg^{-1} respectively. Sesame residue has the potential of producing B that ranges from 183 to 214.89 mg B ha^{-1}. B concentration in sesame residue did not differ significantly *($p < 0.05$)* with elevation (Table 2 and Figure 6d). Perhaps, the B concentration of residue on <650 m, 650–850 m, 850–1050 m, and >1050 m elevation were 10.1 mg B/ha, 10.1 mg B/ha, 9.8 mg B/ha, and 9.6 mg B/ha respectively (Table 2). Moreover, 202.7 mg B/ha, 202.7 mg B/ha, 196.7 mg B/ha, and 192.6 mg B/ha were the potential B that could be produced for the elevation of <650 m, 650–850 m, 850–1050 m, and >1050 m respectively. There was an accumulation of boron in the lower slope positions (Knight and Farrell, 2000). Moreover, Boron is readily soluble in water and should move with the flow of water through the landscape. Thus, because the lower slope positions represent catchment areas in the field and periodically experience waterlogged conditions, boron would be expected to accumulate in these areas. Therefore, in this study B concentration in sesame residue was higher for fresh residue and highest elevation than old residue and lowest elevation respectively (Table 4).

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 ($p < 0.01$) 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 ($p < 0.01$) correlated with TN, Fe, B and S with the value of $r = 0.73$, $r = 0.76$, $r = 0.86$ and $r = 0.81$ respectively. Furthermore, TN highly significantly ($p < 0.01$) 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 ($p < 0.01$) 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 Zn 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 ($p < 0.05$) correlated with 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 (Bruns 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, 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.
Aneja, 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.
Bahadur, 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., Sidhu, B.S., Bahl, 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.
Bradstreet, R.B., 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, (methodsofsoilan2), pp. 595–624.
Briat, J.F., Fobis-Loisy, I., Grignon, N., Lobréaux, 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.
Bruns, 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., Marschner, H., 1988. Enhanced superoxide radical production in roots of zinc-deficient plants. J. Exp. Bot. 39 (10), 1449–1460.
Charan, G., Bharti, 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. 55 (3-4), 127–142.
Crush, J.R., Evans, J.P.M., Cosgrove, G.P., 1989. Chemical composition of ryegrass (Lolium perenne L.) and prairie grass (Bromus willdenowii 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 Ruijter, F.J., Huijsmans, J.F.M., Rutgers, B., 2010. Ammonia volatilization from crop residues and frozen green manure crops. Atmos. Environ. 44 (28), 3362–3368.
Deininger, K., Byerlee, D., 2011. Rising Global Interest in farmland: Can it Yield Sustainable and Equitable Benefits? The World Bank.

Feng, S., Fu, Q., 2013. Expansion of global drylands under a warming climate. Atmos. Chem. Phys. 13 (10), 81–110.

Frossard, E., Bucher, M., Mächler, F., Mozafar, A., Hurrell, R., 2000. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric. 80 (7), 861–879.

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Sutton, M.A., 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320 (5878), 889–892.

Gelderman, R., 2009. Estimating Nutrient Loss from Crop Residue Fires. http://openprairie.sdstate.edu/extension_extra/366.

Grundon, N.J., Asher, C.J., 1988. Volatile losses of sulfur from intact plants. J. Plant Nutr. 11 (5), 563–576.

Hall, D., 2010. Boron. Department of Agriculture and Food Wester, Australia, pp. 1–2.

Hassan, Z., Anwar, Z., Khattak, K.U., Islam, M., Khan, R.U., Khattak, J.Z.K., 2012. Civic pollution and its effect on water quality of river Toi at district Kohat, NWFP. Res. J. Environ. Earth Sci. 4 (3), 334–339.

Hurtt, G.C., Chini, L.P., Frolking, S., Betts, R.A., Feddema, J., Fischer, G., Jones, C.D., 2011. Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. Climatic Change 109 (1-2), 117.

Hurtt, G.C., Frolking, S., Fearon, M.G., Moore, B., Shevliakova, E., Malyshev, S., Houghton, R.A., 2006. The underpinnings of land-use history: Three centuries of global gridded land-use transitions, wood-harvest activity, and resulting secondary lands. Global Change Biol. 12 (7), 1208–1229.

Imtiaz, M., Alloway, B.J., Shah, K.H., Siddiqui, S.H., Memon, M.Y., Aslam, M., Khan, P., 2003. Zinc nutrition of wheat: II: interaction of zinc with other trace elements. Asian J. Plant Sci. 2 (2), 156–160.

Jain, N., Bhatia, A., Pathak, H., 2014. Emission of air pollutants from crop residue burning in India. Aerosol Air Qual. Res. 14 (1), 422–430.

Karlen, D.L., Wollenhaupt, N.C., Erbach, D.C., Berry, E.C., Swan, J.B., Eash, N.S., Jordahl, J.L., 1994. Crop residue effects on soil quality following 10-years of no-till corn. Soil Tillage Res. 31 (2-3), 149–167.

Kiekens, L., 1995. Zinc. In: Alloway, B.J. (Ed.), Heavy Metals in Soils, second ed. Blackie Academic and Professional, London, pp. 284–305.

Knight, J.D., Farrell, R.E., 2000, February. Topographic influences on micronutrient distributions in Saskatchewan soils. Soils and Crops Workshop. http://hdl.handle.net/10388/9932.

Kutman, U.B., Yildiz, B., Cakmak, I., 2011. Effect of nitrogen on uptake, remobilization and partitioning of zinc and iron throughout the development of durum wheat. Plant Soil 342 (1-2), 149–164.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304 (5677), 1623–1627.

Lal, R., 2005. World crop residues production and implications of its use as a biofuel. Environ. Int. 31 (4), 575–584.

Lal, R., Kimble, J.M., 1997. Conservation tillage for carbon sequestration. Nutrient Cycl. Agroecosyst. 49 (1-3), 243–253.

Lal, R., Griffin, M., Apt, J., Lave, L., Morgan, M.G., 2004. Managing Soil Carbon.

Linden, D.R., Clapp, C.E., Dowdy, R.H., 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil Tillage Res. 56 (3-4), 167–174.

Lindsay, W.L., Norvell, W.A., et al., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil science society of America journal 42 (3), 421–428.

Liu, J., Khalaf, R., Ulén, B., Bergkvist, G., 2013. Potential phosphorus release from catch crop shoots and roots after freezing-thawing. Plant Soil 371 (1-2), 543–557.

Lozier, T.M., Macrae, M.L., Brunke, R., Van Eerd, L.L., 2017. Release of phosphorus from crop residue and cover crops over the non-growing season in a cool temperate region. Agric. Water Manag. 189, 39–51.

Mathew, M.M., Majule, A.E., Marchant, R., Sinclair, F., 2016. Variability of soil micronutrients concentration along the slopes of Mount Kilimanjaro, Tanzania. Appl. Environ. Soil Sci. 2016.

McDowell, R.W., Sharpley, A.N., Crush, J.R., Simmons, T., 2011. Phosphorus in pasture plants: potential implications for phosphorus loss in surface runoff. Plant Soil 345 (1-2), 23–35.

McNeill, A.M., Eriksen, J., Bergström, L., Smith, K.A., Marstorp, H., Kirchmann, H., Nilsson, I., 2005. Nitrogen and sulphur management: challenges for organic sources in temperate agricultural systems. Soil Use Manag. 21 (1), 82–93.

Metzger, R.A., Benford, G., 2001. Sequestering of atmospheric carbon through permanent disposal of crop residue. Climatic Change 49 (1-2), 11–19.

Moustakas, N.K., Akoumianaki-Ioannidou, A., Barouchas, P.E., 2011. The effects of cadmium and zinc interactions on the concentration of cadmium and zinc in pot marigold ('Calendula officinalis' L.). Aust. J. Crop. Sci. 5 (3), 277.

Nazir, R., Khan, M., Masab, M., Rehman, H.U., Rauf, N.U., Shahab, S., Shaheen, Z., 2015. Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam Kohat. J. Pharmaceut. Sci. Res. 7 (3), 89.

Olsen, S.R., Dean, L.A., 1965. Phosphorus 1. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, (methodsofsoilanb), pp. 1035–1049.

Parr, J.F., Stewart, B.A., Hornick, S.B., Singh, R.P., 1990. Improving the sustainability of dryland farming systems: a global perspective. In: Advances in Soil Science. Springer, New York, NY, pp. 1–8.

Pathak, H., Bhatia, A., Jain, N., Aggarwal, P.K., 2010. Greenhouse gas emission and mitigation in Indian agriculture–A review. In: ING bulletins on regional assessment of reactive nitrogen, bulletin, 19, pp. 1–34.

Pathak, H., Singh, R., Bhatia, A., Jain, N., 2006. Recycling of rice straw to improve wheat yield and soil fertility and reduce atmospheric pollution. Paddy Water Environ. 4 (2), 111.

Pederson, G.A., Brink, G.E., Fairbrother, T.E., 2002. Nutrient uptake in plant parts of sixteen forages fertilized with poultry litter. Agron. J. 94 (4), 895–904.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267 (5201), 1117–1123.

Pritchard, M.W., Lee, J., 1984. Simultaneous determination of boron, phosphorus and sulphur in some biological and soil materials by inductively-coupled plasma emission spectrometry. Anal. Chim. Acta 157, 313–326.

Reed, S.C., Coe, K.K., Sparks, J.P., Housman, D.C., Zelikova, T.J., Belnap, J., 2012. Changes to dryland rainfall result in rapid moss mortality and altered soil fertility. Nat. Clim. Change 2 (10), 752.

Rengel, Z., Römheld, V., 2000. Root exudation and Fe uptake and transport in wheat genotypes differing in tolerance to Zn deficiency. Plant Soil 222 (1-2), 25–34.

Rengel, Z., Römheld, V., Marschner, H., 1998. Uptake of zinc and iron by wheat genotypes differing in tolerance to zinc deficiency. J. Plant Physiol. 152 (4-5), 433–438.

Rennenberg, H., 1984. The fate of excess sulfur in higher plants. Annu. Rev. Plant Physiol. 35 (1), 121–153.

Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P., Huber-Sannwald, E., 2007. Global desertification: building a science for dryland development. Science 316 (5826), 847–851.

Shah, A., Niaz, A., Ullah, N., Rehman, A., Akhlaq, M., Zakir, M., Suleman Khan, M., 2013. Comparative study of heavy metals in soil and selected medicinal plants. J. Chem. 2013.

Shi, R., Zhang, Y., Chen, X., Sun, Q., Zhang, F., Römheld, V., Zou, C., 2010. Influence of long-term nitrogen fertilization on micronutrient density in grain of winter wheat (Triticum aestivum L.). J. Cereal. Sci. 51 (1), 165–170.

Shorrocks, V.M., 1997. The occurrence and correction of boron deficiency. Plant Soil 193 (1-2), 121–148.

Shukla, U.C., Mittal, S.B., 1980. Characterization of the zinc retained in some soils of India using pH gradient elution. Soil Sci. Soc. Am. J. 44 (1), 29–33.

Smith, P., Martino, D., Cai, Z., et al., 2008. Greenhouse gas mitigation in agriculture. Phil. Trans. Roy. Soc. Lond. B 363, 789–813.

Smith, B.N., 1984. Iron in higher plants: storage and metabolic role. J. Plant Nutr. 7 (1-5), 759–766.

Tekalign, T., Haque, I., Aduayi, E.A., et al., 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working document, (13).

Terefe, G., Wakjira, A., Berhe, M., Tadesse, H., et al., 2012. Sesame production manual. Ethiopia: Ethiopian Institute of Agricultural Research Embassy of the Kingdom of the Netherlands.

Torma, S., Vilček, J., Lošák, T., Kužel, S., Martensson, A., 2018. Residual plant nutrients in crop residues–an important resource. Acta Agric. Scand. Sect. B Soil Plant Sci. 68 (4), 358–366.

Trust, B.A., Fry, B., 1992. Stable sulphur isotopes in plants: a review. Plant Cell Environ. 15 (9), 1105–1110.

Turner, C.L., Blair, J.M., Schartz, R.J., Neel, J.C., 1997. Soil N and plant responses to fire, topography, and supplemental N in tallgrass prairie. Ecology 78 (6), 1832–1843.

Van der Lee, J.J., Walinga, I., Manyek, P.K., Houba, V.J.G., Novozamsky, I., et al., 1987. Determination of boron in fresh and in dried plant material by plasma emission spectrometry after extraction with HF-HCL. Communications in soil science and plant analysis 18 (8), 789–802.

Viator, R.P., Johnson, R.M., Richard Jr., E.P., 2005. Challenges of post-harvest Residue Management in the Louisiana Sugarcane Industry.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277 (5325), 494–499.

Wilhelm, W.W., Johnson, J.M., Karlen, D.L., Lightle, D.T., 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. Agron. J. 99 (6), 1665–1667.