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Impacts of Gümüşhane cement dust emissions on soil elemental compositions

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Abstract: The cement dust deposition can cause environmental pollution and heavy metal contamination, which negatively impacts soil nutrient availability and hence crop productivity. Thus, this study evaluates the impact of cement dust emissions on soil elemental compositions in different tillage managements. In this study, composite soil samples were taken from conventional tillage (CT), and no-till (NT) managed fields under wheat-sugar beet (potato)-fallow cropping sequence. Soil samples were randomly collected from 0–30 cm depth in three replications and different distances (1, 2, 4, 6, 8, and 10 km) from a cement plant. Soil pH, clay, and $CaCO_3$ contents were higher under CT than those under NT, whereas; sand and K contents were greater under NT management. The CT significantly decreased K content compared to those under NT by 5% in 2014. In addition, soil Mg^{+2} content decreased ($p < 0.002$) by increasing the distance. Soil Mg^{+2} content at 1 km was significantly higher than those at 4 km (by 3%), 2 km (by 4%), 8 km (by 10%), 6 km (by 10%), and 10 km (by 19%). Similarly, distance significantly influence soil Cu ($p < 0.001$), Zn^{+2} ($p < 0.008$), and Mn^{+2} ($p < 0.0002$), and K ($p < 0.001$), however, there were not any clear trend according to increases in distance from cement plant. The moving average of soil bacteria and fungi populations and their ratios have shown that the bacteria and fungi populations increased with distance, where increases in the fungi population under CT were more dramatic than those under NT management. Moreover, the principal component analysis showed that soils under NT were differently influenced by cement dust emission than CT managed soils. In conclusion, cement dust accumulation under both tillage practices negatively influenced soil elemental compositions and related microbial populations.

Key words: Cement dust, conventional tillage, no-tillage, soil elemental compositions, soil microbial communities

1. Introduction

Industrial activities produce cement dust via airborne particles from thermal processes, increasing environmental pollution, CO_2 fluxes, and unsustainable soil health. Many industrial processes, such as cement production, produce alkaline materials, causing more significant atmospheric GHG emissions. Alkaline manufactured wastes may lead to leachates which contain trace metals from oxyanions (e.g., As, Cr, Mo, Se, V), and can be very active in alkaline water (Gomes et al., 2016). The direct impacts of cement dust deposition include soil alkalization and altering soil chemistry. The cement particles move into the soil as dry, humid, or occult pollutants and undermine its physicochemical conditions (Lamare &Singh, 2020).

Differentiations significantly influence soil physical and chemical properties in cement dust production, which may negatively impact plant growth (Arul and Nelson, 2015). Due to its impacts on soil pH and chemical composition, cement dust pollution can cause alkalization (Bilen, 2010; Mlitan et al., 2013; Lamare and Singh, 2020). Therefore, cement dust deposition is destructive to soil functionality. Cement dust accumulation in soils may influence soil microbial activities, microbial biomass and elemental compositions (Alavi, 2017), and microbial community compositions associated with soil moisture, temperature, and pH (Dhal et al., 2013; Kalembasa and Symanowicz, 2012).

On the other hand, soil tillage is a significant contributor to agricultural management. Soil tillage might be necessary for some regions and climates, whereas no-till can be applied and benefit agricultural productivity compared to conventional systems. However, intensive tillage, such as conventional tillage, may physically disperse soil aggregates, decrease enzyme activities, and result in colloidal and particle dispersion (Ozlu, 2020). Therefore, tillage management around cement plants may cause a more significant impact of cement on soil properties deeper in soil profile quicker than no-till management

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since tillage may mix cement in deeper horizons. However, cement impact on soil‘s deeper layer under no-till may be more challenging and take longer than conventionally tilled soils.

There is a lack of information regarding different tillage management influences on soil fertility (elemental compositions) during cement dust accumulation in soils. The present work focuses on evaluating impacts of cement dust deposition in soil on available, total nitrogen (TN) and available phosphorus (Pav), macro (N, P, Ca, Mg, K, $CaCO_3$) and micronutrients contents (Fe, Cu, Zn, and Mn) within different distance and different tillage managements.

2. Materials and methods

2.1. Study area and description

The present study was located around the Gümüşhane cement plant in Turkey. Gümüşhane Cement Plant was built on January 6, 1988 (Aşkale Çimento. Gümüşhane Çimento Fabrikası, 2013). The study soils indicate a well-drained and nearly flat (slope <2%) clay loam soils under wheat (*Triticum vulgare*), sugar beet (*Beta vulgaris*), and (potato; *Solanum tuberosum*) production, and fallow since 2000 (15 years). In general, this study area has humid summers cold and snowy winters with an average annual temperature of 4.3 °C in the winter and 16.4 °C in the summer. In addition, the average annual rainfall of this area is 463.7 mm, respectively.

2.2. Soil sampling and preparation

Composite soil samples were taken from 0–30 cm depth three times in 2014 under wheat and sugar beet growing season. Four soil samples were conducted from each tillage management (conventional tillage, CT; and no-till, NT) and each distance (1, 2, 4, 6, 8, and 10 km) within three replications. Soil samples were kept in an ice cooler for transport to the lab and stored at –20 °C in the freezer for laboratory analysis. Wind direction (from northwest to northeast) and speed (2.1 m sn^{-1}) were considered when each sampling location was selected. A total of 36 soil samples were conducted around the cement plant within three replications.

2.3. Laboratory analysis

Soil cation exchange capacity (CEC) was determined as the sum of the exchangeable cations using the atomic absorption spectrophotometer (Hanlon et al., 1989). Microelements were analyzed using the diethylene triaminepentaacetic acid extraction method (Lindsay and Norvell, 1978).

Soil texture classes were identified using USDA NRCS – soil texture calculator (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167). The moving average of soil $CaCO_3$, pH, total nitrogen and available phosphorus content, bacteria population, fungi population, and bacteria: fungi ratio were predicted c. Moving average is a time series analysis technique. Here in this study, the distance was set as time, and analysis was conducted by distance. Each mean value represents an average of three different distances. Briefly, soil $CaCO_3$ content was measured using the pressure calcimeter method (Leoppert and Suarez, 1996). Soil pH was analyzed using the pH meter with the glass electrode meter in 1:2.5 soil: water ratio (Handershot et al., 1993). Moreover, total soil nitrogen (TN) content was determined by the micro-Kjeldahl method. Further, exchangeable cations were tested by Melich I solution. Furthermore, available P_2O_5 (PAv) was analyzed by the ammonium molybdate-ascorbic acid method after extracting the soil with 0.5M Na_2CO_3 (Knudsen and Beegle, 1988).

Soil bacteria and fungi populations were determined by the soil dilution plate method (Nandhini and Josephine, 2013). The automated colony counter was used for bacteria as colony-forming units (CFU) g^{-1} of oven-dried equivalent field-moist soil. Fungal colonies growing on agar were observed under a microscope at 10–30×. Total fungi were calculated by viable fungal spore g^{-1} of oven-dried soil (Maiti, 2013). The moving average of soil $CaCO_3$, pH, total nitrogen and available phosphorus content, bacteria population, fungi population, and bacteria: fungi ratio were also determined by using Microsoft excel. Here in this study, the distance was set as time, and analysis was conducted by distance. Each mean value represents an average of three different distances.

2.4. Statistical analysis

The two-way ANOVA was performed to examine differences among each treatment and distance. Duncan‘s LSD method was performed to evaluate overall impacts at $\alpha < 0.05$ in the JMP package (SAS, 2014). Moreover, Pearson‘s correlation method was performed to study relationships between elemental composition and pH of study soils under cement dust accumulation and tillage practices in Gümüşhane district by using R software. Principle component analysis and multilinear discriminant analysis were processed in the JMP package (SAS, 2014).

3. Results

3.1. Soil textural classes and moving average of soil pH, $CaCO_3$, total nitrogen, and available phosphorus

Soil texture classes under CT managements showed significant differences between two groups (i) closer than 4 km and (i) farter than 4 km (Figure 1). Soils closer than 4 km were classified as clay loam textured, whereas soils farter than 4 km were identified as clay textured soils. However, soils under NT management are classified as clay loam soils.

In general, soil pH ranged from 6.90 at 10 km distance to 7.67 at a 2 km distance (Figure 2). The moving average

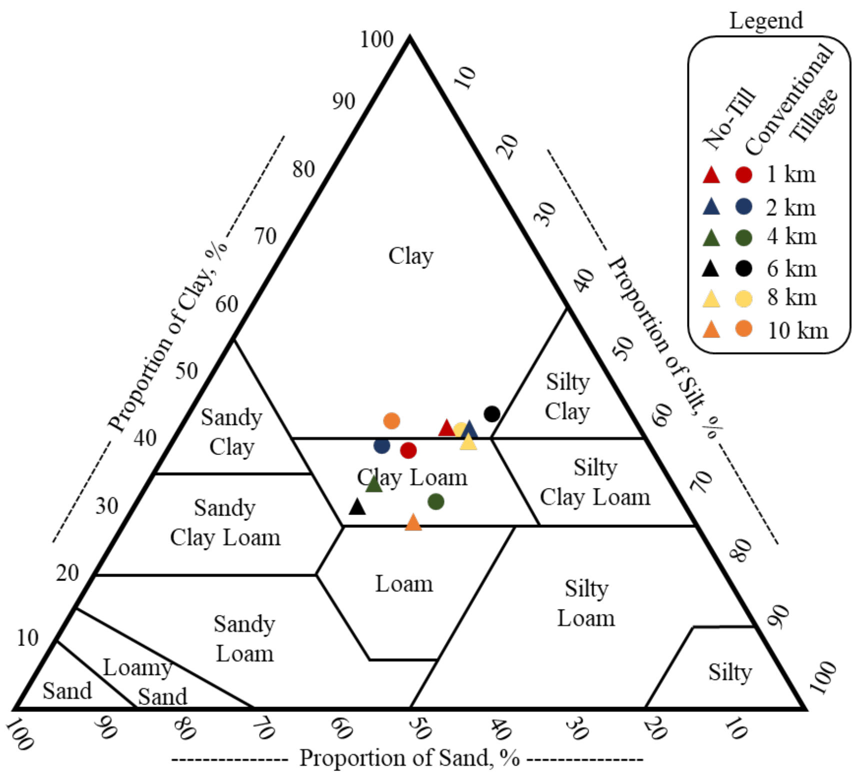

Figure 1. Soil texture claasses of conventional tillage and no-till fields at different distance from the cement plant.

results showed that soil pH was negatively associated with distance ($p < 0.0001$) from the cement plant. In addition, soils under CT had greater pH compare to NT systems. The moving average of soil $CaCO_3$ content was significantly influenced by both distances ($p < 0.0001$) and tillage management ($p < 0.0001$). Soil $CaCO_3$ content was greater under CT compared to NT systems. Soil $CaCO_3$ content under CT systems was greater than 4% at all distances, whereas those under NT decreased below 3.8% farter than 4 km. A similar trend was also observed for available phosphorus content (P_{Av}). Moreover, differences in total nitrogen content (TN) and P_{Av} were not significant under the impacts of distance and soil tillage management. Further, both distances and tillage management did not influence CEC (Table).

3.2. Soil elemental compositions

Even though the K^{+1} content of soils was significantly influenced by distance, differences in K^{+1} did not show a clear trend indicates increasing/decreasing with distance from the cement plant (Table). However, soil tillage management significantly influenced soil K^{+1} content, where CT significantly decreased K^{+1} content compared to those under NT by 5% in 2014. Soil Ca^{+2}, Na^{+1}, and Fe^{+2} contents were not significantly influenced neither by distance nor tillage management.

Soil Mg^{+2} content decreased ($p < 0.002$) by increasing the distance. Soil Mg^{+2} content at 1 km was significantly higher than those at 4 km (by 3%), 2 km (by 4%), 8 km (by 10%), 6 km (by 10%), and 10 km (by 19%). However, soil Mg^{+2} content was not significantly influenced by tillage practices ($p < 0.2$). Distance significantly influence soil Cu ($p < 0.001$), Zn^{+2} ($p < 0.008$), and Mn^{+2} ($p < 0.0002$). However, there was not any clear trend according to increases in distance from the cement plant. Tillage practices did not significantly influence soil Mg^{+2}, Cu^{+2}, Zn^{+2}, and Mn^{+2} contents (Table).

3.3. Moving average of soil microbial populations

The moving average of soil bacteria and fungi populations and their ratios have shown that the bacteria population increased with distance under CT and NT managements, where the relationship between bacteria population and distance in CT management was linear positive (Figure 3). In addition, the soil fungi population increased with distance in both CT and NT managements, where increases in CT were more dramatic than those in NT management. Moreover, the ratio of bacteria over fungi populations were not influenced by distance in CT managements, whereas increases in this ratio were observed only after 2 km in NT management.

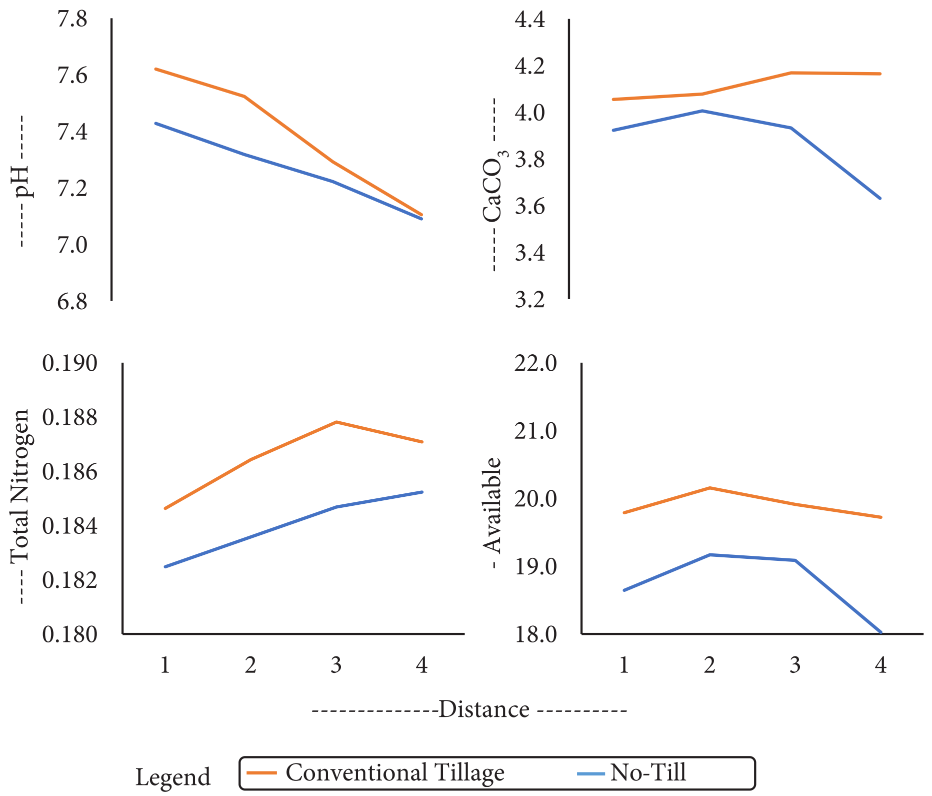

Figure 2. Moving averages of soil pH (1:2 soil:water ratio), $CaCO_3$ content (mg kg^{-1}), total nitrogen content (mg kg^{-1}), and available phosphorus content (mg kg^{-1}) under conventional tillage and no-till management along with the distance from the cement plant.

Table. Soil elemental composition under cement dust accumulation and tillage practices in Gümüşhane district.

Treatment		***Ca^{+2}***	***Mg^{+2}***	***Na^{+1}***	***K^{+1}***	***CEC***	***Fe^{+2}***	***Cu^{+2}***	***Zn^{+2}***	***Mn^{+2}***
		me 100 g soil^{-1}					***mg kg^{-1}***			
Distance	**1**	11.5^{a}	6.64^{a}	0.36^{a}	4.04^{b}	27.9^{ab}	21.9^{a}	3.39^{bc}	3.24^{a}	8.78^{d}
	2	11.0^{ab}	6.38^{ab}	0.36^{a}	3.85^{bc}	28.9^{ab}	20.4^{ab}	3.37^{bc}	3.05^{b}	9.58^{c}
	4	11.0^{ab}	6.43^{ab}	0.36^{a}	3.43^{d}	27.7^{b}	21.3^{ab}	3.33^{c}	3.03^{b}	10.3^{b}
	6	10.2^{bc}	6.02^{b}	0.36^{a}	3.65^{cd}	29.0^{ab}	19.8^{b}	3.38^{bc}	3.03^{b}	8.72^{d}
	8	10.6^{bc}	6.05^{b}	0.36^{a}	3.76^{c}	29.6^{a}	21.1^{ba}	3.76^{a}	3.25^{a}	10.2^{bc}
	10	9.49^{c}	5.57^{c}	0.36^{a}	4.31^{a}	28.3^{ab}	20.7^{ba}	3.55^{b}	3.32^{a}	12.0^{a}
Tillage	**CT**	10.5^{A}	6.22^{A}	0.36^{A}	3.75^{A}	28.4^{A}	20.6^{A}	3.44^{A}	3.18^{A}	9.93^{A}
	NT	10.8^{A}	6.14^{A}	0.36^{A}	3.93^{A}	28.7^{A}	21.1^{A}	3.49^{A}	3.13^{A}	9.93^{A}
Distance		0.06	0.002	0.35	0.0001	0.12	0.15	0.001	0.008	0.0002
CT vs. NT		0.06	0.19	0.69	0.049	0.42	0.67	0.17	0.14	0.99

Different letters in each column indicate significant differences between different distance and tillage applications (*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; Duncan's test). TN - total nitrogen content; PAv - available phosphorus content; $CaCO_3$ - calcium carbonate content; Ca^{+2} - calcium content; Mg^{+2} - magnesium content; Na^{+1} - sodium content; K^{+2} - soil potassium content; CEC - cation exchange capacity; Fe^{+2} - iron content; Cu^{+2} - copper content; Zn^{+2} - zinc content; Mn^{+2} - manganese content; CT - conventional tillage; NT - no-till.

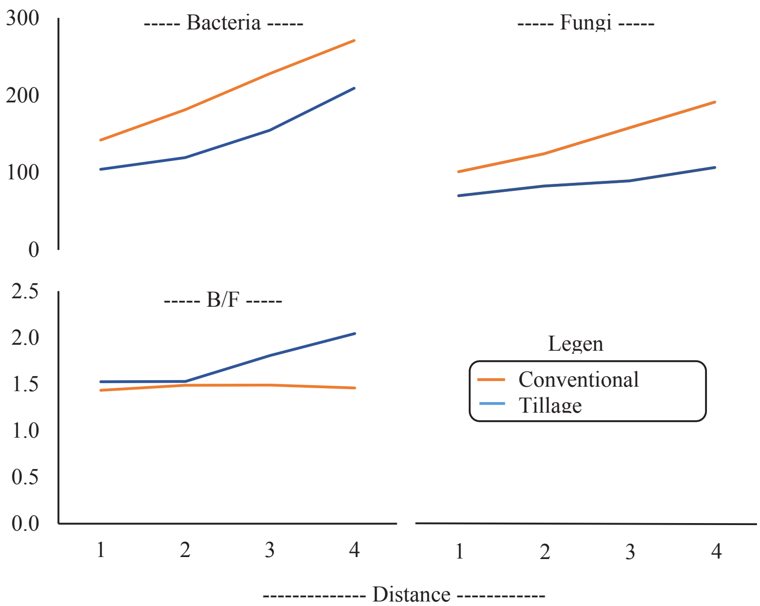

Figure 3. Moving average of soil bacteria (×1.000.000 (CFU g^{-1}) or (cfu g^{-1} soil)) and fungi (×1000 (CFU $g^{-1)}$ or (cfu g^{-1} soil)) communities and nacteria/fungi ratio over distance from Gümüşhane Cement Plant.

4. Discussion

In this study, soil pH was positively correlated with PAv, $CaCO_3$, Ca+2, and Mg^{+2}, but negatively correlated with Mn^{+2}, $Cu^{+2,}$ and Zn^{+2} content (Figure 4). Soil pH was also negatively associated with distance from the cement plant. This can be due to greater accumulation of $CaCO_3$, $Ca^{+2,}$ and Mg^{+2} by deposition of cement dust (Zerrouqi et al., 2008) since the pH at a longer distance is more neutral (Bilen, 2010; Kara and Bolat, 2007; Khamparia et al., 2012). A significant correlation of soil pH with Ca^{+2} and Mg^{+2} contents support this justification (Figure 4). Moreover, soil pH was higher under CT in comparison to those under NT. Previous studies also supported our findings by reporting that NT significantly decreased soil pH compare to those under CT (Busari and Salako, 2013; Ghimire et al., 2017). Similarly, Busari et al. (2015) documented that tillage practices generally influence soil pH, CEC, exchangeable cations, and TN.

As was explained in the results, the differences in TN and P_{Av} were not significant under the impacts of distance and soil tillage management. Here, it was observed that TN was negatively correlated with Cu^{+2}, $Zn^{+2,}$ and Na^{+1} contents but positively correlated with P_{Av} content. Similarly, P_{Av} content was positively correlated with TN content, $CaCO_3$ content but negatively correlated with K^{+1} (Figure 4). In addition, the K^{+1} content of soils was significantly influenced by distance. However, differences in K^{+1} did not show a clear trend that indicates increasing/decreasing with distance. This might be due to the different impacts of different soil properties. The lower silt and clay content can lower K^{+1} fixing capacity, whereas liming can enhance soil K^{+1} retention (Lafond and Simard, 1999; Lamare and Singh, 2020). It was reported that cement dust impacts due to alkalization on soil chemical composition, properties, and soil ecosystem (Addo et al., 2013). Furthermore, CT significantly decreased K^{+1} content compare to those under NT. Bertol et al. (2007) reported that soil exchangeable K content under no-till management was 2.2 times higher than those under CT, on average.

Soil Ca^{+2}, Na^{+1}, and Fe^{+2} contents were not significantly influenced by distance or tillage management (Table). Soil $CaCO_3$ content was significantly influenced by both distance and tillage management (Figure 2). The cement dust‘s raw materials were documented to include 80% limestone and 20% clay (Dabkowska et al., 2014). Limestone contains at least 50% $CaCO_3$ (Gupta and McNeil, 2012). This shows that distance closer to cement plant attempts to accumulate more cement dust, which indicates $CaCO_3$ accumulation. Soil $CaCO_3$ content was significantly higher under CT in comparison to those under NT. The interaction between tillage management and the cement plant‘s distance shows that gretaer $CaCO_3$ content might be due to higher cement deposition, which contains $CaCO_3$, Ca^{+2}, or Mg^{+2} (Bilen et al., 2019).

Soil Mg^{+2} contents decreased by increasing in the distance (Table). Soil K^{+1} and Mg^{+2} contents have significantly increased by cement kiln dust addition (Lafond and Simard, 1999; Khamparia et al., 2012). Soil Mg^{+2} content was positively correlated with soil Fe^{+2} and Ca^{+2} contents, pH, but negatively correlated with Mn^{+2}

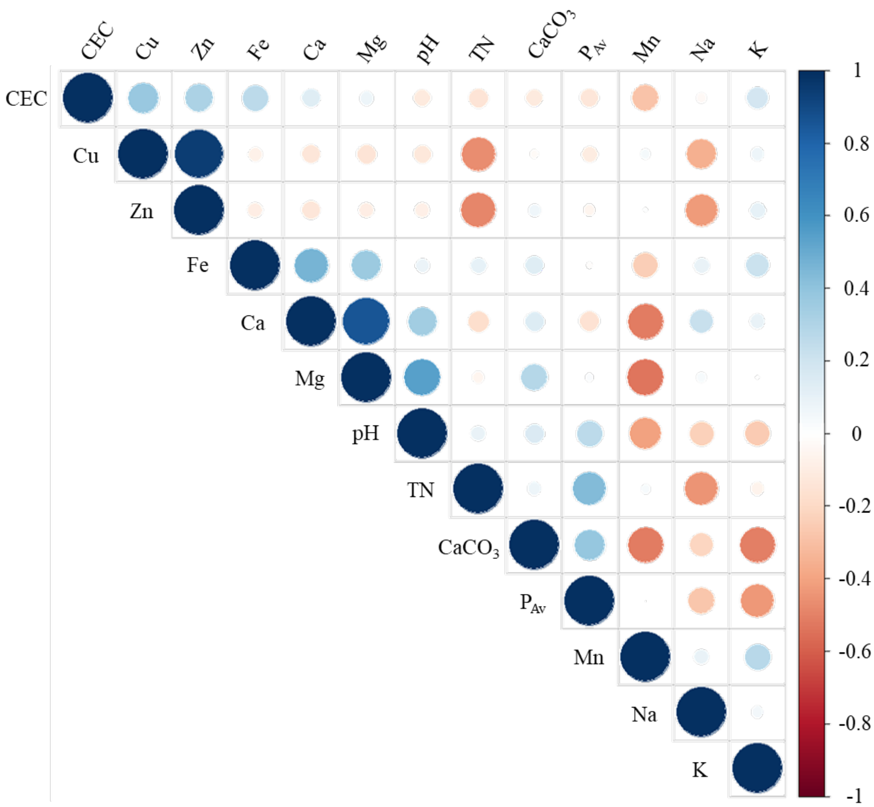

Figure 4. Pearson's correlation analysis of soil elemental compositions under cement dust distance and tillage practices for 0–30 cm depth in Gümüşhane district. The color and size of the circle denote the magnitude and direction of the relationship.

content. Furthermore, distance significantly influences soil Cu^{+2}, Zn^{+2}, and Mn^{+2}; however, there was no clear trend according to increases in distance from the cement plant. Tillage practices did not significantly influence soil Mg^{+2}, Cu^{+2}, Zn^{+2}, and Mn^{+2} contents. Cu^{+2} had a significantly positive correlation with CEC, Zn^{+2}, and negatively correlated with Na^{+1} content (Figure 4). This might be because of lower soluble metals in more alkaline soils around a cement plant (Kara and Blat, 2007). Previous studies reported that soil pH increases to attempt to reduce Fe^{+2}, Cu^{+2}, Zn^{+2}, and Mn^{+2} availabilities (Arimanwa et al., 2016; Singh et al., 2010).

Moreover, the moving average of soil bacteria and fungi communities showed similar trends where these communities' population increased by distance and tillage application. These findings overlap with results from multilinear discriminant analysis. The multilinear discriminant analysis showed that distance was a significant factor in differentiating all soil properties' overall status together (Figure 5). This indicates that cement dust emission is a significant factor which changes soil conditions in both CT and NT managements.

Finally, principal component analysis (Figure 6) showed that soils under NT and CT systems clustered in two groups where soil microelements played a critical role in this separation. Soils under NT systems were differently influenced by cement dust emission than CT managed soils. The leading key players in these separations were Ca^{+2}, Mg^{+2}, Fe, and TN.

Tillage practices significantly influenced soil pH under the impacts of cement dust deposition, whereas soil pH was higher under CT in comparison to those under NT. Similarly, soils under CT showed greater clay and $CaCO_3$ content compares to those under NT, whereas; sand content and K^{+1} content were greater under NT in comparison to those under CT. However, Ca^{+2}, Mg^{+2}, Na^{+1}, Cu^{+2}, Zn^{+2}, Fe^{+2}, TN, P_{Av} and Mn^{+2} contents, and CEC were not influenced by tillage practices. Moreover, the moving average of bacteria and fungi populations under CT was significantly higher than NT.

Pearson's correlation diagram showed that soil pH, exchangeable Ca^{+2} and Mg^{+2}, and $CaCO_3$ showed significant correlations. The multilinear distriminant analysis showed that cement dust emission is a significant factor that changes soil conditions in both CT and NT managements. Moreover, the principal component analysis showed that soils under NT and CT systems clustered in two groups where soil microelements played a critical role

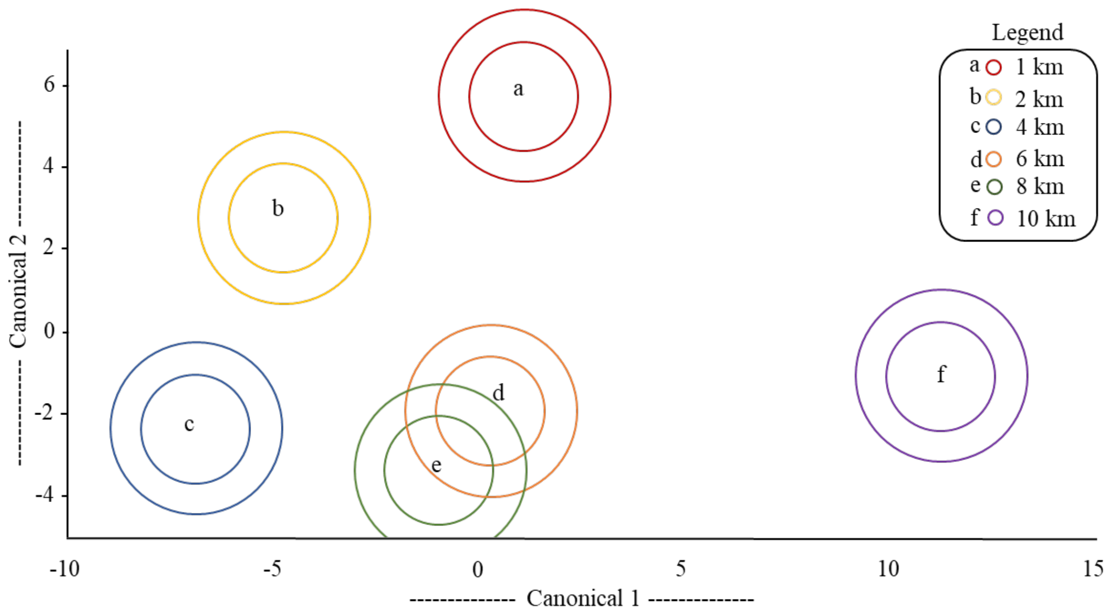

Figure 5. Multilinear discriminant analysis of soil microbial properties, under cement production impacts in different distances ($R^2 = 0.83$). a, 1 km; b, 2 km; c, 4 km; d, 6 km; e, 8 km; f, 10 km. BP, bacteria population; FP, fungi population; B:F, bacteria and fungi ratio; clay, clay content; silt, silt content; sand, sand content; pH, soil acidity; CEC, cation exchange capacity; TN, total nitrogen; P_{AV}, available phosphorus; K, potassium content; Ca, calcium content; $CaCO_3$, calcium carbonate content; Mg, magnesium content; Na, sodium content; Fe, iron content; Cu, copper content; Zn, zinc content; Mn, manganese content; NT, no-till; CT, conventional tillage.

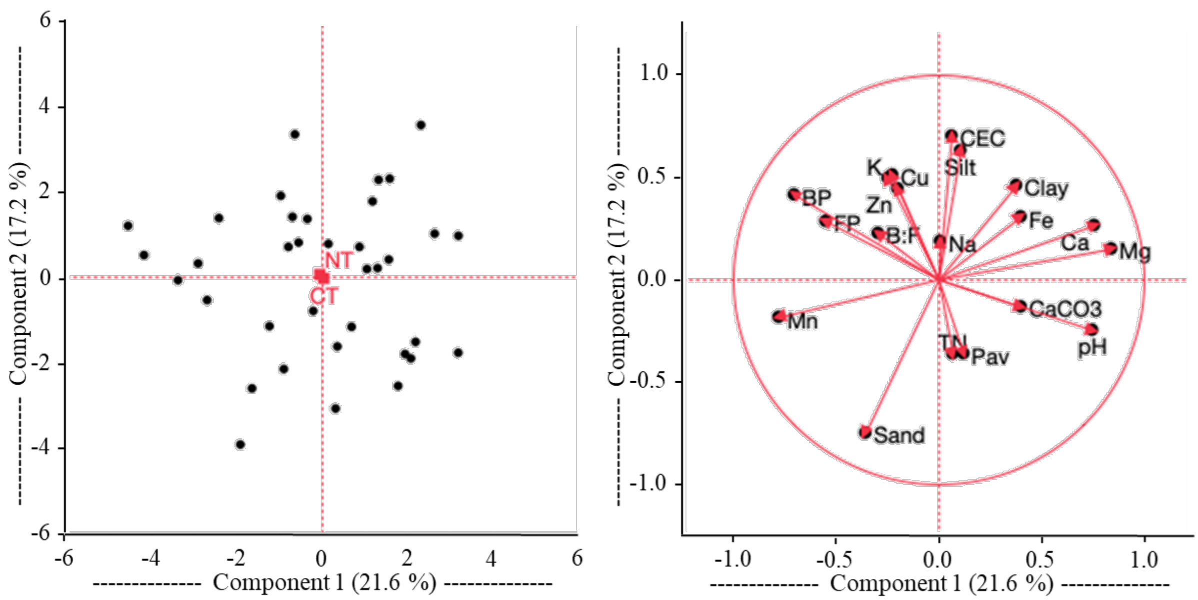

Figure 6. Principle component analysis of soil properties considering tillage (conventional tillage and no-till) influences. BP, bacteria population; FP, fungi population; B:F, bacteria and fungi ratio; clay, clay content; silt, silt content; sand, sand content; pH, soil acidity; CEC, cation exchange capacity; TN, total nitrogen; P_{AV}, available phosphorus; K, potassium content; Ca, calcium content; $CaCO_3$, calcium carbonate content; Mg, magnesium content; Na, sodium content; Fe, iron content; Cu, copper content; Zn, zinc content; Mn, manganese content; NT, no-till; CT, conventional tillage.

in this separation. Further, soils under NT systems were differently influenced by cement dust emission than CT managed soils.

In conclusion, the present study's findings indicate that cement dust accumulation under both tillage practices negatively influenced some soil elemental compositions.

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