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# Effects Of Stubble Burning on Selected Physical and Chemical Properties in Alkaline Agricultural Soil

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**Abstract**

Stubble burning is a traditional soil management method that affects soil quality and fertility and has often been preferred by farmers. In this study conducted to understand the short-term effects of stubble burning on soil properties in alkaline agricultural soils, 100 soil samples were taken from 20 wheat fields with stubble burned (STB, n=10) and non-stubble burned (NSB, n=10) in Araban. The samples were analyzed for aggregate stability (AS), pH, carbonates (IC), electrical conductivity (EC), soil organic matter (SOM), available phosphorus ($P_{av}$), and extractable potassium ($K_{ex}$). Correlation (CA), principal component (PCA), and hierarchical cluster analysis (HCA) were applied to the data. The results showed that AS and pH values were 3% and 2% lower ($p<0.05$), while IC and $P_{av}$ contents were approximately 23% higher ($p<0.01$ and $p<0.05$) in NSB. No significant differences were observed in EC values and SOM and $K_{ex}$ contents between STB and NSB ($p>0.05$). PCA accounted for 74.9% and 76.4% of total variance in NSB and STB, respectively. According to HCA results, it was determined that the components were completely changed. Many statistical approaches showed that stubble burning changed the ongoing relationships between selected physical and chemical properties of soils before burning due to the direct and indirect effects of heat and ash. In conclusion, these disturbed relationships are likely to negatively affect the productivity of alkaline field soils in the long term.

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## 1. Introduction

Stubble burning is a widely used soil management technique among farmers globally (Bahşi et al., 2023). This practice is favored due to its ability to facilitate soil cultivation, provide cost-effective disposal of residues, control pests and diseases, increase crop yields, and lack economic value (Halder et al., 2023). However, the burning of stubble, a significant source of soil organic matter (SOM) (Arunrat et al., 2023), has raised concerns as it threatens the sustainability of soil quality and health (Palta and Kaur, 2024).

Stubble burning generates heat and ash, which alter the soil's physical, chemical, and biological properties, ultimately affecting agricultural productivity (Jamali et al., 2021). For instance, in rice fields of Bangladesh with high clay content, low soil organic carbon (SOC), and weak AS, where stubble was burned, the mean weight diameter (MWD) decreased by 19% and SOC by 20% compared with the unburned soil (Halder et al., 2023). In Denmark, after 28-36 years of cereal cultivation, the SOC levels were 13% higher in fields where stubble burning did not occur compared with those where stubble was burned (Schjønning, 2023). Studies have shown that the soil pH in rice fields where stubble burning occurs is significantly higher than that in unburned fields. However, the EC, $P_{av}$, and $K_{ex}$ contents remain unchanged (Preesong and Yampracha, 2022). On the other hand, it was noted that the levels of $P_{av}$ and $K_{ex}$ increased in the soil post-stubble burning, but returned to their initial concentrations after a year (Arunrat et al., 2023).

The cultivation of wheat in Türkiye covers an area of approximately 11.5 million hectares (Anonymous, 2024a), and stubble burning is deeply entrenched as a customary practice (Bahşi et al., 2023). Although it is formally prohibited by legislation (Yakupoğlu et al., 2024), statistics indicate that roughly 30% of grain farming regions still engage in the burning of stubble (Yıldırım, 2023). In addition, the agricultural lands in the Mediterranean region, such as those in Gaziantep, are characterized by low levels of SOM (Tunç and Demir, 2021), making stubble burning a significant contributor to the economic setbacks faced by the agricultural sector in Türkiye (Yakupoğlu et al., 2022).

The goal of this study was to investigate whether changes occur in the composition of selected soil general properties and the relationships among these properties in alkaline wheat soils following stubble burning. The findings of this research aim to fill the existing knowledge gap regarding the effects of stubble burning on alkaline agricultural soils, which are prevalent in the Mediterranean Basin and in the agricultural regions of Gaziantep, a significant commercial and agricultural center. Additionally, this study represents the first examination of stubble burning in the region, which is expected to provide valuable information for the agricultural economy of the Gaziantep province, helping to protect soil health, improve soil quality and fertility, and increase productivity.

## 2. Materials and Methods

### 2.1. Study area and soil sampling

Located in the southeastern region of Türkiye, the Araban district of Gaziantep is surrounded by Besni in the north, Pazarcık in the west, Halfeti in the east and Yavuzeli in the south (Figure 1). The Araban Plain, a colluvial plain between high mountains in the north and south, has an average altitude of 600 m (Tunç et al., 2021). The Araban Plain, which is in the category of Class I agricultural lands where products such as wheat, barley, corn, chickpeas and garlic are widely grown, has an area of approximately 540 $km^2$ (Tunç et al., 2013, 2021). As is the case with Gaziantep agricultural soils (Avcı and Deveci, 2013), agricultural soils of Araban Plain are also located geologically in a zone with limestone and gypsum (Tunç et al., 2013), and most of them are classified as Calcic Luvisols (Lk) and Calcic Xerosols (Xk) (Anonymous, 2022). Furthermore, in Araban, the Mediterranean climate, which is generally expressed as “Csa” according to the Koppen-Geiger climate classification, indicates that the winter months are generally moderate, and the summers are dry and hot (Kottek et al., 2006). The annual average temperature in the Araban Plain is 6.9 ˚C (- 3 ˚C to + 18 ˚C) and the amount of precipitation is approximately 520 mm (Tunç et al., 2021; Anonymous, 2024b).

Two neighboring wheat fields, one with stubble burning (STB) and one without (NSB), soil properties are like each other, and the same parent materials were selected as a sampling location (Figure 1). A total of 100 soil samples were taken from NSB and STB at each of the sampling locations (n=10) from a depth of 0-20 cm with a steel shovel. The soil samples were transported to the Gaziantep University Soil Ecology Laboratory, where they were air-dried and sifted through a 2-mm sieve.

## 2.2. Soil analysis

The AS (%) value was determined using a wet sieving method with a wet sieving apparatus (Eijelkamp, 08.13, Netherlands) (Le Bissonnais, 1996; Rohošková and Valla, 2004). Soil pH and EC values (dS m$^{-1}$) were measured with a multimeter (Consort C5020, Turnhout, Belgium) by taking soil-water (1/2.5 m v$^{-1}$) saturation sludge (Richard, 1954). The inorganic carbonate (IC; %) content was determined with a Scheibler calcimeter (Eijelkamp M1.08.53.D, Holland) using the method recommended for soils with low SOM and $MnO_2$ contents (Allison and Moodie, 1965). The SOM contents of the soil were calculated by multiplying the SOC values determined by the titrimetric method (Walkley and Black, 1934) with the Van Bemmelen factor (1.724) (Nelson and Sommers, 1996). The $P_{av}$ (mg kg$^{-1}$) content was determined using a spectrophotometer (UV-1280, Shimadzu Corporation, Japan) of the extracts obtained with ammonium bicarbonate ($NH_4HCO_3$) (Olsen et al., 1954), and the $K_{ex}$ (mg kg$^{-1}$) content was calculated using a flame photometer (BWB XP flame photometer, BWB Technologies, England) of the extracts obtained with ammonium acetate ($CH_3COONH_4$), using the standard curve (Helmke and Sparks, 1996).

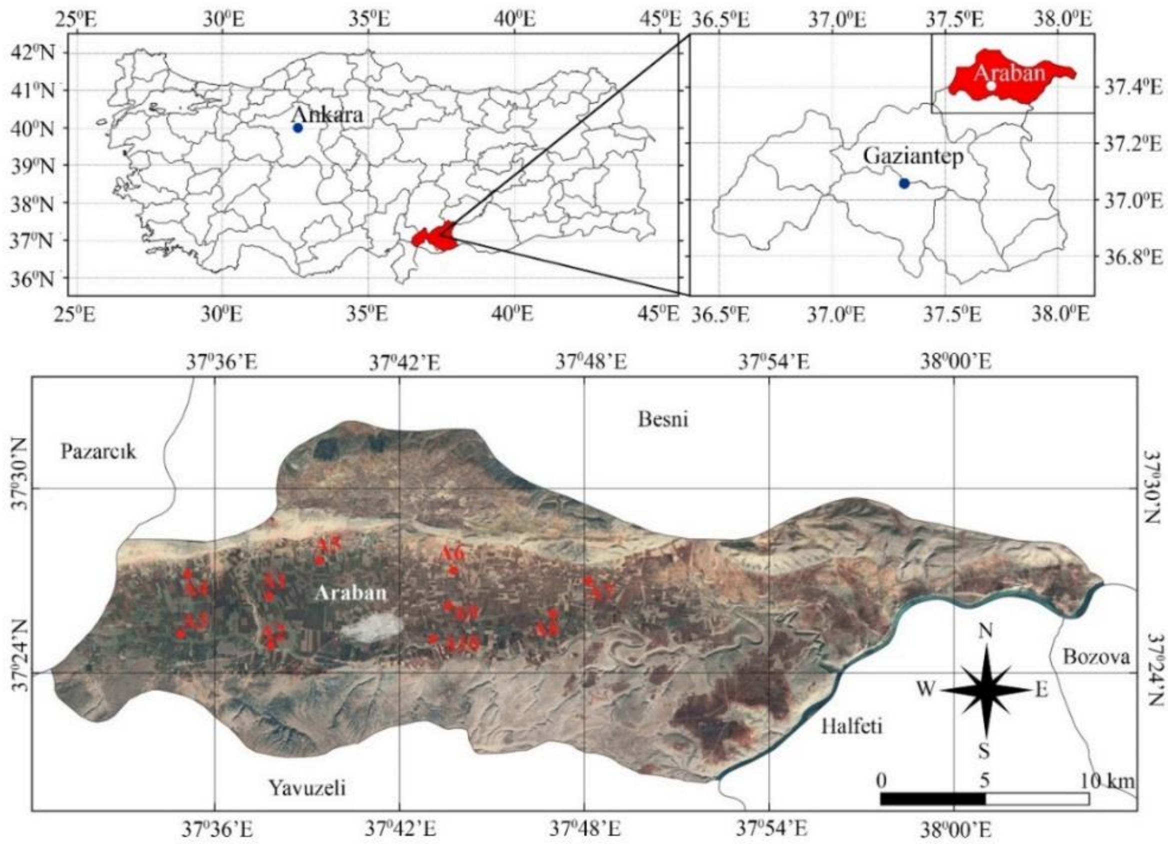


**Figure 1.** The sampling locations in study area (A1-10: sample locations).

### 2.3. Quality of analysis

Each analysis was repeated thrice, and the arithmetic average was calculated. As a reference material, UME RM 9908a was used for SOM and IC, and UME RM 9918c was used for EC (TUBITAK, Ankara). The arithmetic means of three replicate analyses from the reference material for SOM, IC, and EC corresponded to 96.8%, 101.8%, and 92.1% of the reference values, respectively.

### 2.4. Statistical analysis

To analyze the data, we utilized SPSS Statistics (Version 27, IBM, USA) for normality testing, Jamovi (Version 2.4) for Sample T-Test and correlation analysis (Jamovi Project, 2023), and R Studio (Version 2023.12.1 Build 402, Posit Software, PBC) for principal component (PCA), hierarchical cluster analysis (HCA), and graphics (RCoreTeam, 2022). Our PCA, conducted using the Varimax method, employed the KMO measure of sample adequacy for assumptive checks, with components having eigenvalues values greater than 1 being retained. HCA was performed using the ward.D2 method.

## 3. Results and Discussion

### 3.1. The contents of selected general soil properties before stubble burning

Analysis results on selected general soil properties were found to be consistent with the results of previous studies carried out in the region (Tunç et al., 2013, 2020, 2021). According to mean values, results revealed that for AS, pH, EC, IC, SOM, $K_{ex}$, and $P_{av}$ were 55.98 ± 10.70%, 7.77 ± 0.05, 0.77 ± 0.05 dS $m^{-1}$, 9.31 ± 4.97%, 0.86 ± 0.25%, 55.48 ± 4.36 mg $kg^{-1}$, and 8.74 ± 7.49 mg $kg^{-1}$, respectively (Table 1). The analysis results indicated that the soils exhibited a slightly alkaline (Hartemink and Barrow, 2023) soil pH, which varies within the categories of non-saline to slightly saline (Richard, 1954) for EC, and slightly calcareous to calcareous (Kaçar, 2016) for IC. Furthermore, it was observed that soils with low levels of SOM were inadequate for $K_{ex}$ (Pizer, 1967) and ranged from insufficient to moderately adequate for $P_{av}$ (Olsen and Sommers, 1982). These findings are consistent with the results presented in previous studies of agricultural soils (Tunç et al., 2012; Tunç and Demir, 2021), which have a high risk of erosion (Tunç et al., 2013), annual precipitation in the range of 400-600 mm (Anonymous, 2024b) and located in a transition zone between the Mediterranean and continental climate (Tunç et al., 2013, 2014) and shaped from limestone and gypsum parent material (Demir et al., 2023).

### 3.2. Changes in selected general soil properties after stubble burning

In NSB, AS and pH were lower by approximately 3% and 2% ($p$<0.05), respectively, while IC and $P_{av}$ were higher by about 23% ($p$<0.01 and $p$<0.05, respectively). No significant differences were observed in EC values and SOM and $K_{ex}$ contents between STB and NSB ($p$> 0.05; Table 1). These results showed that AS, pH, IC and $P_{av}$ were significantly affected by the heat and ash generated by stubble burning. This supports the findings of previous studies conducted in the Mediterranean region soils (Jiménez-Pinilla et al., 2016; Thomaz, 2018). The elevated AS in STB may be due to high carbonate content, contradicting prior studies (Daroch et al., 2024; Halder et al., 2023). Keeley (2009) reported that cementing agents like carbonate may influence AS due to heat from burning. Previous research indicates an increase in soil pH post-stubble burning (Arunrat et al., 2023; Palta and Kaur, 2024), linked to ash contribution affecting $H^+$ concentrations that determine soil pH value in soil solutions (Young, 2013). Also, alterations in soil pH after stubble burning significantly affect nutrient bioavailability (Hartemink and Barrow, 2023). Contrary to earlier claims of temperature resistance up to 1000 °C (Rabenhorst, 1988), decreases in IC of regional agricultural soils with high carbonate contents (Bozgeyik and Çimrin, 2020; Demir et al., 2024) in STB, support previous other findings (Jiménez-Pinilla et al., 2016; Keeley, 2009). The reduction in $P_{av}$ in STB, like earlier study (Kirkby and Fattore, 2006), which limits plant growth and agricultural productivity, may result from ash loss by erosion (Soto et al., 1995; Wu et al., 2023). Additionally, repeated stubble burning adversely impacts the long-term phosphorus pool due to $P_{av}$ losses (Resende et al., 2011).

As reported in the previous study (Preesong and Yampracha, 2022), the lack of significant EC differences in STB and NSB may be influenced by soil moisture variations (Tütmez, 2024), particularly in the agricultural soils of Araban, which is in a semiarid transition region between the Mediterranean and continental climates (Tunç and Demir, 2021). This observation is consistent with results of previous research in tropical agricultural fields (Arunrat et al., 2023). Stubble burning also significantly impacts SOM, a critical indicator of soil quality and agricultural productivity (Tunç and Demir, 2021). Moreover, it has been shown that the negative effects of stubble burning on soil carbon persist for more than six years (Roper et al., 2021). The lower SOM contents in STB compared to NSB align with previous studies (Can and Dogan, 2017; Palta and Kaur, 2024), though significant differences were absent between in NSB and STB contrary to previous studies (Arunrat et al., 2023; Halder et al., 2023) and this can probably be explained by the very low SOM contents of the regional soils (Çelik et al., 2017; Şimşek Semercioğlu et al., 2023). Also insufficient fire temperatures may also account for the unchanged SOM levels (Thomaz, 2017). Contrary to studies suggesting ash increases $K_{ex}$ contents post-burn (Ghosh et al., 2023; Preesong and Yampracha, 2022), no significant differences were observed between STB and NSB $K_{ex}$ levels.

**Table 1.** Descriptive statistics results of the selected soil general properties (Min.: minimum, 1 st Q: first quartile, Med.: median, 3 rd Q: third quartile, Max.: maximum, StD: the standard deviation, Kurt.: kurtosis, Skw.: skewness, CV: the coefficient of variation, * : $p$<0.05, ** : $p$<0.01, ns: no significance).

| | | Min. | 1 st Q | Mean | Med. | 3 rd Q | Max. | StD | Kurt. | Skw. | CV | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS (%) | NSB | 44.16 | 54.24 | 55.98 | 55.89 | 57.72 | 75.30 | 10.7 | -0.71 | 0.54 | 19.11 | * |
| | STB | 51.32 | 56.80 | 57.62 | 57.04 | 58.45 | 65.28 | 5.08 | -1.36 | 0.29 | 8.82 | |
| pH (%) | NSB | 7.71 | 7.76 | 7.77 | 7.77 | 7.78 | 7.85 | 0.05 | -0.48 | 0.39 | 0.61 | * |
| | STB | 7.79 | 7.91 | 7.92 | 7.90 | 7.94 | 8.09 | 0.10 | -0.77 | 0.33 | 1.21 | |
| EC ($dS\ m^{-1}$) | NSB | 0.63 | 0.74 | 0.72 | 0.73 | 0.79 | 1.11 | 0.14 | 4.86 | 2.00 | 17.82 | ns |
| | STB | 0.68 | 0.76 | 0.77 | 0.75 | 0.78 | 0.93 | 0.07 | 2.60 | 1.29 | 8.76 | |
| IC (%) | NSB | 1.89 | 8.50 | 9.31 | 9.46 | 10.12 | 15.90 | 4.97 | -1.41 | -0.08 | 53.42 | ** |
| | STB | 4.54 | 6.83 | 7.12 | 6.81 | 7.40 | 10.60 | 1.76 | 0.48 | 0.76 | 24.80 | |
| SOM (%) | NSB | 0.47 | 0.82 | 0.86 | 0.85 | 0.90 | 1.23 | 0.25 | -0.91 | -0.17 | 28.90 | ns |
| | STB | 0.52 | 0.78 | 0.81 | 0.78 | 0.84 | 1.14 | 0.18 | -0.05 | 0.28 | 22.76 | |
| $K_{ex}$ ($mg\ kg^{-1}$) | NSB | 46.80 | 54.77 | 55.48 | 56.00 | 56.19 | 60.00 | 4.36 | 0.04 | -0.76 | 7.86 | ns |
| | STB | 39.80 | 55.76 | 56.79 | 60.00 | 57.82 | 60.00 | 6.31 | 7.20 | -2.61 | 11.12 | |
| $P_{av}$ ($mg\ kg^{-1}$) | NSB | 1.53 | 7.52 | 8.74 | 6.68 | 9.96 | 25.75 | 7.49 | 2.06 | 1.43 | 85.67 | * |
| | STB | 2.75 | 6.24 | 6.71 | 7.03 | 7.18 | 11.73 | 2.88 | -0.55 | 0.39 | 42.97 | |

### 3.3. Effects of stubble burning on relationships in soils

CA (Figure 2), PCA, and HCA (Figure 3) were employed to assess the impact of stubble burning on soil relationships. CA indicated negative correlations between AS with EC ($r^2$ = - 0.601 *), soil pH with $P_{av}$ and EC ($r^2$ = - 0.669 ** and $r^2$ = - 0.768 **), and IC with SOM and $K_{ex}$ ($r^2$ = - 0.563 * and $r^2$ = - 0.524 *) in NSB, while positive correlations were noted between $P_{av}$ and EC, SOM, and $K_{ex}$ ($r^2$ = 0.521 *, $r^2$ = 0.666 ** and $r^2$ = 0.760 **). In STB, negative correlations were observed between EC with $K_{ex}$ ($r^2$ = - 0.718 **), and IC with AS and EC ($r^2$ = - 0.786 ** and $r^2$ = - 0.582 *), while a positive correlation between IC and pH ($r^2$ = 0.844 **) was identified. PCA accounted for 74.9% and 76.4% of total variance in NSB and STB, respectively. In NSB, PC1 (33.4%) was characterized by SOM, $P_{av}$ and $K_{ex}$, PC2 (28.8%) by AS and EC (Figure 3A), and PC3 (17.7%) by IC and pH (Figure 3B). In STB, it was determined that IC, pH, SOM, and $P_{av}$ contributed to PC1 (31.2%), AS, and SOM to PC2 (24,3%; Figure 3D) and EC and $K_{ex}$ to PC3 (20,9%; Figure 3E). PCA and HCA confirmed alterations in soil properties post-burning across localities. CA, PCA, and HCA elucidated the pre-burn relationships in NSB, as reported in previous studies (Karaduman and Çimrin, 2016; Tunç et al., 2022), which shifted due to stubble burning in STB (Imaz et al., 2010).

In NSB, PC1 focused on nutrient elements, while STB highlighted the direct impact of stubble burning on soil properties. The positive correlation of SOM with $P_{av}$ in NSB As in the prior study (Tunç et al., 2021), and the absence of significant relationships in STB support this hypothesis. Additionally, this aligns with previous findings on SOM's role in P cycling within NSB (Braschi et al., 2003). In STB, prior studies indicated that SOM, IC, pH, and $P_{av}$ in PC1 (Halder et al., 2023; Palta and Kaur, 2024) are the selected general soil properties influenced by stubble burning. In contrast to NSB, the positive correlation of soil pH in STB is attributed to increased alkaline compounds due to the loss of IC and heightened pH (Thomaz, 2021).

PC2 in both NSB and STB was linked to factors influencing soil aggregate formation. EC was found to impact AS in NSB and IC in STB, although their positive relationship in STB was not significant. This underscores IC's role in enhancing AS post-stubble burning, while in NSB, soil metals such as $Na^{+}$ contributed to aggregate formation (Muneer and Oades, 1989). Previous research indicated that carbonates facilitate aggregate formation following stubble burning (Xie et al., 2024). A laboratory study on calcareous soils in the Mediterranean Region demonstrated that AS decreased at low temperatures but increased with higher temperatures (500-700 °C) in the presence of carbonates (Jiménez-Pinilla et al., 2016). Amézketa (1999) posited that this phenomenon might be due to the release of polyvalent alkaline cations, particularly $Ca^{2+}$, from IC combustion, which as inorganic stabilizers for AS.

The contributions of IC and pH in NSB, alongside EC and $K_{ex}$ in STB, indicate that PC3 reflects relationships between IC and soil pH in NSB, with ash significantly affecting $K_{ex}$ in STB. This study, differing from previous studies (Demir et al., 2023; Karaduman and Çimrin, 2016), found no correlation between pH and IC in NSB, while a strong positive correlation in STB highlighted IC's significance on pH post-stubble burning. Furthermore, previous research linked the rise in pH after stubble burning to ash's influence on soil metals, silicas, sesquioxides, phosphates, and organic or inorganic acid contents (Halder et al., 2023; Kumar et al., 2019).

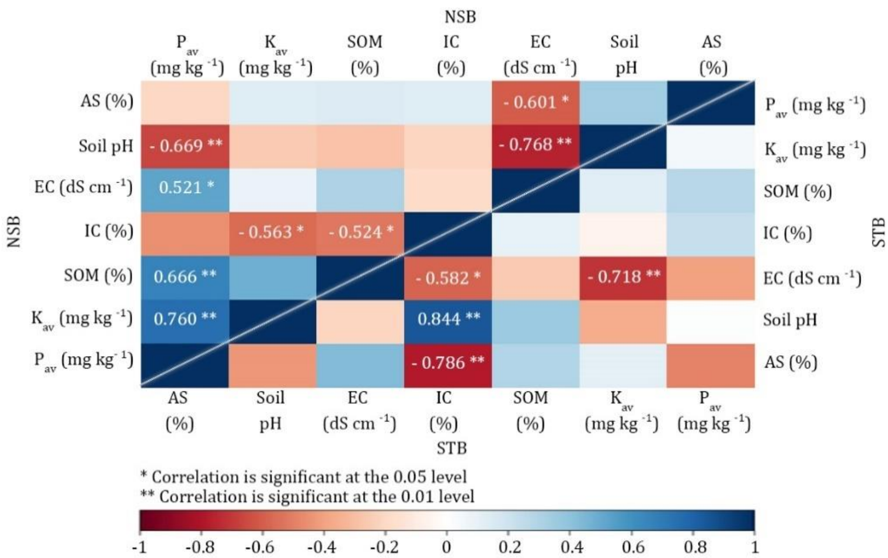


**Figure 2.** The comparative correlation diagram between selected soil general properties in NSB and STB.

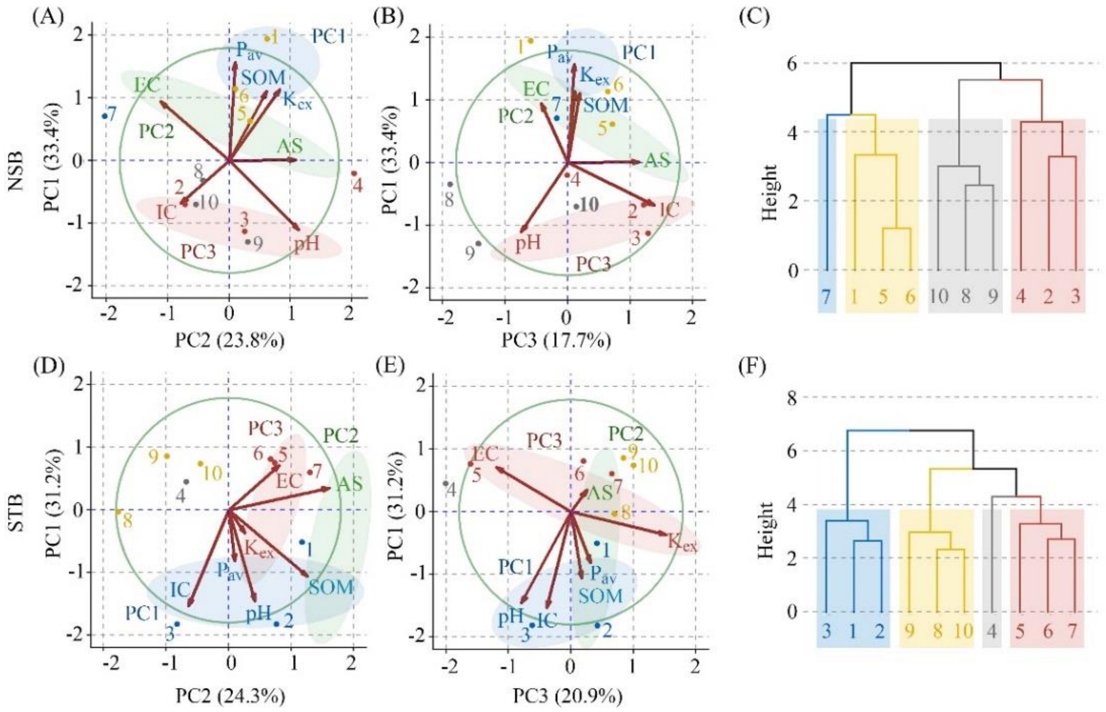


**Figure 3.** PC1 and PC2 (A), PC1 and PC3 diagram (B) of PCA and dendrogram of HCA (C) in NSB and PC1 and PC2 (D), PC1 and PC3 diagram (E) of PCA and dendrogram of HCA (F) in STB.

## 4. Conclusion

A comparative analysis of alkaline wheat field soils derived from limestone and gypsum parent materials found that stubble burning led to a notable increase in both AS and soil pH values, while concurrently causing a significant reduction in IC and $P_{av}$ contents. The study indicated that IC played a crucial role in the observed rise in AS and pH. Furthermore, the elevated temperatures resulting from stubble burning were identified as a key factor contributing to the decline in IC and ash content in $K_{ex}$. The non-significant reduction in SOM after stubble burning was linked to the substantial decrease in $P_{av}$ contents. The findings suggest that alterations in pH due to stubble burning could have profound implications for the availability of essential nutrient elements. PCA and HCA corroborated the significant changes in selected soil properties that are vital for soil quality and health.

The results underscore the potential risks that stubble burning poses to soil quality, health, and agricultural productivity if such farmers persist. Keeping soil organic matter, which is critical for both natural ecosystems and agricultural systems due to its role in sequestering greenhouse gases, is imperative for enhancing productivity and ensuring the sustainability of nutritious food production. Therefore, it is advisable to establish and implement educational initiatives and appropriate regulations aimed at persuading farmers to discontinue the practice of stubble burning.

### Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

### Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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