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SHORT-TERM EFFECT OF WHEAT RESIDUE BURNING ON SOIL PROPERTIES IN CHITWAN

Krishna Aryal[1*], Janmajaya Gairhe[1], Aashika Bhusal[1] and Barsha Subedi[1]
[1]Institute of Agriculture and Animal Science, Tribhuvan University, Nepal
*Corresponding author: krishna.aryal@rc.tu.edu.np
Krishna Aryal: 0000-0001-5938-8300
Janmajaya Gairhe: 0000-0001-7934-3003
Aashika Bhusal: 0009-0009-0363-335X
Barsha Subedi: 0009-0006-7640-6164

ABSTRACT

Crop residue burning is widely practiced in terai region of Nepal as it is cheap, easy, and convenient method for managing post-harvest crop remnants. Although burning practice is commonly perceived to rapidly improve soil fertility, its immediate effects on soil properties remain poorly understood. This study examined the short-term effects of wheat residue burning on key physico-chemical soil properties across three sites *viz*: Phasera, Jamauli and Salauli of Khairahani Municipality, Chitwan, Nepal. A total of 180 soil samples (30 pre -burn and 30 post burn) from each site were collected during the time of wheat harvest at the depth of 0-15 cm. A paired t-test compared pre- and post-burn conditions for bulk density, particle density, pH, organic matter (OM), total nitrogen (TN), available phosphorus (P), and potassium (K). Results revealed site-specific response to burning. Bulk density remains unaffected across the sites while pH (5.62±0.56 to 6.01±0.73; $p < 0.01$) increased significantly at Phasera. Similarly, OM and TN showed limited changes except at Salauli, available P declined markedly at Jamauli (142.67±79.88 mg kg^{-1} to 91.88±81.91 mg kg^{-1}; $p<0.01$) while available K increased significantly across all the sites. The findings demonstrate that residue burning induces complex, nutrient-specific shifts, with short-term benefits of pH increment and K release, however it increases the risk of P loss and inconsistent OM response. Therefore, further investigation of the long-term impacts of residue burning on soil health is essential, considering post burning sampling time, burning intensity, and residue volume.

Key words: *Burned soil, nutrient shifts, site-specific, soil fertility, soil health*

INTRODUCTION

Soil health is the foundation of sustainable agriculture as it directly influences crop productivity, ecosystem functions and environmental quality. Crop residues, when incorporated into the soil, become the fraction of soil organic matter which plays a pivotal role in enhancing soil physical, chemical and biological properties. The decomposition of crop residues improves soil fertility through better soil aggregation, nutrient retention, and stimulation of microbial activity (Aleminew, 2024). However, the widespread practice of burning crop residues poses a significant threat to the soil health. The necessity of maximizing system productivity for feeding the growing population has brought paradigm shift from traditional to more mechanized and intensive farming practice resulting in the generation of substantial (22.8 million tons) amount of crop residues in Nepal (SAARC Energy Centre, 2021). In recent years, residue management has become a significant challenge due to farm mechanization particularly in the terai plains of Nepal (CSAM, 2023; Panta, 2013). The use of reapers, threshers and combined harvesters which left behind the long stubbles and residues scattered on the field are difficult to manage. Consequently, these residues are sorted by open burning to prepare the field for subsequent crops. Lower preferences of the combine harvested straw by animals, declining trend in livestock rearing, less market value of the straw, shortage of labor due to overseas employment, shorter window period due to greater cropping intensity has further pushed the Nepalese farmers to adopt residue burning as quick, cheap and convenient method of crop waste disposal (Poudel, 2017; Basnyat, 2022).

Although burning practices offer short-term labor savings and faster turnaround between crops, it creates adverse impacts on environment, soil, crops, human and animal health. Burning results in the emission of greenhouse gases such as CH_4, CO, N_2O and NO; particulate matters (PMs), and polyaromatic hydrocarbons which pollutes the air and contribute to health hazards and climate change issues (Saikiya, 2025; Abdurrahman et al., 2020). It is estimated that one tonne of rice residue on burning releases 13 kg particulate matter, 60 kg CO, 1460 kg CO_2, 3.5 kg NOx, 0.2 kg SO_2 (Benbi & Brar, 2021). In addition, burning leads to the loss of entire amount of carbon(C), approximately 80 – 90 % of nitrogen(N), 25 % of phosphorous(P), 20 % of potassium(K) and 50 % of sulphur (S) present in the crop residues (Thakur et al., 2021).

Wheat crop residues serve as a significant reservoir of plant nutrients, retaining approximately 25–30% of the total N and P uptake, 35–40% of S and 70–75% K. When incorporated into the soil, one tonne of wheat residue can contribute approximately 4–5 kg N, 0.7–0.9 kg P, and 9–11 kg K (Singh & Sidhu, 2014). Existing research showed varying responses of crop residue burning on soil properties depending upon the soil type, residue type and environmental conditions. Some of the studies reported the short-term positive effects resulting in increment in pH, Electrical conductivity (EC), available P and available K (Kaur et al., 2019; Kadham et al., 2022; Pradhan et al., 2025) while some studies highlighted negatives effects such as loss of N, organic C, available P, exchangeable Calcium(Ca), exchangeable magnesium(Mg), deterioration of soil structure, reduction in porosity, water holding capacity, microbial populations and enzymatic activities(Tripathi et al., 2015; Kaur et al., 2019; Tawfeeq et al., 2025; Pradhan et al., 2025). Such degradation in soil quality reduces the efficiency of the applied manures and fertilizers creating more financial burden to restore soil fertility (Lin & Begho, 2022; Mehta & Badegaonkar, 2023).

In Nepal, Existing studies have focused on environmental, socioeconomic and public health aspects of residue burning. Research efforts developed gridded emission inventories that quantified the emission of carbon dioxide (CO_2), methane (CH_4), particulate matter ($PM_{2.5}$) and other pollutants from open residue burning and documented their contributions in ambient air quality, regional haze, and associated health risks (Das et al., 2020). Studies in Terai region have also examined the key determinants of farmers' decision to burn residue (Bajracharya et al., 2021). However, region specific field evidence regarding the impact of residue burning on soil physicochemical properties remains scarce. Therefore, this study was conducted to evaluate the short-term burning effect on soil bulk density, pH, organic matter, total N, available P and available K in major wheat growing sites of Khairahani Municipality, Chitwan.

MATERIALS AND METHODS

The study was conducted at Khairahani Municipality of Chitwan district which lies in Bagmati Province of Nepal. It is located at 27.6198°N latitude and 84.5746°E longitude with an elevation of 190masl. This area represents the subtropical terai region and is characterized by intensive cereal based cropping system, predominantly the rice-wheat rotations. Three different sites, *viz*. Phasera, Jamauli and Salauli were purposively selected due to the prevalence of residue burning after wheat harvest. Soil sampling was conducted at two stages: before residue burning(pre-burn) and after residue burning(post-burn). For the pre-burn stage, soil samples were collected after wheat harvest in March 2024. A total of 90 composite samples (30 per site) were obtained from the topsoil (0–15 cm depth). Each composite sample was prepared by pooling 8 subsamples taken in a Z pattern across the plots. For the post-burn stage, sampling was repeated at the same sites and plots 24 hours after wheat residues were burned, yielding another 90 composite samples (30 per site). Another 30 sets of soil samples from each site under both pre-burn and post burn conditions were collected simultaneously using core sampler of 7.8 cm diameter and 10cm height ensuring minimal disturbance for bulk density measurement. The collected samples were air dried, grounded using mortar and pestle and passed through a 2mm sieve to ensure uniform particle size and to remove any large debris. Soil samples were analyzed for selected soil properties in the soil science laboratory of Rampur Campus. Bulk density was calculated by dividing the weight of oven dried soil sample at 105^0C for 24 hr. to the total volume of soil obtained from core sampler. The soil pH was measured with a pH meter using 1:2.5 suspension of soil in water. Organic matter was measured by Walkley and Black method. Soil total N was estimated from organic matter, available P concentration was determined by modified Olsen's bicarbonate method using spectrophotometer and available K concentration was determined by neutral ammonium acetate method using flame photometer following the standard procedure as described in the manual developed by soil management directorate, Nepal (Government of Nepal, 2017). The data obtained were compiled and analyzed using Microsoft Excel (Microsoft 365 Version) and R studio (version 2024) software. Prior to performing statistical tests, the normality of the data was assessed using the Shapiro-Wilk test in R studio. Since the data were normally distributed, a paired sample t-test was employed to compare pre-burn and post-burn soil parameters at each site. The test was performed at a 5% level of significance ($p \leq 0.05$) to determine whether differences between pre- and post-burning values were statistically significant.

RESULTS AND DISCUSSION

Bulk density

Bulk density is a physical soil parameter which represents soil compactness and influence root penetration, aeration and water infiltration. The effect of burning wheat residues on soil bulk density is illustrated in Figure 1. The results indicate a slight decrease in soil bulk density after residue burning across all the sites. Specifically, Phasera and Salauli showed minor reductions in the mean value of bulk density by 0.93% and 0.88%, respectively, whereas Jamauli showed higher reduction of 3.96%. Although the result showed minimal change in soil bulk density before and after burning, the values were statistically non-significant($p>0.05$).

Our findings align with findings from Kumar et al. (2025), where bulk density exhibited minimal differences from 0 to 21 days following rice residue burning in Indian soils. This suggests that residue burning did not substantially alter soil bulk density within short period following the burning event. The marginal reduction observed is likely to be associated with short-term thermal effects which induce microcrack formation in the soil matrix, leading to temporary surface loosening.

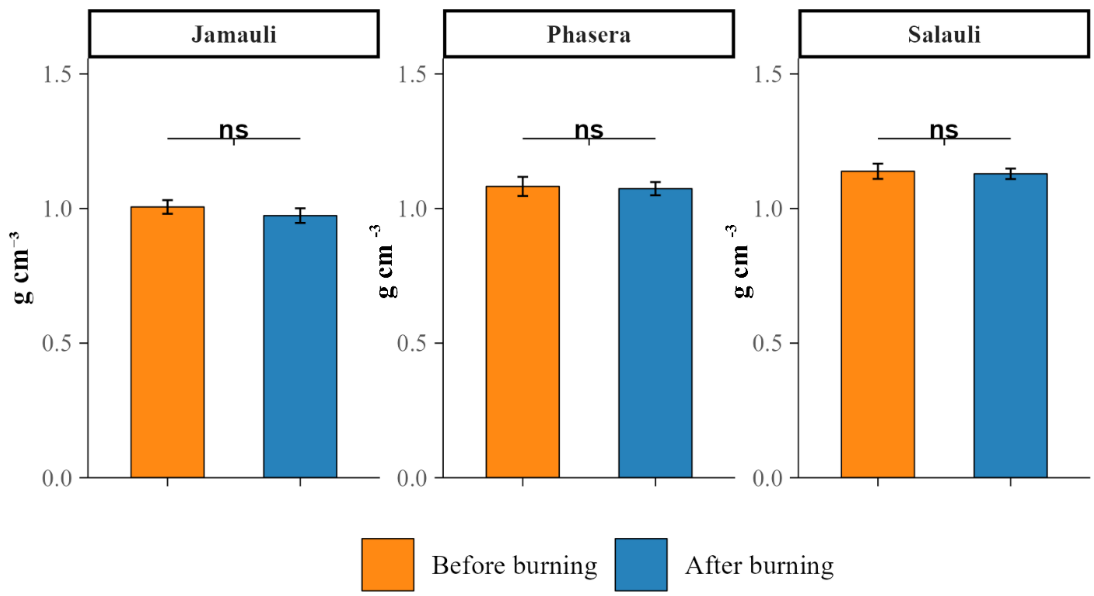

Figure 1: Effect of wheat residue burning on soil bulk density across different study sites

Soil pH

The effect of wheat residue burning on soil pH is presented in figure 2. Soil pH showed a general increasing trend after wheat residue burning across all study sites. Burning effect on soil pH was most pronounced at Phasera where mean pH increased significantly from 5.62±0.56 to 6.01±0.73 ($p < 0.01$). In contrast, changes at Jamauli (6.33±0.55 to 6.42±0.51) and Salauli (5.91±0.68 to 6.14±0.55) were statistically non-significant. Similar findings have been reported by Arunrat et al. (2023), who noted significant increases in soil pH immediately after burning of rice straw.

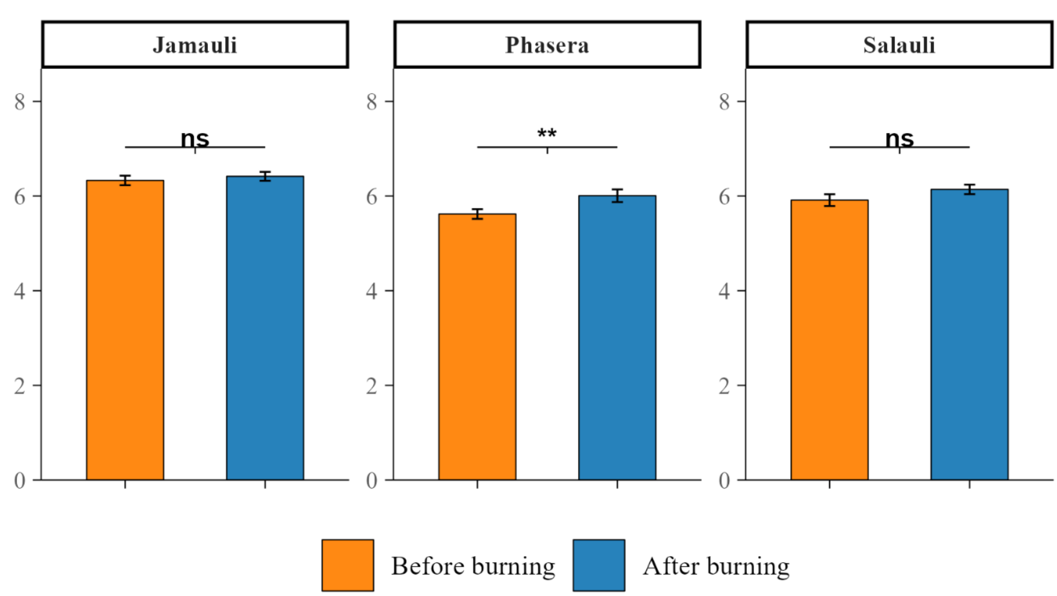

Figure 2: Effect of wheat residue burning on soil pH across different study sites

The observed rise in soil pH following burning is attributable to loss of OH group from the clay minerals, formation of oxides and production of ash rich in basic cations such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}, which neutralize soil acidity. Variability in residue quantity, burning intensity, and ash distribution may also have contributed to the observed differences among sites. It is noted that the extent of pH increase depends strongly on initial soil conditions. The significant increase in soil pH at Phasera is attributed to its initially acidic soil condition, which makes pH changes more pronounced after the addition of alkaline ash. Acidic soils generally exhibit a stronger response to residue burning due to their lower buffering capacity. In contrast the non-significant pH changes at Jamauli and Salauli is likely due to its higher pH value, differences in soil texture and organic matter content. Such soils possess greater buffering capacity due to which soils can resist rapid changes even after the addition of alkaline materials (Brady& Weil, 2014)

Soil organic matter

Soil organic matter content (OM) exhibited site-specific responses to wheat residue burning (Figure 3). At Phasera and Jamauli, differences in OM between pre- burning and post-burning soils were statistically non-significant, with values remaining relatively stable (1.96±0.56 vs. 2.00±0.38% and 2.59±137 vs. 2.63±1.54%, respectively). However, at Salauli, OM increased significantly from 1.59±0.72 to 1.88±0.40% ($p < 0.05$), suggesting a localized positive effect of burning on OM. These results align with those reported by Kumari et al. (2023).

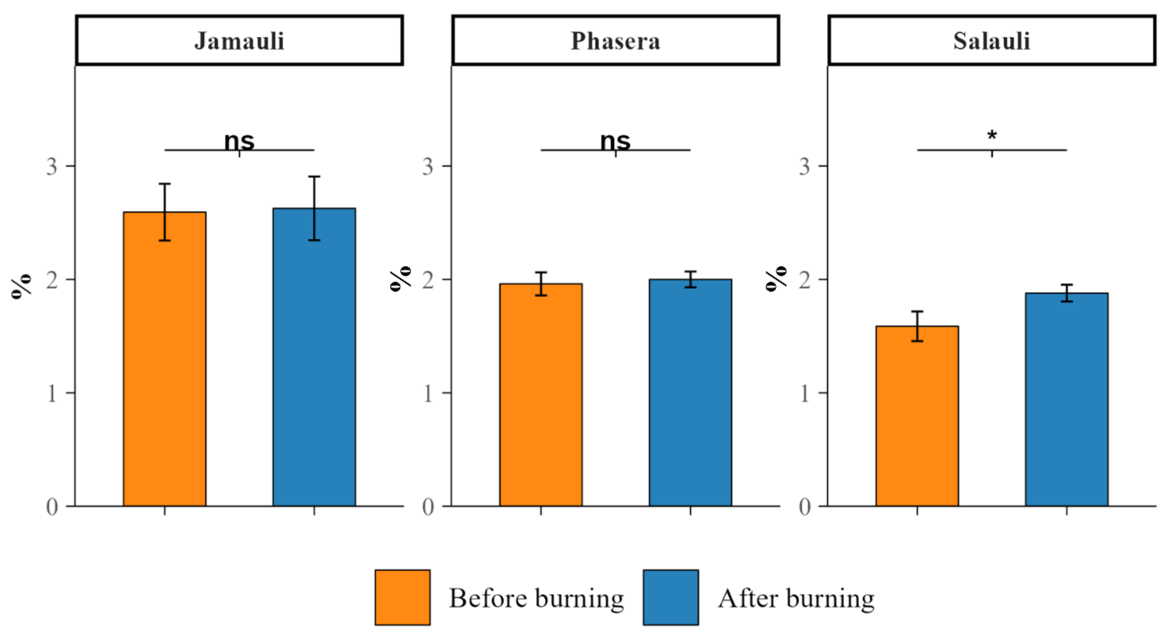

Figure 3: Effect of wheat residue burning on soil OM across different study sites

In Phasera and Jamauli results indicate that burning did not contribute meaningfully to OM build up in the short post burning period. During burning, a greater fraction of carbon in the residue get lost as CO_2 and other gaseous emissions, while only a small portion remains as ash or partially charred material. As a result, the net contribution of burning to stable

OM is typically minimal (Mohan et al., 2018). The significant increase in OM at Salauli is attributed to the deposition of recalcitrant carbon fractions like black carbon and charcoal due to partial charring of the residues. Charred materials are relatively resistant to microbial decomposition and can be measured as part of soil organic matter shortly after burning, leading to an apparent short-term increase (Pellegrini et al., 2022)

Total soil nitrogen

Soil total nitrogen (TN) content exhibited limited response to wheat residue burning at most sites (Table 1). At Phasera and Jamauli, the mean value for TN before and after burning residue remain stable and showed no significant differences. However, at Salauli significant increase in TN was observed.

The results of TN after burning at Phasera and Jamauli documented the fact that N is highly susceptible to volatilization during residue burning. A substantial proportion of residue N is lost as gaseous forms such as N_2, NO_x, and NH_3 during combustion, resulting in little or no net gain in soil N pools.

Table 1: Effect of wheat residue burning on soil total nitrogen at different sites of Khairahani, Chitwan during 2024

Sites	Total nitrogen (%)												
	Before burning					After burning					t-value	p-value	Sig.
	Mean	SD	SE	Min	Max	Mean	SD	SE	Min	Max			
Phasera	0.10	0.03	0.005	0.01	0.21	0.10	0.02	0.003	0.06	0.16	-0.38	0.71	NS
Jamauli	0.13	0.07	0.01	0.02	0.33	0.13	0.08	0.01	0.01	0.35	-0.17	0.87	NS
Salauli	0.08	0.04	0.01	0.02	0.22	0.09	0.02	0.004	0.06	0.13	-2.53	0.016	*

*Note: SD= standard deviation; SE= standard error; NS= non-significant; * significant at 5% level($p<0.05$)*

The absence of significant changes in TN at two of the study sites is consistent with earlier findings by Tawfeeq et al. (2025) who noted that TN responses to burning are known to vary with fire intensity, residue load, and post-burning sampling time. The stability of soil N pools in Phasera and Jamauli is possibly due to high fire intensity which likely increase N volatilization loss. Moreover, the relatively short interval between burning and soil sampling may have coincided with a transitional phase when enhanced N mineralization occurred, yet substantial losses through volatilization or leaching had not fully manifested. This temporal effect could partly explain the stability of N levels at Phasera and Jamauli. In contrast the observed increase in TN at Salauli is attributed to burning of high volume of residue load which favored the formation and deposition of charred material. Partially combusted organic materials are resistant to mineralization which contribute to the higher value of TN shortly after burning, especially when sampling is conducted soon after the event. In addition, the conversion of organic N into more condensed and resistant forms during burning may increase the proportion of N.

Soil available phosphorous

The effect of wheat residue burning on soil available P showed notable variations across study sites (Table 2). At Phasera and Salauli, residue burning resulted in only minor reductions in soil available P, with decreases of 12.1% and 4.3%, respectively; however, these changes were not statistically significant ($p > 0.05$). In contrast, Jamauli exhibited a substantial and statistically significant decline in available P after burning, with a 35.6% reduction compared to pre-burning levels.

Table 2: Effect of wheat residue burning on soil available phosphorous at different sites of Khairahani, Chitwan during 2024

Sites	Available P (mg kg^{-1})												
	Before burning					After burning					t-value	p-value	Sig.
	Mean	SD	SE	Min	Max	Mean	SD	SE	Min	Max			
Phasera	183.41	69.98	12.78	63.70	370.63	161.22	65.76	12.01	29.89	358.37	1.16	0.26	NS
Jamauli	142.67	79.88	14.58	20.61	275.84	91.88	81.91	14.95	6.03	290.09	3.08	0.004	**
Salauli	86.93	75.74	13.83	5.36	371.63	83.17	52.95	9.67	6.36	191.98	0.27	0.79	NS

*Note: SD= standard deviation; SE= standard error; NS= non-significant; ** significant at 1% level($p<0.01$)*

The significant decline in available P at Jamauli is attributed to the thermal alteration of soil phosphorus fractions during residue burning. High temperatures generated at the soil surface during burning promotes the conversion of available P to unavailable P through fixation with calcium, iron, and aluminum oxides. Additionally, burning-induced increases in soil pH and ash deposition may temporarily enhance P solubility; however, subsequent reactions can lead to precipitation of P as sparingly soluble compounds, thereby reducing its availability in the short term. Similar reductions in available P following residue burning have been reported by Tripathi et al. (2015) and Kaur et al. (2019), who attributed these changes to heat-induced transformations and losses of organic P pools. The minor changes in available P at Phasera and Salauli suggest a buffering effect of inherent soil properties and baseline nutrient status. Phasera exhibited relatively high initial P levels, which may have masked the immediate impact of residue burning. Moreover, differences in soil texture, organic matter content, and mineralogy among the sites may have moderated the extent of P transformation during burning.

Soil available potassium

The K content was significantly increased across all the study sites after burning of the wheat residue (Table 3). After burning available K increased by 57.1%, 31% and 27.7% at Phasera, Jamauli and Salauli respectively. The observed increases were statistically significant at $p < 0.01$ for all sites.

Table 3: Effect of wheat residue burning on soil available potassium at different sites of Khairahani, Chitwan during 2024

Sites	Available K (mg kg^{-1})												
	Before burning					After burning					t-value	p-value	Sig.
	Mean	SD	SE	Min	Max	Mean	SD	SE	Min	Max			
Phasera	66.47	24.67	4.50	39.82	138.55	104.41	55.26	10.09	44.11	284.72	-3.56	0.001	**
Jamauli	93.96	48.11	8.78	30.08	199.32	123.10	62.85	11.48	31.14	238.54	-3.38	0.002	**
Salauli	32.23	10.01	1.83	18.76	68.45	41.17	17.45	3.19	18.76	101.50	-3.64	0.001	**

*Note: SD= standard deviation; SE= standard error; NS= non-significant; ** significant at 1% level($p<0.01$)*

The marked increase in available K following wheat residue burning is attributed to the fact that K is not volatilized during combustion but is instead concentrated in ash in readily soluble forms. Upon deposition on the soil surface, ash-derived K dissolves rapidly, increasing exchangeable and water-soluble K fractions. Similar post-burning increases in soil available K have been reported by Kaur et al. (2019), Tawfeeq et al. (2025) and Arunrat et al. (2023) and are considered one of the most consistent nutrient responses to residue burning likely due to the release of K from ash and organic matter during combustion. However, the magnitude of increase varied among sites due to differences in residue load, initial soil properties, and burning intensity.

CONCLUSION

Soil properties responded differently to wheat residue burning among the sites. Residue in short post burning time typically resulted in the increment of soil pH, OM, TN and available K. In contrast, bulk density and available P decreased, but results were not consistent across all the sites. This variation features the influence of site-specific factors on soil response to burning. So, further study is needed that counts residue volume, burning intensity and multiple post burning sampling intervals that accounts for better understanding of the long-term impacts of crop residue burning on soil health.

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