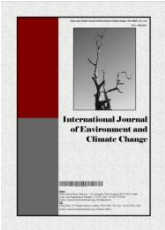

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Impact of *In-situ* Paddy Straw Burning on Soil Enzyme Activity, Soil Microbial Population and Green House Gas Emissions in Sandy Loam Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rice - maize cropping system is one of the predominant cropping systems in Telangana state, which also produces large quantities of residues, whose disposal is a major problem. A large quantity of paddy straw is burnt on the farm to clear the field for succeeding crop. On the farm, a significant amount of paddy straw is burned to prepare the land for a subsequent crop. Burning crop residue damages the air and results in the loss of a significant amount of biomass plant nutrients and the entire amount of carbon. The purpose of the study was to investigate the impact of paddy straw burning on soil biological properties (enzyme activities, microbial population) and to know the amount of green house gas (GHG) emissions released due to burning of residue, under two tillage systems *viz.*, no tillage and conventional tillage. Results indicated that there was a

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significant decrease in soil microbial population, dehydrogenase activity (41.52% in NT and 40.07% in CT), acid and alkaline phosphatase activity and urease activity in soil due to residue burning. It also indicated that there was a rise in CO_2, CH_4 and N_2O emissions 48 hours after residue burning. It can be concluded that crop residue burning leads to decrease in the enzyme activities and soil microbial population. It also leads to rise in green house gas emissions. The impact of rice straw burning on different microbial genera has to be further studied by researchers.

Keywords: Paddy straw burning; soil enzyme activity; microbial population; GHG emissions; pre-burning; post-burning.

1. INTRODUCTION

In Asia, rice is the crop that produces the largest residue (826 million tonnes), accounting for 84% of global production. In South Asia, rice straw is typically taken out of the fields and used for cattle feed and other things. The average amount of N, P, and K in rice crop wastes is 0.7%, 0.23%, and 1.75%. As a result, in Asia and globally, the amount of NPK present in rice crop wastes generated is between 22.3 106 and 26.26 106 t $year^{-1}$ [1]. Burning residues is the main factor in the immediate and large decrease in bacterial and fungal populations in the top 2.5 cm of the soil. However, in order to accelerate the decomposition of agricultural residue under in situ decomposition, extra resources like water, nutrients, and bio-inoculum are needed [2]. As a by-product of harvesting rice, rice straw is produced. During harvest, rice straw is removed together with the rice grains and is either heaped or spread out on the field depending on whether it was harvested manually or by machines.

The ratio of straw to paddy varies based on variety and growth, falling between 0.7 and 1.4. Due to the shorter turnaround times needed for increased rice farming, this keeps growing quickly. Only half of the war has been won by the development of game-changing combine harvesters, which reduce the enormous labour costs involved with manual straw gathering. With two to three crops each year, it is also unable to incorporate straw into the soil for fertilizer in intensive systems since there is not enough time for decomposition. This leads to poor soil fertilisation properties, which ultimately impede crop establishment. Open-field straw burning has significantly increased during the past ten years as a result of a lack of alternatives [3].

From the perspective of the farmers, burning may be viewed as the most appropriate way to get rid of rice straw. It serves as a cost-effective solution as well as a successful pest control technique [4]. Burning crop residues results in atmospheric pollution and the loss of a significant amount of biomass and plant nutrients, including all of the carbon, about 80–90% of the nitrogen, 25% of the phosphorus, 20% of the potassium and 50% of the sulphur present in crop residues [5]. The objective of the present study is to evaluate the short term effects of *in-situ* rice residue burning on soil enzyme activity, microbial population and green house gas emissions.

2. MATERIAL AND METHODS

The experiment was conducted in a sandy clay loam soil. The initial soil sample was collected at 0-15 cm deep from random locations in the field and it was shade dried, pounded and 2 mm sieved and used for analysis of physical, physico-chemical and chemical properties of soil by adopting standard procedures. The initial soil properties of the experimental site were presented in Table 1.

Table 1. Initial Soil Properties of the experimental site

S. No.	Property	Values
1.	Sand (%)	55
2.	Silt (%)	45
3.	Clay (%)	6.6
4.	Soil Texture	Sandy loam
5.	pH	8.4
6.	EC (dSm^{-1})	0.45
7.	Organic Carbon (%)	0.57
8.	Bulk Density (Mg m^{-3})	1.30

Table 2. Methods of enumeration of soil microbes

S. No	Microorganism	Method	Reference	Agar used
1	Bacteria	Serial dilution pourmethod	Thorton [6]	Nutrient agar
2	Fungi	Serial dilution pour method	Martin [7]	Potato Dextrose agar
3	Actinomycetes	Serial dilution pourmethod	Allen [8]	Actinomycetes isolation agar

Soil samples were collected before and after burning from the plots at the root zone and were analyzed immediately or were stored in refrigerator for the analysis of soil enzyme activities and soil microbial population.

2.1 Microbial Count

Number of bacteria/fungi/ actinomycetes in 1 g soil = $\frac{\text{No.of Colony Forming Units (CFU)} \times \text{dilution}}{\text{The dry weight of 1 g moist soil} \times \text{aliquot taken}}$

2.2 Soil Enzyme Activity

2.2.1 Dehydrogenase activity

In screw-capped test tubes, one gram of soil samples were weighed. 50 mg $CaCO_3$ was added to the mixture, followed by addition of 2.5 ml distilled water and 1 ml of 3 % TTC. The contents of the tube were stirred and incubated at room temperature for 24 hours. After the formation of red precipitate, a few millilitres of methanol was added and shaken to dissolve it. The contents were filtered and volume was made up to 25 ml with methanol. At 485 nm, the red colour intensity was measured [9].

2.2.2 Phosphatase activity

The method described by Tabatabai and Bremner [10] was used to measure the acid phosphatase activity, while the protocol developed by Eivazi and Tabatabai [11] was used to estimate the alkaline phosphatase activity. A screw-capped test tube was filled with one gram of soil, 0.2 millilitres of toluene, 4 millilitres of MUB (pH 6.5 for acid phosphatase or pH 11 for alkaline phosphatase), and one millilitre of p-nitrophenyl phosphate. Samples were swirled and were incubated at 37 degrees for one hour. 1 ml of 0.5M CaCl2 and 4 ml of NaOH were added after incubation. The contents were then filtered and yellow colour intensity was measured using spectrophotometer at 420 nm. Each sample has a control where 1 ml of p-nitrophenol solution was added after the addition of 0.5M $CaCl_2$ and 4 ml of NaoH.

2.2.3 Urease

Five grams of soil sample was weighed into a volumetric flask (50 ml). To this, 0.2 ml of toluene followed by 9 ml of THAM buffer were added. The contents were mixed thoroughly and 1 ml of urea solution was added. The tube was stoppered and incubated at 37°C for 2 hours. To reaction was terminated using KCl - $AgSO_4$ mixture (35 ml) and the volume was made up to 50 ml. 20 ml of suspension was pipetted out after mixing the contents. The amount of NH_4 released was measured by distilling the 20 ml of suspension with 0.2 g of MgO for 4 minutes and by titrating with 0.05N H_2SO_4. 1 ml of urea solution were used as controls after the addition of KCl - $AgSO_4$ [12].

2.3 GHG Emissions

During the crop growing season, CO_2, N_2O, and CH_4 fluxes from the soil surface were measured using static flux chambers and a GC gas analyzer. Sampling was done before and after the burning of crop residue. At each sampling site, a 10-cm-high vented rectangular aluminium chamber with a sampling port was installed in a water channel welded to an anchor (50 40 10 cm) inserted 10 cm into the earth. Anchors were installed perpendicular to the crop row so that the crop row and inter-row were contained within each chamber. Flux measurements were usually taken between the hours of 08:00 and 12:00 to avoid daily variations in the flux pattern. Within each replication of each treatment plot, duplicate flux measurements were taken. Gas samples were taken with a syringe from inside the chambers at 0, 15, and 30 minutes following installation. Gas samples (40 mL to ensure sample overpressure in tubes) were then injected into 20-mL evacuated vials with butyl rubber septa and transferred to the laboratory in CRIDA for gas chromatography analysis. The gas chromatograph employed was a Varian 3800 fully automated equipment with an electron capture detector for quantifying N_2O and FID and TCD detectors for measuring CH_4 and CO_2, respectively. Fluxes were calculated from the linear or nonlinear increase in concentration

(selected according to the emission pattern) in the chamber head space with time [13].

2.4 Statistical Analysis

For comparison of mean values pre and post burning of residue, paired t test was performed using data analysis tool in microsoft excel. The eta statistic values were computed using the formula:

$$t^2 / t^2 + (n+1)$$

3. RESULTS AND DISCUSSION

3.1 Soil Enzyme Activity

The data related to soil enzyme activity in response to residue burning was presented in Table 1. The mean values of dehydrogenase activity under no tillage (61.94 µg TPF g^{-1} soil day^{-1}) was higher than conventional tillage (53.31 µg TPF g^{-1} soil day^{-1}) before burning of the residue (Table 3). Dehydrogenase activity (µg TPF g^{-1} soil day^{-1}) was drastically reduced 48 hours after burning in both no tillage (35.14 µg TPF g^{-1} soil day^{-1}) and conventional tillage (29.83 µg TPF g^{-1} soil day^{-1}). Similar trend was observed in case of acid and alkaline phosphatase activity. The acid phosphatase activity before burning of the residue was 91.31 µg PNP g^{-1} soil hr^{-1} and 78.74 µg PNP g^{-1} soil hr^{-1} in no tillage and conventional tillage systems respectively. Post-burning of the residue, there was a decrease in the acid phosphatase activity (as indicated by right tailed t test) in both no tillage (48.83 µg PNP g^{-1} soil hr^{-1}) and conventional tillage (28.97 µg PNP g^{-1} soil hr^{-1}). The alkaline phosphatase activity before burning of the residue was 106.90 µg PNP g^{-1} soil hr^{-1} and 94.95 µg PNP g^{-1} soil hr^{-1} in no tillage and conventional tillage systems respectively. Post-burning of the residue, there was a decrease in the alkaline phosphatase activity in both no tillage (47.82 µg PNP g^{-1} soil hr^{-1}) and conventional tillage (41.18 µg PNP g^{-1} soil hr^{-1}). The mean values of urease activity under no tillage (49.04 µg NH_4^+N g^{-1} soil $2hr^{-1}$) was higher than conventional tillage (40.72 µg NH_4^+N g^{-1} soil $2hr^{-1}$) before burning of the residue (Table 3). Urease activity was drastically reduced 48 hours after burning (Table 3) in both no tillage (20.59 µg NH_4^+ N g^{-1} soil 2 hr^{-1}) and conventional tillage (16.44 µg NH_4^+ N g^{-1} soil $2hr^{-1}$). As the t stat values are greater than t critical values for all the enzymes, it can be noted that there was significant impact of stubble burning on soil enzymatic activity in both tillage systems. Further there was decrease in the enzyme activity post burning of the residue, which was indicated by right tail t test. The eta square statistic was > 0.7 for all the enzyme activities, which indicated a large effect size of stubble burning on soil enzyme activity in both tillage systems.

Decline in dehydrogenase enzyme due to residue burning indicates lower microbial activity in the soil [14]. The decrease in the alkaline phosphatase activity due to residue burning was supported by the study conducted by Ajwa et al. [15], who found the decrease in alkaline phosphatase activity after burning of the residue. Any direct effects due to physical destruction of the microbial population by burning would lead to decreases in microbial populations after burning in the top soil layer of the soil profile. The effects of residue burning are probably caused by volatile losses of readily available C compounds that are important energy sources for microbial activity which, in turn, could affect the accumulation of soil enzymes.

3.2 Microbial Population

The data pertaining to microbial population is given in Table 4. The bacterial population before burning was higher in no tillage (18.83 X 10^5 cfu /g of soil) than conventional tillage (13.25 X 10^5 cfu /g of soil). Post-burning there was a decline in bacterial population in both no tillage (9.08 X 10^5 cfu /g of soil) and conventional tillage system (7.17 X 10^5 cfu /g of soil). The fungal population before burning was higher in no tillage (13.33 X 10^3 cfu /g of soil) than conventional tillage (10.08 X 10^3 cfu /g of soil). Post-burning there was a decline in fungal population in both no tillage (10.83 X 10^3 cfu /g of soil) and conventional tillage system (8 X 10^3 cfu /g of soil). Actinomycetes population before burning was higher in no tillage (20.08 X 10^4 cfu /g of soil) than conventional tillage (13.25 X 10^4 cfu /g of soil). Post-burning there was a decline in actinomycetes population in both no tillage (13.50 X 10^4 cfu /g of soil) and conventional tillage system (9.08 X 10^4 cfu /g of soil). The population of bacteria, fungi and actinomycetes declined after burning. As the t stat values are greater than t critical values for microbial population, it can be noted that there was significant impact of stubble burning on soil microbial population. Further there was decrease in the microbial population post burning of the residue, which was indicated by right tail t test. The eta square statistic was > 0.7 for bacterial

population in both the tillage systems and actinomycetes population in conventional tillage, which indicated a large effect size of stubble burning on population of these organisms. The eta square statistic was > 0.6 for fungal population in both tillage systems and actinomycetes population in no tillage, which indicated a moderate effect size of stubble burning on population of these organisms.

The reduction in microbial population may be due to the generation of heat due to burning crop residues resulting in higher temperature; this may have deleterious effects on microbial survival. Similar results were recorded by Kumar et al. [16]. Helgason et al. [17] reported that conservation tillage practices increase bacterial and fungal population in the soil.

Table 3. Comparison of Soil enzyme activities from pre and post burning of crop residue from both tillage systems

Soil enzyme activity	NT		CT	
	Pre- burning	Post-burning (48 hrs after burning)	Pre-burning	Post-burning (48 hrs after burning)
Dehydrogenase				
Dehydrogenase (µg TPF g^{-1} soil day^{-1}) - Mean	61.94	35.14	53.31	29.83
Stdev	4.02	3.58	5.13	3.08
SEm	1.64	1.46	2.10	1.26
t stat (5)		10.020		14.434
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.93		0.97
Acid Phosphatase				
Acid Phosphatase (µg PNP g^{-1} soil hr^{-1}) Mean	91.31	48.83	78.74	28.97
Stdev	6.92	5.30	10.38	6.67
SEm	2.83	2.16	4.24	2.72
t stat (5)		17.022		7.558
t critical (one tailed (lower/right tail))		2.015		2.015
Eta square		0.98		0.89
Alkaline phosphatase				
Alkaline phosphatase (µg PNP g^{-1} soil hr^{-1}) Mean	106.90	47.82	94.95	41.18
Stdev	4.59	7.10	6.52	5.17
SEm	1.87	2.90	2.66	2.11
t stat (5)		19.146		16.813
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.98		0.98
Urease				
Urease (µg NH_4^+N g^{-1} soil $2hr^{-1}$) Mean	49.04	20.59	40.72	16.44
Stdev	8.20	5.37	6.01	4.92
SEm	3.35	2.19	2.45	2.01
t stat (5)		6.644		9.343
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.86		0.93

Table 4. Comparison of soil microbial population from pre and post burning of crop residue from both tillage systems

Soil Microbial population	NT		CT	
	Pre-burning	Post-burning (48 hrs after burning)	Pre-burning	Post-burning (48 hrs after burning)
	Bacteria			
Bacteria (10^5 cfu /g of soil) Mean	18.83	9.08	13.25	7.17
Stdev	1.21	1.86	1.08	0.93
SEm	0.49	0.76	0.44	0.38
t stat (5)		27.129		12.864
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.99		0.96
	Actinomycetes			
Actinomycetes (10^4 cfu /g of soil) Mean	20.08	13.50	13.25	9.08
Stdev	2.65	1.87	1.54	1.07
SEm	1.08	0.76	0.63	0.44
t stat (5)		3.929		4.829
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.69		0.77
	Fungi			
Fungi (10^3 cfu /g of soil) Mean	13.33	10.83	10.08	8.00
Stdev	1.72	1.03	1.74	1.30
SEm	0.70	0.42	0.71	0.53
t stat (5)		2.565		4.110
t critical (one tailed (lower/right tail)		2.015		2.015
Eta square		0.48		0.71

Table 5. Comparison of GHG emissions from pre and post burning of crop residue from both tillage systems

GHG emissions	NT		CT	
	Pre-burning	Post-burning (48 hrs after burning)	Pre-burning	Post-burning (48 hrs after burning)
	CO_2			
CO_2 Emissions (µg C/g of soil/ hr) Mean	0.26	33.55	0.44	49.35
Stdev	0.15	1.96	0.09	2.18
SEm	0.06	0.80	0.04	0.89
t stat (5)		-44.866	-54.537	
t critical (one tailed (Upper/left tail)		2.015	2.015	
Eta square		1.00	1.00	
	N_2O			
N_2O Emissions (µg N/g of soil/ hr) Mean	14.79	38.71	11.56	38.17
Stdev	0.96	1.45	1.09	1.01
SEm	0.39	0.59	0.45	0.41
t stat (5)		-55.293	-44.963	
t critical (one tailed (Upper/left tail)		2.015	2.015	
Eta square		1.00	1.00	
	CH_4			
CH_4 Emissions (µg C/g of soil/ hr) Mean	16.87	41.58	25.81	40.71

GHG emissions	NT		CT	
	Pre-burning	Post-burning (48 hrs after burning)	Pre-burning	Post-burning (48 hrs after burning)
Stdev	1.03	1.01	0.83	1.51
SEm	0.42	0.41	0.34	0.62
t stat (5)		-58.341	-32.961	
t critical (one tailed (Upper/left tail)		2.015	2.015	
Eta square		1.00	0.99	

3.3 GHG Emissions

The data related to GHG emissions is presented in Table 5. Before residue burning, the CO_2 emissions in CT (0.44 µg C/g of soil/ hr) were higher than NT (0.26 µg C/g of soil/ hr). Post-burning resulted in release of greater amounts of CO_2 in both the tillage systems *i.e*., NT (33.55 µg C/g of soil/ hr) and CT (49.35 µg C/g of soil/ hr). Methane emissions (µg C/g of soil/ hr) in NT and CT prior to burning of the residue was 16.87 µg C/g of soil/ hr and 25.81 µg C/g of soil/ hr respectively. After burning of the residue, there was increase in methane emissions in NT (41.58 µg C/g of soil/ hr) and CT (40.71 µg C/g of soil/ hr). N_2O emissions (µg N/g of soil/ hr) in NT and CT before burning of residue was 14.79 and 11.56 respectively. There was a rise in N_2O emissions post residue burning in both NT and CT which was 38.71 µg N/g of soil/ hr and 38.17 respectively µg N/g of soil/ hr. As the t stat values are greater than t critical values for GHG emissions, it can be noted that there was significant impact of stubble burning on GHG emissions. The t stat value was negative for all the three gases which indicates that mean values of gases pre-burning of the stubble were less than post-burning. Further there was increase in the GHG emissions post burning of the residue, which was indicated by left tail t test. The eta square statistic was > 0.7 for all the three gas emissions in both the tillage systems, which indicated a large effect size of stubble burning on GHG emissions.

There was an increase in CO_2, CH_4 and N_2O emissions after burning and these results were in accordance with the results obtained by [18] who found that open field rice residue burning leads to 5.34 ± 2.33 megaton (Mt) of CO_2 release 44 ± 14 kiloton (kt) of CH_4 and 2 ± 2 kt of NO_X release into the atmosphere. Methane is produced during biomass burning in field due to incomplete combustion. The results are in agreement with [19] who reported that open field burning of rice straw and other crop residues emits species such as CO_2, nitrous oxide (N_2O), CH_4, CO, non-methane hydrocarbons (NMHC), NOx, SO_2, particulate matter (PM) and few others species. As huge piles of dried crop residues start burning in the field at a time there is scarcity of oxygen supply during the process because the rate of burning is much faster than that of supply of oxygen to the residue heap from the surrounding. As a result, there is a deficiency of oxygen, which triggers an incomplete combustion of residues resulting in the methane production and subsequent emission [19]. Carbon dioxide may be produced due to complete combustion of the crop residues. It is assumed that the N contained in crop residues is to stimulate N_2O emissions [20].

4. CONCLUSION

In situ crop residue burning significantly affects soil biological properties. Crop residue burning has negative impact on the soil environment in short term as well as long term. The short term effects were discussed in the above paper. Crop residue burning leads to decrease in the enzyme activities and soil microbial population. The crop residue burning generates lots of heat because of which soil temperature rises and creates unfavourable conditions for the microbes to survive. It also increases GHG emissions, which is harmful to the environment. So, we conclude that as crop residue burning is harmful to environment and soil health, this practice has to be discouraged and alternate options of residue management like spraying of decomposers consortium on the crop stubbles or incorporation of crop residues must be practiced.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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