International Journal of Plant & Soil Science

Volume 37, Issue 9, Page 641-648, 2025; Article no.IJPSS.143903
ISSN: 2320-7035

Effects of Long-Term Sugarcane Trash Management Practices on Soil Enzyme Activities in Maharashtra, India

A. M. Memane [a++*], V. N. Ghorpade [a#], D. H. Phalke [a†], A. B. Gosavi [a†], S. U. Deshmukh [a‡], P. B. Jagtap [a#] and A. D. Mandake [a^]

[a] Division of Soil Science, College of Agriculture, Pune (MS), Mahatma Phule Krishi Vidyapeeth, Rahuri, India.

Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i95741

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/143903

Original Research Article

Received: 04/07/2025
Published: 16/09/2025

ABSTRACT

This study aimed to evaluate the "Effects of Long-Term Sugarcane Trash Management Practices on Soil Enzyme Activities in Maharashtra" was conducted during 2023-2025 at Post Graduate laboratory, College of Agriculture, Pune. The study focused on dominant sugarcane growing districts in Maharashtra state, under different sugar recovery zones *viz.,* high, medium and low. Furthermore, a correlation analysis was performed to examine the relationships between soil

[++] *M.Sc. (Agri) Student;*
[#] *Assistant Professor of Soil Science;*
[†] *Associate Professor of Soil Science;*
[‡] *Senior Research Assistant;*
[^] *Assistant Professor of Chemistry;*
**Corresponding author: E-mail: memaneaishwarya2@gmail.com;*

Cite as: *A. M. Memane, V. N. Ghorpade, D. H. Phalke, A. B. Gosavi, S. U. Deshmukh, P. B. Jagtap, and A. D. Mandake. 2025. "Effects of Long-Term Sugarcane Trash Management Practices on Soil Enzyme Activities in Maharashtra, India". International Journal of Plant & Soil Science 37 (9):641–648. https://doi.org/10.9734/ijpss/2025/v37i95741.*

biological properties, ratoon sugarcane yield and commercial cane sugar content. An additional t-test was also employed to compare the mean scores of enzyme activities *viz.,* dehydrogenase, urease, acid phosphatase, alkaline phosphatase and β-glucosidase between the sugarcane trash management and trash burning practices, providing insights into the effects of these practices on ratoon cane yield and commercial cane sugar (CCS%) in ratoon sugarcane across different sugar recovery zones of Maharashtra. However, trash management (trash and mulching) leads to higher enzyme activities *viz.,* dehydrogenase, urease, acid phosphatase, alkaline phosphatase and β-glucosidase, higher ratoon sugarcane yield and commercial cane sugar (CCS%) as compared to trash burning practices.

Keywords: Sugarcane; trash management; dehydrogenase; urease; acid and alkaline phosphatase; β-glucosidase.

1. INTRODUCTION

Sugarcane is a vital global cash crop and in India, its industry plays a key role in rural development by generating employment and boosting farm income. Mechanized harvesting produces sugarcane trash, which can be converted into organic compost on-site to enhance soil properties. To improve cane productivity, soil health and resource efficiency, Mahatma Phule Krishi Vidyapeeth, Rahuri, introduced climate-resilient ratoon management technology involving zero tillage, trash mulching, integrated nutrient management and fertigation via crow bar. Soil enzymes, secreted by microbes serve as sensitive indicators of land management and aid in organic matter decomposition. Beneficial microbes and their enzymes accelerate the breakdown of sugarcane waste, promoting sustainable agriculture.

A class of enzymes present in soil plays a vital role in maintaining its ecological balance, physical and chemical properties, fertility and overall health. Enzymes are proteins that function as biological catalysts in living things (Alef and Nannipieri, 1995; Onal, 2010). In the degradation of organic matter, soil enzymes perform crucial biochemical roles (Burns, 1983; Sinsabaugh et al*.,* 1991). These enzymes contributes to the biochemical breakdown of organic matter in soil system as a whole. Furthermore, these enzymes catalyses the reaction required for the degradation of organic wastes, stabilization of soil structure, nutrient cycling and essential functions of soil microbes (Kocak, 2020). By reducing the activation energy levels of various reactions, enzymes are molecules that accelerate them.

Soil enzymes are a functional factor that is directly tied to microorganisms and can be used to measure the health of soil. Dehydrogenase, β-glucosidase and phosphatase activities are strongly related to nutrient dynamics of soil (Tabatabai 1982, Bandick & Dick, 1999). Soil dehydrogenase is one of the enzymes that directly measures soil microbial activity, revealing the microbial processes occurring in the soil (Kaur and Kaur, 2021). An essential enzyme that is vital to the fertility and health of soil is urease. Its primary function is the breakdown of urea into ammonium and it can be found in both living things and soil organic matter. The term "phosphatase" refers to a large class of enzymes that hydrolyses organic phosphorus molecules into inorganic polyphosphates found in soils. This process is crucial for P cycling in phosphorus-deficient soils. Both acid and alkaline phosphatase were assessed, depending on the soil's pH ranges (pH 4-6 and 9-11). Alkaline phosphatase activity occurs in neutral or alkaline soils, while acid phosphatase activity is primarily seen in acidic soils. The β-glucosidase enzyme is involved in the carbon cycle and cleaves cellobiose into glucose molecules.

2. MATERIALS AND METHODS

The experimental field survey was conducted during January, 2023 to April, 2025. The experiment was conducted in major 16 sugarcane growing districts from the three sugar recovery zones *viz*., high, medium and low sugar recovery zones from Western Maharashtra, North Maharashtra and Marathwada region were selected for the study. From each district 22 farmers were selected among them 11 farmers were following continuous *in situ* sugarcane trash management system and 11 farmers were following sugarcane trash burning system. They were following these systems since from last ten years. Thus, total 180 farmers were selected and required data was collected by survey method during the year 2023-24 through well-structured schedule. The soil samples were collected from

the depth at 0 to 30 cm where the active root zone of sugarcane exist (Smith et al., 2005) for the analysis of biological properties of soil and stored at 4^0C temperature (Dadenko et al., 2009). The soil biological properties were analysed from collected soil samples from different recovery zones of Maharashtra and were utilized for establishing correlation coefficient ('r' values) among different ratoon sugarcane yield and CCS%. The dehydrogenase enzyme assay was carried out according to the method described by Casida et al. (1964), urease enzyme assay was carried out according to the method described by Tabatabai and Bremmner (1972), acid and alkaline phosphatase enzyme was measured by using the method developed by Eivazi and Tabatabai (1977) and assay of β-glucosidase enzyme was carried out by the method described by Eivazi and Tabatabai (1988) with little modification. The t test was used for statistical analysis of data (Panse and Sukhatme,1985).

3. RESULTS AND DISCUSSION

The data regarding the influence of sugarcane trash management practices on dehydrogenase activities after harvest of sugarcane ratoon are reported in Table 1. This study showed that among the three sugar recovery zones, the dehydrogenase activities in the high recovery zone ranged from (81-89 µg TPF g^{-1} soil 24 hr^{-1}) was significantly higher in trash management practices than medium recovery zone (73-81 µg TPF g^{-1} soil 24 hr^{-1}) and low recovery zone (65-73 µg TPF g^{-1} soil 24 hr^{-1}). In case of trash burning practices also the dehydrogenase activities in the high recovery zone ranged from (58-64 µg TPF g^{-1} soil 24 hr^{-1}) was significantly higher than medium recovery zone (50-57 µg TPF g^{-1} soil 24 hr^{-1}) and low recovery zone (42-49 µg TPF g^{-1} soil 24 hr^{-1}). Phalke et al. (2016) also observed similar findings in respect of dehydrogenase activities in sugarcane trash management practices.

From above investigation, it was observed that the dehydrogenase activities in all sugar recovery zones were significantly higher in trash management practices than trash burning practices. High recovery zone has higher dehydrogenase activities due to environmental factors *viz.,* soil aeration and moisture content and there might be impact of addition of organic carbon through organic matter like sugarcane trash. The *in situ* recycling of sugarcane trash along with its industrial waste significantly increased the soil dehydrogenase activity reported by Pacharane et al. (2021).

The data on the influence of sugarcane trash management practices on urease activities after harvest of sugarcane ratoon are reported in Table 2. The perusal of data revealed that the urease activities of soil was significantly increased due to sugarcane trash management practices. This study showed that among the three sugar recovery zones, the urease activities in the high recovery zone ranged from (11-12 µg NH_4^+-N g^{-1} day^{-1}) was significantly higher in trash management practices than medium recovery zone (10-11 µg NH_4^+-N g^{-1} day^{-1}) and low recovery zone (9-10 µg NH_4^+-N g^{-1} day^{-1}). In case of trash burning practices also the urease activities in the high recovery zone ranged from (7-8 µg NH_4^+-N g^{-1} day^{-1}) was significantly higher than medium recovery zone (6-7 µg NH_4^+-N g^{-1} day^{-1}) and low recovery zone (5-6 µg NH_4^+-N g^{-1} day^{-1}). Phalke et al. (2016) also observed similar findings in respect of urease activities in sugarcane trash management practices.

Table 1. Influence of sugarcane trash management practices on dehydrogenase activities after harvest of ratoon sugarcane

Dehydrogenase activities (µg TPF g^{-1} soil 24 hr^{-1})						
	High recovery zone		Medium recovery zone		Low recovery zone	
	Trash management	Trash burning	Trash management	Trash burning	Trash management	Trash burning
Mean	84.73	60.67	77.89	53.73	69.16	46.11
Range	81-89	58-64	73-81	50-57	65-73	42-49
Variance	4.77	3.28	4.49	3.91	8.96	3.80
t_{cal}	46.45**		45.64**		35.33**	
t_{tab} (@ 5%)	2.00		2.00		2.00	
t_{tab} (@ 1%)	2.39		2.39		2.39	
P value	0.00		0.00		0.00	
Result	Sign.		Sign.		Sign.	

Table 2. Influence of sugarcane trash management practices on urease activities after harvest of ratoon sugarcane

Urease activities (µg NH_4^+-N g^{-1} day^{-1})						
	High recovery zone		Medium recovery zone		Low recovery zone	
	Trash management	Trash burning	Trash management	Trash burning	Trash management	Trash burning
Mean	11.78	7.47	10.51	6.71	9.68	5.58
Range	11-12	7-8	10-11	6-7	9-10	5-6
Variance	0.01	0.06	0.06	0.05	0.05	0.10
t_{cal}	86.07**		62.68**		58.61**	
t_{tab} (@ 5%)	2.00		2.00		2.00	
t_{tab} (@ 1%)	2.39		2.39		2.39	
P value	0.00		0.00		0.02	
Result	Sign.		Sign.		Sign.	

Table 3. Influence of sugarcane trash management practices on acid phosphatase activities after harvest of ratoon sugarcane

Acid phosphatase activities (µg PNP g^{-1} 2 hr^{-1})						
	High recovery zone		Medium recovery zone		Low recovery zone	
	Trash management	Trash burning	Trash management	Trash burning	Trash management	Trash burning
Mean	423.33	299.6	379.53	258.8	340.7	223.9
Range	400-440	280-320	360-400	240-280	320-360	200-240
Variance	90.39	138.66	128.05	118.09	150.90	107.54
t_{cal}	44.74**		42.14**		39.79**	
t_{tab} (@ 5%)	2.00		2.00		2.00	
t_{tab} (@ 1%)	2.39		2.39		2.39	
P value	0.00		0.00		0.00	
Result	Sign.		Sign.		Sign.	

From above investigation, it was observed that the urease activities in all sugar recovery zones were significantly higher in trash management practices than trash burning practices. High recovery zone has higher urease activity due to environmental factors *viz.,* rainfall, temperature and increased from 20 to 70°C and with further increase in temperature, the activity decreased rapidly (Kumari et al., 2017). The positive relationship between urease activity and temperature. When soil temperature was high, organic matter decomposed easily in soil and using organic fertilizers like compost, straw mulch and sewage sludge increases the activity of urease (Kang and Andreas, 2022). The results showed that higher enzymatic activity of urease in dry straw and its relationship with the greater amount of SOC and CO_2, agrees with the results reported by Beri et al. (1978) for sugarcane straw.

The data regarding the influence of sugarcane trash management practices on acid phosphatase activities after harvest of sugarcane ratoon are reported in Table.3. This study showed that among the three sugar recovery zones, the acid phosphatase activities in the high recovery zone ranged from (400-440 µg PNP g^{-1} 2 hr^{-1}) was significantly higher in trash management practices than medium recovery zone (360-400 µg PNP g^{-1} 2 hr^{-1}) and low recovery zone (320-360 µg PNP g^{-1} 2 hr^{-1}). In case of trash burning practices also the acid phosphatase activities in the high recovery zone ranged from (280-320 µg PNP g^{-1} 2 hr^{-1}) was significantly higher than medium recovery zone (240-280 µg PNP g^{-1} 2 hr^{-1}) and low recovery zone (200-240 µg PNP g^{-1} 2 hr^{-1}). Chang et al. (2007) also observed similar findings in respect of acid phosphatase activities in sugarcane trash management practices.

Further, it was observed that the acid phosphatase activities in all sugar recovery zones are significantly higher in trash management practices than trash burning practices. High recovery zone has higher acid

phosphatase activity due to environmental factors *viz.,* temperature, moisture content and acid phosphatase activity of soils increased with temperature from 20°C to 70°C and decreased constantly with further increase in temperature to 90°C (Rao, 1989). On the other hand, the micro-climate aspect has a positive effect on the biological properties, which is due to the positive effect of the available moisture, which increases the microbial activity of the soil and leads to an increase in the production of phosphatase in the soil. Juma and Tabatabai (1978) also showed that phosphatase activity was related to soil organic matter, organic P, inorganic P and N availability in soil.

The data on the influence of sugarcane trash management practices on alkaline phosphatase activities after harvest of sugarcane ratoon was reported in Table 4. The perusal of data revealed that the alkaline phosphatase activities of soil was significantly increased due to sugarcane trash management practices. This study showed that among the three sugar recovery zones, the alkaline phosphatase activities in the high recovery zone ranged from (700-760 µg PNP g^{-1} 2 hr^{-1}) was higher in trash management practices than medium recovery zone (640-700 µg PNP g^{-1} 2 hr^{-1}) and low recovery zone (580-640 µg PNP g^{-1} 2 hr^{-1}). In case of trash burning practices also the alkaline phosphatase activities in the high recovery zone ranged from (520-580 µg PNP g^{-1} 2 hr^{-1}) was significantly higher than medium recovery zone (460-520 µg PNP g^{-1} 2 hr^{-1}) and low recovery zone (400-460 µg PNP g^{-1} 2 hr^{-1}). Chang et al. (2007) also observed similar findings in respect of alkaline phosphatase activities in sugarcane trash management practices.

From above investigation, it was observed that the alkaline phosphatase activities in all sugar recovery zones were significantly higher in trash management practices than trash burning practices. High recovery zone has higher alkaline phosphatase activity due to environmental factors like temperature. Kumari et al. (2017) reported that alkaline phosphatases activity of soils increased with increase in temperature from 20-70°C and then activity decreased slowly till 90°C and rapidly decreased with further increase in temperature to 90°C. As soil enzymes are the main drivers of soil organic matter (SOM), degradation and litter decomposition, the dependence of these enzymes on global changes including warming, precipitation, drought and associated soil moisture will assist in understanding the relationships among SOM stock, carbon cycle and microbial nutrient demand. Increase in soil moisture increases the phosphatase activity; however, alkaline phosphatase activity was better correlated with soil water content. Highest activity was found during the winter and monsoon season (Kumar et al*.,* 2015).

The data revealed that the influence of sugarcane trash management practices on soil β-glucosidase activities after harvest of sugarcane ratoon are reported in Table 5. The perusal of data revealed that the β-glucosidase activities of soil was significantly increased due to sugarcane trash management practices. This study showed that among the three sugar recovery zones, the β-glucosidase activities in the high recovery zone ranged from (17-18 µg PNP g-1 day-1) was significantly higher in trash management practices than medium recovery zone (16-17 µg PNP g^{-1} day^{-1}) and low recovery zone (15-16 µg PNP g-1 day-1).

Table 4. Influence of sugarcane trash management practices on alkaline phosphatase activities after harvest of ratoon sugarcane

Alkaline phosphatase activities (µg PNP g^{-1} 2 hr^{-1})						
	High recovery zone		Medium recovery zone		Low recovery zone	
	Trash management	Trash burning	Trash management	Trash burning	Trash management	Trash burning
Mean	733.2	554	665.7	488.53	610.2	434.93
Range	700-760	520-580	640-700	460-520	580-640	400-460
Variance	238.23	254.48	276.01	298.53	340.79	207.44
t_{cal}	44.22**		40.48**		40.10**	
t_{tab} (@ 5%)	2.00		2.00		2.00	
t_{tab} (@ 1%)	2.39		2.39		2.39	
P value	0.00		0.00		0.00	
Result	Sign.		Sign.		Sign.	

Table 5. Influence of sugarcane trash management practices on β-glucosidase activities after harvest of ratoon sugarcane

	β-glucosidase activities (µg PNP g^{-1} day^{-1})					
	High recovery zone		Medium recovery zone		Low recovery zone	
	Trash management	Trash burning	Trash management	Trash burning	Trash management	Trash burning
Mean	17.63	13.64	16.61	12.70	15.64	11.61
Range	17-18	13-14	16-17	12-13	15-16	11-12
Variance	0.06	0.07	0.05	0.04	0.05	0.06
t_{cal}	59.99**		69.53**		65.47**	
t_{tab} (@ 5%)	2.00		2.00		2.00	
t_{tab} (@ 1%)	2.39		2.39		2.39	
P value	0.00		0.00		0.00	
Result	Sign.		Sign.		Sign.	

In case of trash burning practices also the β-glucosidase activities in the high recovery zone ranged from (13-14 µg PNP g^{-1} day^{-1}) was significantly higher than medium recovery zone (12-13 µg PNP g^{-1} day^{-1}) and low recovery zone (11-12 µg PNP g^{-1} day^{-1}). Phalke et al. (2016) also observed similar findings in respect of β-glucosidase activities in sugarcane trash management practices.

The β-glucosidase activities in all sugar recovery zones were significantly higher in trash management practices than trash burning practices. This might be due to impact of addition of organic carbon through organic matter like sugarcane trash. The β-glucosidase enzymes are considered soil quality indicators and are widely distributed in nature and associated with the carbon cycle (C), demonstrating sensitivity to soil management and different soil types. Deng and Tabatabai (1996, 1997) reported that the activities of glucosidase were highly correlated with soil organic C content and suggested that organic matter plays an important role in protecting soil enzymes.

4. CONCLUSION

- All enzyme activities including dehydrogenase, urease, acid phosphatase, alkaline phosphatase and β-glucosidase were significantly higher in trash management practices over trash burning practices of sugarcane ratoon.
- High recovery zone showed higher enzyme activities *viz.,* dehydrogenase, urease, acid phosphatase, alkaline phosphatase and β-glucosidase in comparison with medium and low recovery zones in trash management as well as trash burning practices of sugarcane ratoon.
- These findings confirmed the importance of trash management in sugarcane for better improvement in soil health, sugarcane yield and sugar recovery of sugarcane growing areas of Maharashtra and a viable option from the farmer's perspective.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Alef, K., & Nannipieri, P. (1995). Enzyme activities. In K. Alef & P. Nannipieri (Eds.), *Methods in applied soil microbiology and biochemistry* (pp. 311–373). London: Academic Press.

Bandick, A. K., & Dick, R. P. (1999). Field management effects on soil enzyme

activities. *Soil Biology and Biochemistry, 31*(11), 1471–1479.

Beri, V., Goswami, K. P., & Brar, S. A. (1978). Urease activity and its Michhaelis constant for soil systems. *Plant and Soil, 49*(1), 105–115.

Burns, R. G. (1983). Extracellular enzyme-substrate interactions in soil. In J. H. Slater, R. Wittenbury, & J. W. T. Wimpenny (Eds.), *Microbes in their natural environments* (pp. 249–298). London: Cambridge University Press.

Casida, L. E., Klein, D. A., & Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science, 98*(6), 371–376.

Chang, E., Chung, R., & Tsai, Y. (2007). Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. *Soil Science and Plant Nutrition, 53*(2), 132–140.

Dadenko, E. V., Kazeev, K. S., Kolesnikov, S. I., & Valkov, V. F. (2009). Changes in the enzymatic activity of soil samples upon their storage. *Eurasian Soil Science, 42*(12), 1380–1385.

Deng, S. P., & Tabatabai, M. A. (1996). Effect of tillage and residue management on enzyme activities in soils: II. Glycosidase. *Biology and Fertility of Soils, 22*(2), 208–213.

Deng, S. P., & Tabatabai, M. A. (1997). Effect of tillage and residue management on enzyme activities in soils: III. Phosphatases and arylsulfatase. *Biology and Fertility of Soils, 24*(2), 141–146.

Eivazi, F., & Tabatabai, M. A. (1977). Phosphatase in soil. *Soil Biology and Biochemistry, 9*(3), 167–172.

Eivazi, F., & Tabatabai, M. A. (1988). Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry, 20*(5), 601–606.

Juma, N. G., & Tabatabai, M. A. (1978). Distribution of phosphomonoesterases in soils. *Soil Science, 126*(2), 101–108.

Kang, N., & Andreas, S. P. (2022). Soil moisture and temperature effects on granule dissolution and urease activity of urea with and without inhibitors—An incubation study. *Agriculture, 117*, 2037.

Kaur, J., & Kaur, G. (2021). Dehydrogenase activity as a biological indicator of soil health. *Chemical Science Review and Letters, 10*, 326–329.

Kocak, B. (2020). Importance of urease activity in soil. *Cukurova University, Faculty of Arts and Sciences, Department of Biology.*

Kumar, S., Chaudhuri, S., & Maiti, S. K. (2015). Soil phosphatase activity in natural and mined soil – A review. *Indian Journal of Environmental Protection.*

Kumari, J. A., Rao, P. C., Padmasri, A., & Kumar, B. A. (2017). Effect of temperature on soil enzyme alkaline phosphatase. *Bulletin of Environment, Pharmacology and Life Sciences, 6*(3), 282–286.

Onal, S. (2010). Enzimler. In A. Yildirim, F. Bardakci, M. Karatas, & B. Tanyolaç (Eds.), *Molekuler Biyoloji* (pp. 249–296). Ankara, Türkiye: Nobel Yayin Dagitim.

Pacharane, S., Patil, S., Durgude, S. A., Ram, S., & Yadav, K. (2021). Effect of long-term *in situ* recycling of sugarcane trash and industrial waste on soil health under sugarcane land use system in an Inceptisol. *International Journal of Current Microbiology and Applied Sciences, 10*(3).

Panse, V. G., & Sukhatme, P. V. (1985). *Statistical methods for agriculture workers* (pp. 1–347). Indian Council of Agricultural Research, New Delhi.

Phalke, D. H., Patil, S. R., Pharande, A. L., Manna, M. C., Sahu, A., & Kaur, S. (2016). Effect of *in situ* recycling of sugarcane crop residues on soil enzyme activities under soybean–maize system. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 86*, 299–307.

Rao, S. V. (1989). *Distribution, kinetics and some interactions of urease and phosphatases in soils* (Ph.D. thesis). Acharya N. G. Ranga Agricultural University, Hyderabad.

Sinsabaugh, R. L., Antibus, R. K., & Linkins, A. E. (1991). An enzymic approach to the analysis of microbial activity during plant litter decomposition. *Agriculture, Ecosystems and Environment, 34*, 43–54.

Smith, D. M., Bamber, N. G. I., & Thorburn, P. J. (2005). Growth and function of the sugarcane root system. *Field Crops Research, 92*, 169–183.

Tabatabai, M. A., & Bremner, J. M. (1972). Assay of urease activity in soils. *Soil Biology and Biochemistry, 4*, 479–487.

Tabatabai, M. A. (1982) Soil enzyme. *Soil health and sustainable agriculture in Brazil* 43.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/143903