In-Situ Rice residue management practicesand its impact on climate, Soil fertility and crop productivity -A review

ABSTRACT

The rice wheat is the most production system in Indo-Gangetic Plains (IGP) of India contributes about two-third of the total food production of the country. Rice maximum area covered with 32 percent of total crop area followed by Wheat about 23 percent in India. Rice residues are important natural resources, and recycling of these residues effects on soil properties and crop productivity. Rice-wheat sequence with total yield of 10 - 12 t·ha^{-1} removes more than 300 kg N, 30 kg P, and 300 kg K ha^{-1} from the soil. Residue burning causes nutrient loss of 100% C, 90% N, 60% S and 25% each of P and K.and effects of air pollution include respiratory diseases, skin and eye irritation and other ailments On the basis of reported research results by different researchers, an analysis has been made.To avoid residues burning in rice wheat cropping system it needs to review and upgrade the technology with Rice residues as in-situ incorporate with microbial consortia in wheat crop is a good option for their management. Incorporate with microbial consortia increased yield, water productivity and profitability, while decreasing *Phaleris minor* weed. Also improvements in soil quality. Since rice residues contain significant quantities of plant nutrients, their continuous application will have positive effect on fertilizer management and minimize air pollution.

Key words: Rice residue, Productivity,Microbial consortia

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Introduction

The rice wheat is the most production systemin Indo-Gangetic Plains (IGP) of India covering nearly 10.5 million hectares including 4.1 million hectares of the north western states comprising Punjab, Haryana, and western Uttar Pradesh, a highly productive rice-wheat zone of the Indo-Gangetic Plains of India contributes about two-third of the total food production of the country. Rice maximum area covered with 32 percent of total crop area followed by Wheat in India. But a rice-wheat sequence with total yield of 10 - 12 t·ha^{-1} removes more than 300 kg N, 30 kg P, and 300 kg K ha^{-1} from the soil[(12)].

Rice residue is an agricultural waste residues,it important natural resources, and recycling of these residues improves the soil physical, chemical and biological properties. A rice-wheat sequence that yields 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat, removes more than N

300, P 30 and K 300 kg ha^{-1} from the soil; the residues of rice and wheat amount to as much as 7-10 t ha^{-1} yr^{-1}. Asian farmers need to manage 5-7 t ha^{-1} of rice residues, wheat straw is mostly used as dry fodder for animals, whereas, paddy straw (residues) becomes surplus in the fields due to high lignin and silica and low protein content, it is harmful for cattle.

Mostly farmers option to the burning practice as it is easy and swift alternative to clean the fields and ignorance of farmers about their value and lack of proper technology for in situ incorporation of residues. However, this burning practice leads to huge losses of precious organic matter, plant nutrients, creates environmental pollution and also results in fire hazards, etc. Further, this burning practice also reduces the efficacy of herbicides as the ash produced interferes with the applied herbicides particularly root uptake ones, which results in more infestation of weeds and ultimately nutrient mining by weeds. For improving soil health and crop productivity, there is an urgent need for in-situ and ex situ management of rice residues by surface mulching, incorporating, compost and spray of microbial consortia (Pusa decomposer and waste decomposer) it in soil. Rice residues are potential source of crop residues in the field after harvest is one way to stabilize the soil fertility. Farmers and researchers have shown increased interest in crop rotation and management of crop residues as valuable management tools because of increased costs of inorganic fertilizers and reduced yields in monoculture cropping systems. Research studies have shown that the return of crop residues improved the tilth and fertility of soil, crop productivity, reduced the wind and water erosion, and prevented nutrients losses by run-off and leaching.

Generate of Rice residue

The approximate production of crop residue per annum is 500 million tonnes[(2)] which is likely to increase. In India predominant cropping system is rice-wheat system which accounts approximately 25% of the residue production.[(11)] The quantity of residue produced can be analyzed by residue to crop ratio and dry matter portion of residue in crop biomass. The highest crop residue generation was estimated in Uttar Pradesh (60 mt) followed by Punjab (51 mt) and Maharashtra (46 mt). Crop residue generated through different crops can be categorized into cereals, pulses, oil seeds, sugarcane and fiber crops on the basis of crop type. More than half of the residue generated through cereals (59 %) followed by sugarcane (27%) and minimum by fiber crops (3%) surplus residues from the cereal crops, 44 MT is from rice followed by 24.5 MT from wheat.[(28)]Production of rice residue in India 225.48 MT and surplus of rice residue 43.85 MT.[(3)]

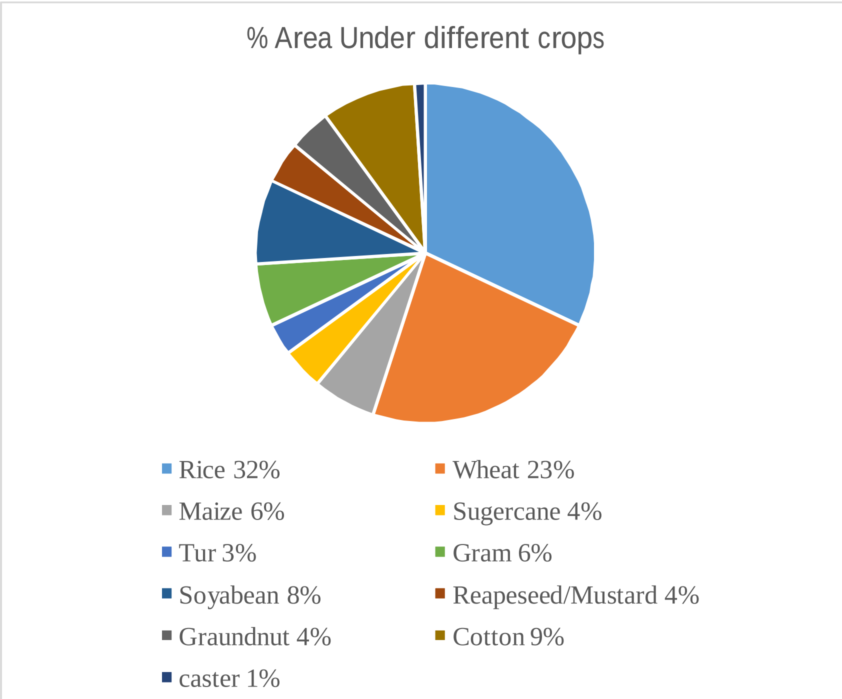

Figure 1: Distribution of total area under selected crops (TIFAC & IARI report 2018)

Table 1: Area, residue production and surplus residue of rice in state of India

S/N	state	Area (000 ha)	Residue production(000 t)	Annual surplus (000 t)
1	Andhra Pradesh	2570.87	16925.74	1340.52
2	Arunachal Pradesh	126.07	356.78	35.32
3	Assam	2523.32	10484.05	1134.64
4	Bihar	3206.94	15035.21	3043.12
5	Chhattisgarh	4169.95	14759.48	1461.19
6	Goa	44.30	248.33	63.92
57	Gujarat	719.95	3156.28	937.41
8	Haryana	1242.66	7733.03	1827.19
9	Himachal Pradesh	74.84	262.43	155.88
10	Jammu & Kashmir	275.86	711.71	70.46
11	Jharkhand	1501.87	7488.94	1482.81
12	Karnataka	1384.03	8315.67	413.00
13	Kerala	201.91	1090.07	92.67
14	Madhya Pradesh	1799.86	5776.53	571.25
15	Maharashtra	1581.83	6200.23	613.79
16	Manipur	195.46	994.58	636.78
17	Meghalaya	40.47	201.64	59.89
18	Mizoram	57.85	122.03	59.70

19	Nagaland	185.44	857.59	84.90
20	Odisha	4115.25	15502.85	1971.68
21	Punjab	2896.47	23067.68	16787.33
22	Rajasthan	140.89	586.46	0.00
23	Sikkim	11.50	42.38	4.20
24	Tamil Nadu	1757.13	12598.97	1247.30
25	Telangana	1710.15	11429.93	905.25
26	Tripura	309.07	1786.33	141.48
27	Uttar Pradesh	5837.43	27701.21	7437.92
28	Uttarakhand	271.17	1240.69	184.24
29	West Bengal	5372.47	30648.82	1085.21
30	**All India**	**44360**	**225487**	**43857.0**

(Anonymous, 2018)

Plant nutrient in Rice residue

Cereal residues are good sources of plant nutrients and the primary source of SOM (as C constitutes about 40% of the total dry biomass), and are important components for the stability of agricultural ecosystems. About 40% of N, 30–35% of P, 80–85% of K, and 40–50% of S absorbed by rice crop remain in the vegetative parts at maturity. Similarly, about 25-30% of N and P, 35-40% of S, and 70-75% of K uptake are retained in wheat residues. Typical amounts of nutrients in rice straw at harvest are 5–8 kg N, 0.7–1.2 kg P, 12–17 kg K, 0.5–1 kg S, 3–4 kg Ca, 1–3 kg Mg, and 40–70 kg Si per ton of straw on a dry weight basis.[19]

Practices of in-situ rice residue management

Rice residue burning

Among cereals, the major portion of residue generated through rice followed by wheat crop. Major share of residue generation is by sugarcane, rice, wheat, maize and some oilseeds, while the share of other agricultural crops is negligible. In-situ burning of this residue varied from state to state in accordance to its usage pattern. In paddy fields, fraction of crop residue subjected to burning ranged between 8 to 80 percent across states and is maximum in Punjab, Haryana and Himachal Pradesh (80%) followed by Karnataka (50%) and Uttar Pradesh (25%).[27]Although it has several advantages, due to lack of awareness, majority of the agricultural community in west U.P., Punjab and Haryana are inclined only to the burning of stubble for the next sowing. The leftover paddy residues in the field offer a serious problem during the sowing of the succeeding crop.

Rice or crop residue burning in the field, farmers derive specific benefits such as cost- and time savings It is also a means to control weeds, diseases, and insect[25]However, the burning of rice straw leads to a seriousimpact on soil chemical properties. In situ residue burning, Rice residues such as straw is the only organic material available in significant quantities to most rice farmers. Burning of rice straw to black carbon prior to the next crop cycle would yield a high increment of macronutrients (P and K) and decrease in undesired arsenic mobilization in rice yields.[42] Practice of rice residues burning as an option of post-harvest management increased the soilpH and nutrient availability for K and Zn. Soil organic matter shows a serious depletion in burned soil.[26]Although burning of rice straw tend to promote the release of Ca, Mg and K, such practice also contributes to the serious reduction towards rice straw organic carbon within organic matter.[8] According to (Sharma and Mishra, 2001),the magnitude of C and nutrient loss during burning is influenced by the quantity of residue burned and the intensity of the fire. Complete burning of rice straw at 470 °C in muffle furnace resulted in 100, 20, 20 and 80% losses of N, P, K and S, respectively.[44].

Many research findings show that long-term burningdecreased the microbial population of the soil permanently,severely declining the bacteria population involved in nitrification.[40], Management of residues of previous crop can also inflict qualitative and quantitative changes in weed flora associated with succeeding crop.[30].Residue burning depletes seed bank by removal of viable seeds. On the other hand, burning isalso reported to stimulate emergence of weed species such as wild oats andsilver grass.[16].

Empact on environment of Burning

Burning results huge losses of N (80%), P (25%), K (21%) and S (4-60%), and air pollution, According to reports, New Delhi, Noida and Ghaziabad recorded a peak Air Quality Index (AQI) of around 480 – 490 in the month of November 2019. Health effects of air pollution include respiratory diseases, skin and eye irritation and other ailments.[53]. Rice residue burning contributes towards emission of greenhouse gases with serious environmental implications.[25]. Nonetheless, residue burning is not a viable option as it leaves high carbon (C) footprints and lowers C sustainability of world's largest cropping system (Singh *et al.*, 2020). Besides GHGs emissions, residue burning causes nutrient loss of 100% C, 90% N, 60% S and 25% each of P and K.[18]. Estimates revealed that burning of one tonne of paddy straw accounts for loss of 5.5 kg Nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg Sulphur besides, organic carbon. Generally crop residues of different crops.[4]

Open burning of crop residue in the field generates gaseous and particulate emissions.[7, 57.]. Such residue burning in the field adversely affects both the Health of population include respiratory diseases, skin and eye irritation and other ailments and air pollution [53,5,34.]Inhalation of fine particulate matter (PM) of less than 2.5 µg triggers asthma and can even aggravate symptoms of bronchial attack.

Rice residue removal

Rice residue removal practice widespread in India, Pakistan, Bangladesh and Nepal.Surplus straw from agriculturemay be used for a number of useful purposes such as livestockfeed, fuel, building materials, livestock bedding, compostingfor mushroom cultivation, bedding for vegetables such ascucumber, melons etc. and mulching for orchards and othercrops or as a raw material in industrial processes (e.g., papermaking). In the process, some or all of the nutrients contained instraw may be lost to the rice field.[(18).]

Table 2: Nutrient content of rice straw and amounts removed with [1]tonne of straw residue

	N	**P_2O_5**	**K_2O**	**S**	**Si**
Content in straw, % dry matter	0.5-0.8	0.16-0.27	1.4-2.0	0.05-0.10	4-7
Removal with 1 tonne straw, kg/ha	5-8	1.6-2.7	0.5-1.0	0.5-1.0	40-70

Source Dobermann and Fairhurst 2002

Rice residue incorporation

Incorporation of straw increase soil organic matter and soil N, PAND K contents. In few studies, succeeding yields were lower during first to three years of rice straw incorporation 30 day prior to wheat planting because of immobilization of soil nitrogen in presence of crop residue with wide range of C:N ratio, but in later years, straw incorporation did not affect succeeding yield.[(3).]According to Yadvinder-Singh *et al.,* 2004, the effect of time of incorporation on rice residue decomposition and N mineralization–immobilization was studied in 1992–1993. The mass loss of residue was 25% for a 10 day, 35% for a 20 day, and 51% for a 40 day decomposition period before wheat planting. Nitrogen release from residue ranged from 6 to 9 kg ha during the wheat season. The immobilization of urea N decreased when residue was allowed to decompose for 10 day or longer. The long-term application of rice residue increased C accumulation in soil.

The major disadvantage of incorporation of cereal straw isthe immobilization of inorganic N and its adverse effect due to N-deficiency. Incorporation of rice straw into the soil after itsharvest leads to slow down the decomposition and soil nitrateis immobilized, reducing the N uptake and yield of subsequentwheat crops by about 40%17,18. Due to straw incorporation [(35).]

The straw incorporation significantly increased the wheat yield by an average of 58% compared with straw removal. Soil available nitrogen, phosphorus, and potassium in the 0–20 cm soil layer increased by more than 15% withstraw incorporation compared to straw removal. The soil cation exchange capacity and organic carbon in the 0–20 cm soil layer increased by 8% and 22%, for straw incorporation compared to straw removal, respectively. Straw incorporation significantly elevated the soil saturated water content but decreased the soil bulk density compared with straw removal. Soil aggregates >2 mm, Straw incorporation also notably increased the soil urease, invertase, and catalase activities in the 0–15 cm soil layer by 11.4%, 41.0%, and 12.9%, respectively, and the soil microbial carbon and nitrogen contents in the 0–20 cm soil layer by 59% and 54%. Therefore, full straw incorporation could significantly improve soil fertility and maintain crop yields[(58).]

Lowland rice is a significant source of anthropogenic greenhouse gas emissions (GHGEs) and the primary source of agricultural emissions for many developing countries in Asia. At the same time, rice soils represent one of the largest global soil organic carbon sinks. From anaerobic decomposition.[(1).]However, straw application significantly increased methane (CH_4) emission during rice cultivation from anaerobic decomposition.[(52).]

The retention and incorporation of residue has been reported to increase water-stable aggregates by 15.65% and 7.53% in the 0–15 and 15–30 cm soil layers, respectively. Rice straw mulch increased wheat grain yield, reduced crop water use by 3-11% and improved WUE by 25% compared with no mulch.

According to Dotaniya, 2013.Evaluate that effects of three crop residue management practices (crop residue incorporation, residue burning and residue removal) on nutrient uptake and yield of rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L. emend. Fiori and Paol.) System was studied at Pantnagar, Uttarakhand. Incorporation of crop residue resulted in higher uptake of nitrogen (123.6 kg ha^{-1}) and potassium (179.5 kg ha^{-1}) in rice crop over the other treatments. In case of wheat, N and K uptakes were 11.7% and 7.9% higher with the incorporation of residue than with residue removal. But the response was at par with the burning of residues in both crops, similarly result found more yield and nutrient uptake by the both crop of rice and wheat[(35,32)].

Table 3: Effect of crop residue management practices, nitrogen and potassium levels on yield and nutrient uptake in rice-wheat cropping system

Treatment	**Grain yield ($t\ ha^{-1}$)**		**Nutrient uptake (kg ha-1)**					
			Rice			**Wheat**		
	Rice	**Wheat**	**N**	**P**	**K**	**N**	**P**	**K**

Crop residue removed	6.29	4.26	113.1	21.2	164.2	112.4	19.0	91.7
Crop residue burnt	6.41	6.20	117.6	22.4	175.6	122.8	21.1	97.2
Crop residue incorporated	6.56	6.35	123.6	24.5	179.5	127.3	23.0	99.6
SEm±	0.06	0.07	3.1	0.5	4.4	3.4	0.3	1.9
CD (P=0.05)	0.19	0.21	9.6	1.6	13.8	10.8	0.9	5.8

Source **Dotaniya, 2013**

Rice residue as a surface mulch

Residue retention on the surface of soil seems to be a better option for conservation of soil and avoiding water losses by evaporation. It also reduces the weed seed germination and helps in building of soil microbial populations results in increasing soil organic carbon- a direct indicator of soil health. New advance generation seed drill is evolved for this purpose.[(45)],reported that, the Happy Seeder will lead to wider adoption of conservation agriculture. The Happy seeder works well for direct drilling in standing as well as loose residues provided the residues are spread uniformly. The rice straw mulch increased wheat grain yield, reduced crop water use by 3-11% and improved WUE by 25% compared with no mulch. Mulch produced 40% higher root length densities compared to no-mulch in lower layers (>0.15 m), probably due to greater retention of soil moisture in deeper layers as reported by Chakraborty *et al.* (2008, 2010). When wheat is sown with HS after rice harvest in the residual soil moisture, it eliminates the need for pre-sowing irrigation. Sowing wheat in the residual soil moisture without pre-sowing irrigation will save about 20% in irrigation water, which would help to save 80 kWh of electricity and reduce emission of 160 kg of CO2.

In these areas, as much as 50% of total evapotranspiration (ET) from a crop can be lost through evaporation from the soil surface. In fact, apart from adjusting the growing period of crops, as has been done for rice in India, mulching is the only practice that reduces ET by decreasing evaporation.[(49)]. This crop residue provides a cover that can protect the soil against water run-off and erosion.

Zero-till wheat has been adopted in the rice wheat system in the northwest IGP with positive impacts on wheat yield, profitability and resource use efficiency [(22, 33).] ZT wheat has been adopted on a significant area in the RW system in the NW-IGP with positive impacts on wheat yield, profitability, and resource-use efficiency [(22).] The potential benefits of Zero Tillage can be fully realized only when it is practiced continuously and the soil surface should remain covered at least 30% by previous Crop Residue. Use of Happy Seeder (HS) will lead to wider adoption of Conservation Agriculture in the region.[48]

Impact of Rice residue on weed

Residue incorporation reduced weed density, especially of *Phalaris minor*, resulting highest wheat yield.[29]. Salam *et al.,* 2020.Observed the minimum weed density and dry weight were found in incorporation. Residue retention on the soil surface suppresses weed flora in the RWCS via mulching effects through mechanical impedance of the weed seedlings and by avoiding exposure to light. The allelopathy effects of rice residue may help in controlling weeds in wheat crop. Crop residue retention on the soil surface leads to adverse effects on the efficacy of pre-emergence herbicides.[.28].

Impact Rice residue management on Soil Properties

Effect of of residue management on soil bulk density (BD) found lower soil BD in a conservation agriculture tillage management system Edwards *et al.,* 1992, residue incorporation.[49]Rice residue increase soil hydraulic conductivityand infiltration rate by modifying mainly soil structure, proportion of macrospores, and aggregate stability[36]. pH Most important factors determine soil fertility, which may be influenced by rice residue management. Many reports indicates the increase in the soil pH irrespective of whether rice residue were burnt, Incorporated or mulched. [35]Increase in pH of soil after burning was generally attributed to accretion as ash residue are dominated by carbonates of alkali and alkaline earth metal but alsovariable content of silica, heavy metals, sisqueioxides, phosphorus and small amount of organic and inorganic N. [40]

Long term burning decreased the microbial population of the soil permeabilityseverely declining the bacteria population involved in nitrification.[40], . It take several months to 5 years to recover that activity.[55]Declining nutrient in the soil affect the sequestration of carbon in the soil and lead to decline in the soil fertility, But total C and N in the soil microbial biomass increased immediately after rice straw incorporation under aerobic condition; reached maximum value after one week each application (2 g C as rice straw Kg^{-1}soil after every 6 week), Decreased thereafter.[6]Microbial population also increased because application of rice residue having C: N ratio pf 52.1, and simultaneous application of rice residue and NH_4 -N to the soil under upland soil increased the no. of denitrifiers. In India, soil treated with rice residue inhabited 5-10 time more and 1.5 to 11 time more fungi than in soilwhere residues were either burn or removed [9]

Use of microbial consortia

Recently, Bio decomposer microbial consortium (PUSA decomposing capsule) developed by IARI New Delhi gained popularity and is capable of degrading paddy residue biologically through enzymatic activity within 20-25 days. Delhi government also initiated spraying the decomposer across the city to prevent biomass burning.Rice residue burning issue still holds strong and lesser time window between harvesting and cultivation of two crops is one of the concerns of the farmer Also, for better outcome the decomposing consortium require additional efforts Our aim of this poster presentation is to cover the possibilities and the problems associated with the use of PUSA decomposers from the perspective of Punjab.

PUSA Bio decomposers

•Syntrophic microbial consortia is composed of 6 fungal and 2 bacterial species

• Psychrotrophic and Mesophilic species are employed for the degradation of paddy waste

• Enzymatic activity of consortia leads to degradation of lignocellulose pectin etc

• This leads to conversion of waste to compost which can promote fertility and also decrease air pollution and it occurs in 20 25 days

• Activity leads to decrease in carbon content (As per C/N ratio analysis) and increase in humic and fulvic acid (HA and FA respectively)

•Mesophilic fungi *Aspergillus awamori Aspergillus nidulansPhanerochaetechrysosporium Trichoderma viridePsychrotrophic fungi EupenicilliiumcrustaceumPaceliomycessp*Psychrotrophic bacteria *Bacillus atropheus Bacillus sp*.[45]

A study (Casciatori*et al.*, 2013) reported the conversion of sugarcane bagasse, orange pulp and peel and wheat bran into enzymes. Mixing of wed biomass, crop residue in various ratios (50:50, 50:100) in plots and various sub-plots along with microbes such as *Trichoderma viridi*and *Pleurotus sp* as spawn seeds resulted in increased yield, improvement in soil pH, nitrogen, phosphorus, potassium and soil organic carbon and overall crop productivity and also aiding in environmental sustainability [17].

Table 4: Effect of residue on yield, nitrogen uptake in no-till wheat

Treatment	**Grain yield (kg ha^{-1})**		**Straw yield (kg ha^{-1})**		**NitrogenUptake bywheat(kg ha^{-1})**	
	2005-06	2006-07	2005-06	2006-07	2005-06	2006 -07

R1(Residueremoval)	3069	3386	4752	5021	72.49	82.36
R2(Residueretention)	3264	3581	5019	5296	73.59	86.60
R3 Residueretention with Trichoderma)	3321	3617	5100	5332	73.78	88.34
Sem±	51.90	55.79	60.30	82.66	0.29	1.33
CD (P=0.05)	163.54	175.78	190.00	260.43	0.90	4.18

Source **Kumar *et al.*, 2017**

The rice residue retention with *Trichoderma* application produced significantly higher crop growth (Table 4), yield attributes, grain (3321 and 3617 kg ha-1) and straw yield as compared to residue retention alone (3264 and 3681 kg ha-1) and residue removal (3069 and 3386 kg ha-1). Residue retention with Trichoderma application also registered the highest nitrogen uptake by wheat.[31]

Conclusion

On the basis of reported research results by different researchers, an analysis has been made.To avoid residues burning in rice wheat croppingsystem it needs to review and upgrade the technology withRice residues as in-situ incorporate with microbial consortia in wheat crop is a good option for their management. Incorporate with microbial consortia increased yield, waterproductivity and profitability, while decreasing *Phaleris minor* weed. Also improvements in soil quality. Since rice residues contain significant quantities of plant nutrients, their continuousapplication will have positive effect on fertilizer management and minimizeair pollution.

Reference

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1. Allen, J., Pascual, K. S., Romasanta, R. R., Trinh, M. V., Thach, T. V., Hung, N. V., ... &Chivenge, P., 2020. Rice straw management effects on greenhouse gas emissions and mitigation options. In *Sustainable Rice Straw Management* (pp. 145-159). Springer, Cham.

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2. Anonymous, (2016). Ministry of New and Renewable Energy, New Delhi. (http://mnre.gov.in).http://www.erewise.com/current-affairs/biomass-resources in india_art52cbbb9bcd5d f.mht ml#. Vd9atPmqqko
3. Anonymous, 2018.Estimation of surplus crop residue in inda for biofuel production. Join Report of TIFAC & IARI.

4. Anonymous, 2019. Report on Review of The Scheme "Promotion Of Agricultural Mechanisation For In-Situ Management of Crop Residue in States of Punjab, Haryana, Uttar Pradesh And Nct Of Delhi Ministry of Agriculture and Farmers Welfare Krishi Bhawan Deptt. of Agriculture, Cooperation & Farmers Welfare*Government of India*, New Delhi.
5. Auffhammer, M., Ramanathan, V., Vincent, J., 2006. Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests inIndia. *Proceedings of the National Academy of Sciences* **103**(52): 19668-19672.
6. Azmal, A. K. M., Murmoto, T., Shindo, H. and Nishiyama, M. 1997. Changed in Microbial biomass after continues application of Azzola and rice stra in soil. *Soil Science PlantNutrient*, **43**: 811-818.
7. Badarinath, K.V.S., Chand, T.R.K., Prasad, V.K., 2006. Agricultural crop residue burning in the Indo-Gangetic plains e a study using IRS-P6 AWiFS satellite data. *Current Science***91**(8): 1085-1089.
8. Beerling, D. J., Leake, J. R., Long, S. P., Scholes, J. D., Ton, J., Nelson, P. N., &Kelland, M., 2018. Farming with crops and rocks to address global climate, food and soil security. Nature plants, **4**(3), 138-147.
9. Beri V., Sindhu, B. S.,Bhat, A.K. and Singh, B. 1992. Nutrent and soil properties as affected by management of crop residue. In: Proc. Intl. Symposium on Nutrient on management and sustained productivity Vol 2 Ludhiana, Dept. of Soil, PAU pp. 133-135
10. Beri, V., Sidhu, B.S., Bahl, G.S. and Bhat, A.K. 1995. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. *Soil Use Manage*.**11**:51-54.
11. Bisen, N., and Rahangdale, C.P. (2017). Crop residues management option for sustainable soil health in rice-wheat system: A review. *International Journal of Computational Intelligence Systems*, 5:1038-1042
12. Brar, A. S., Sharma, P., Kahlon, C. S. and Walia, U. S., 2019. Influence of rice residue management techniques and weed control treatments on soil available plant nutrients in rice-wheat cropping system. *American Journal of Plant Sciences* **10**: 55-64
13. Casciatori F.P., Laurentino C. L., Lopes K. C. M., de Souza A. G. and Thomeo J. C., 2013. “Stagnant effective thermal conductivity of Agro-industrial residues for solid-state fermentation”. *International Journal of Food Properties*, **16**: 1578 – 1593.

14. Chakraborty, D., Garg, R. N., Tomar, R. K., Singh, R., Sharma, S. K., Singh, R. K., ... &Kamble, K. H., 2010. Synthetic and organic mulching and nitrogen effect on winter wheat (Triticum aestivum L.) in a semi-arid environment. *Agricultural Water Management*, ***97***(5): 738-748.
15. Chakraborty, D., Nagarajan, S., Aggarwal, P., Gupta, V. K., Tomar, R. K., Garg, R. N., ... & Kalra, N., 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. *Agricultural water management*, ***95***(12): 1323-1334.
16. Chitty, D. and M. Walsh. 2003. The burning issues of annual ryegrass seedcontrol. In '*Crop Updates* 2003 Weeds, Perth
17. Choudhary V.K., Gurjar D. S. and Meena R. S., 2020. "Crop residue and weed biomass incorporation with microbial inoculation improve the crop and soil productivity in the rice (*Oryza sativa* L.) – toria (*Brassica rapa*L.) cropping system". *Environmental and Sustainability Indicators* (in press).
18. Dobermann, A. and Fairhurst, T.H., 2002. Rice straw management, *Better Crops International*, **16**, 7-11**.**
19. Dobermann, A., & Witt, C., 2000. The potential impact of crop intensification on carbon and nitrogen cycling in intensive rice systems. *Carbon and nitrogen dynamics in flooded soils*, 1-25.
20. Dotaniya, M. L., 2013. Impact of crop residue management practices on yield and nutrient uptake in rice-wheat system. *Current Advances in Agricultural Sciences (An International Journal)*, ***5***(2): 269-271.
21. Edwards, J. H., Wood, C. W., Thurlow, D. L. and Ruf, M. E., 1992. Tillage and crop rotation effect on fertility status of Hapludand soil. *Soil Sci. Soc. Am. J., 56*, 1577-1585.
22. Erenstein O and Laxmi V 2008. Zero tillage impacts in India's rice wheat systems: a review. *Soil Till Res* **100:** 1–14.
23. Fisher, R. F., & Binkley, D., 2000. Soil organic matter. Ecology and management of forest soils, 139-160
24. Gadde, B., Bonnet, S., Menke, C., Garivait, S., 2009. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. *Environmental Pollution***157**, 1554-1558.

25. Gujral, J., Davenport, S. and Jayasuriya, S. (2010). Is there a role for agricultural offsets in sustainable infrastructure development: A preliminary assessment of issues', Chapter 25 in India Infrastructure Report 2010, Oxford University Press.
26. Hani, N. W., Rashid, N. F. A., & Hashim, M. H., 2021. Effects of burning rice residues on soil chemical properties in sekinchan rice field. Lumpur International Agriculture, Forestry and PlantationConference (KLIAFP10), 22-23.
27. Jain, V., Kewat, M.L. and Jain, N. (2014). Effect of post-emergence herbicides atvariable soil moisture on weeds and yield of wheat. *Journal of Weed Science*,**46**(3): 244–246
28. Kaur, R., Kaur, M., Deol, J. S., Sharma, R., Kaur, T., Brar, A. S. and Choudhary, O. P. (2021). Soil Properties and Weed Dynamics in Wheat as Affected by Rice Residue Management in the Rice–Wheat Cropping System in South Asia. *Plants MDPI*,**10**: 953
29. Khankhane, P. J., Barman, K. K. and Varshney J. G., 2009. Effect of rice residue management practices on weed density, wheat productivity and soil fertility in a swell-shrink soil *Indian Journal of Weed Science,* **41**(1&2): 41-45.
30. Kumar, K. and K.M. Goh. 2000. Crop residues and management practices:Effects on soil quality, soil nitrogen dynamics, crop yields, and nitrogenrecovery. *Advances Agron*. **68**: 197-31.
31. Kumar, R., Singh, U. P., & Mahajan, G., 2017. Influence of residue and weed management practices on no-till wheat (*Triticum aestvium* L.) under rice-wheat cropping system. *Indian Journal of Soil Conservation*, ***45***(2): 198-202.
32. Kumar, V., & Dash, B., 2016. Long-term effect of crop residues and zinc fertilizer on crop yields, nutrient uptake and fertility buildup under rice-wheat cropping system in calciorthents. *International journal of bio-resource, environment and agricultural sciences (ijbeas). **2**(4): 430-435,*
33. Ladha, J. K., Kumar, V., Alam, M.M., Sharma, S., Gathala, M., Chandana, P., 2009. Integrating crop and resource management technologies for enhanced productivityin South Asia. In: Integrated Crop and Resource Management in the Rice Wheat System of South Asia (Eds: Ladha J K, Singh Y, Erenstein O and Hardy B) *International Rice Research Institute, Los Banos, Philippines*. 69-108
34. Long, W., Tate, R., Neuman, M., Manfreda, J., Becker, A., Anthonisen, N., 1998. Respiratory symptoms in a susceptible population due to burning of agricultural residue. *Chest*, **113**(2): 351.

35. Mandal, K. G., Misra, A. K., Hati, K. M., Bandyopadhyay, K. K., Ghosh, P. K., & Mohanty, M., 2004. Rice residue-management options and effects on soil properties and crop productivity. *Journal of Food Agriculture and Environment*,***2***: 224-231.
36. Mando, A. Strosnijder, L. and Brussard, L. 1996. Effect termites on infiltration into crused soil. *Geoderma*, **74**:13-24
37. NDEP, 2003. The Nevada Handbook for Agricultural Open Burning. Nevada Divisionof Environmental Protection (NDEP), *Las Vegas*, USA.
38. Prasad, R. K., Kumar, V., Prasad, B., & Singh, A. P., 2010. Long-term effect of crop residues and zinc fertilizer on crop yield, nutrient uptake and fertility build-up under rice-wheat cropping system in calciorthents. *Journal of the Indian society of soil Science*, **58**(2): 205-211.
39. Prihar S. S, Arora V. K .and Jalota S. K. 2010. Enhancing crop water productivity to ameliorate groundwater fall. *Curr Sci* **99:** 588- 93
40. Raison, R.J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformation: areview. *Plant Soil* **51**:73-108.
41. Salam, M. A., Ferdus, J., Sultana, A., &Salek, A., 2020. Effect of rice residue on weed suppression and yield performance of boro rice. *Archives of Agriculture and Environmental Science*, ***5***(3): 320-327.
42. Schaller, Jörg& Wang, Jiajia& Planer-Friedrich, Britta., 2018. Black carbon yields highest nutrient and lowest arsenicrelease when using rice residuals in paddy soils OPEN. Scientific Reports. 8. 10.1038/s41598-018-35414-3.
43. Shahid, M., Tripathi, R., Mohanty, S., Thilagam, K., & Nayak, A. K., 2013. Rice Residue Management for Improving Soil Quality. *Rice Knowledge Management Portal*,http://www.rkmp.co.in
44. Sharma, P.K., and Mishra, B., 2001. Effect of burning rice and wheat crop residues: Loss of N, P. K and S from soiland changes in nutrient availability. *J. Indian Soc. Soil. Sci*., **49**:425-429.
45. Shukla *et al.*, 2016 Syntrophic microbial system for ex situ degradation of paddy straw at low temperature under controlled and natural environment Applied Microbiology and Biotechnology **4** 30-37. doi 10 7324 /JABB 2016 40205
46. Sidhu H. S., Manpreet-Singh, Humphreys E., Yadvinder-Singh, Balwinder-Singh, Dhillon S. S., Blackwell J., Bector V., Malkeet- Singh and Sarbjeet-Singh, 2007. The Happy Seeder enables direct drilling of wheat into rice stubble. *Aus J Exp Agric* **47:** 844-54.

47. Sidhu, B.S. and Beri, V. (1989). Effect of crop residue management on yields of different crops and soil properties, Bioogical Wastes, **27**, 15-27.
48. Sidhu, H. S., Humphreys, E., Dhillon, S. S., Blackwell, J., &Bector, V., 2007. The Happy Seeder enables direct drilling of wheat into rice stubble. *Australian Journal of Experimental Agriculture*, ***47***(7): 844-854.
49. Sindhu, A. S. and Sur, H. S., 1993. Effect of incorporation of legume crop straw on soil properties and crop yield in maize –wheat sequence. Tropical Agriculture, **70**(3).
50. Singh, P., Singh, G. and Sodhi, G.P.S. (2020). Energy and carbon footprints of wheat establishment following different rice residue management strategies vis-à-vis conventional tillage coupled with rice residue burning in north-western India, *Energy*, 200, 117554.
51. Singh, Y., Thind, H. S., & Sidhu, H. S., 2014. Management options for rice residues for sustainable productivity of rice-wheat cropping system. *Journal of Research Punjab Agricultural University*, ***51***(3&4): 209-220.
52. Song, H. J., Lee, J. H., Jeong, H. C., Choi, E. J., Oh, T. K., Hong, C. O., & Kim, P. J., 2019. Effect of straw incorporation on methane emission in rice paddy: conversion factor and smart straw management. *Applied Biological Chemistry*, ***62***(1): 1-13.
53. Srinivasan, G. and Abirami, A., 2020. Mitigation of crop residue burning induced air pollution in New Delhi – a review. *International Journal of Engineering Applied Sciences and Technology*, **5**(8): 282-291
54. Tisdell, J. M., 1992. How stubble affects Organic matter, Plants and animals in the soil. *Journal Agriculture*, ***33***:18-21
55. Yadvinder-Singh, Bijay-Singh and J. Timsina. 2005. Crop residuemanagement for nutrient cycling and improving soil productivity inrice-based cropping systems in the tropics. *Advances Agron*.**85**: 269-407.
56. Yadvinder-Singh, Singh, B., Ladha, J. K., Khind, C. S., Khera, T. S., & Bueno, C. S., 2004. Effects of residue decomposition on productivity and soil fertility in rice–wheat rotation. *Soil Science Society of America Journal*, ***68***(3): 854-864.
57. Zhang, H., Ye, X., Cheng, T., Chen, J., Yang, X., Wang, L., Zhang, R., 2008. A laboratory study of agricultural crop residue combustion in China: emission factors andemission inventory. *Atmospheric Environment***42**, 8432-8441.
58. Zhao, X., Yuan, G., Wang, H., Lu, D., Chen, X., & Zhou, J., 2019. Effects of full straw incorporation on soil fertility and crop yield in rice-wheat rotation for silty clay loamy cropland. *Agronomy*, ***9***(3): 133.