Crop residue management in a rice-wheat cropping system on crop-water productivity and soil health: A Review

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Abstract

The rice-wheat system is India's dominant cropping system, and its sustainability is at risk as a result of degradation in soil health and climate change challenges. The high yields of the irrigated rice-wheat system have led to enormous quantities of crop residues being produced. In north-west India, burning of rice straw is common, causing nutrient losses and severe air pollution affecting human health. Innovations in crop residue management can help achieve sustainable productivity in order to avoid straw burning and allow farmers to reduce nutrient and water inputs and reduce risks due to climate change. Significant amounts of plant nutrients are found in crop residues and their judicious application would have a beneficial impact on the nutrient management of the rice wheat system. Long-term residue recycling studies have shown changes in the soil's physical, chemical and biological health. Another possible choice for the management of crop residues is to use a portion of surplus residue for biochar production as soil modification to improve soil health, increase the efficiency of nutrient use, and reduce air pollution and other mushroom cultivation as the conversion of inedible crop residues into valuable food, surface mulch as soil moisture and weed protection, biofuel and compost production. The decomposition of soil residues greatly increases organic carbon and other nutrients in the soil. This collected review literature addressed the potential for residues and possible options for the efficient management of crop residues in the rice wheat cropping system to improve crop water productivity and soil health.

Key words*: Crop residue management, Crop-water productivity, Soil health and Rice- wheat cropping system.*

Introduction:

Rice-wheat cropping systems are considered one of South Asia's major food sources, providing food for 400 million people from a region of 13.5 Mha, primarily concentrated in the Indo-Gangetic plains (Kumar et al., 2018). In India there are 500-550 million tones (Mt) of crop residues are produces annually. (MoA, 2012), The Rice Wheat cropping System (RWS) is one of the widely practiced cropping systems in India and about 90% of area is concentrated in the Indo-Gangetic Plains (IGP) (Janaiah and Hossain, 2003). With the introduction of combine harvesters, more than 75% of the rice area is harvested mechanically in north-western parts of the IGPs. The Ministry of New and Renewable Energy, Govt. India (2009) estimates that approximately 500 Mt of crop residue is produced annually. In Uttar Pradesh (60 Mt), followed by Punjab (51 Mt) and Maharashtratra, the production of crop residues is greater (46 Mt). Maximum residues are produced by cereals (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugar cane among the various crops (12 Mt). Cereal crops (corn, wheat, maize, millets) account for 70%, while rice crops alone account for 34% and wheat ranks second with 22% of crop residues (Fig. 1).

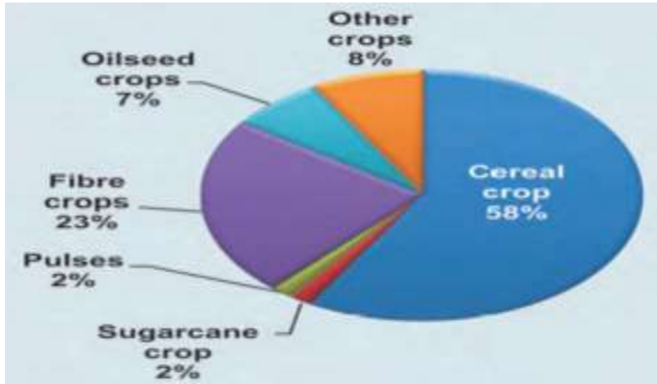

Fig 1: The share of unutilized residues in total residues generated by different crops in India (calculated from MNRE, 2009)

The rice wheat method accounts for almost one-fourth of the crop residue production in India, according to Sarkar et al. (1999). The residue produced is mainly used for open burning as industrial/domestic fuel, animal feed, packaging, bedding, in situ incorporation and manuring, thatching, and left in the field. However, almost all the residue produced is left in the field in the case of combined harvesting, which eventually ends in burning. Both rice and wheat are extensive nutrient feeders, and the double cropping system significantly depletes the nutrient content of the soil. Dobermann and Fairhurst, (2002) reported that a tone of rice straw contained 5-8 kg of nitrogen. A rice-wheat sequence yielding 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat extracts more than 300 kg N, 30 kg P and 300 kg K ha^{-1} from the soil, according to Singh and Singh (2001). Another Gupta et al. (2002) estimate shows that 10 t ha^{-1} crops extract 730 kg of NPK from the soil, which is not always returned to the soil. This can contribute to soil mining for major nutrients, resulting in net negative balance and crop multi-nutrient deficiencies. This is one of the reasons for the rice-wheat system's decline in yield. Therefore, for the maintenance of soil health and the stability of the environment, there are urgent needs for the management of the residues of these crops.

Crop residues management options

The rice wheat cropping method produces enormous amounts of crop residues in India. In North West India, the majority of rice and wheat is harvested by a combination harvester that leaves residues in the ground. As cattle feed, the residues of cereal crops are primarily used. Rice straw and husk for parboiling rice are used as domestic fuel or in boilers. Instead of wheat straw, rice straw management is a serious problem because there is very little processing time between rice harvesting and wheat sowing and because of the lack of adequate recycling technology and the higher content of silica than other crops. Livestock feed, mushroom planting, incorporation, surface retention and mulching, biochar and baling and removal of the straw are some management options available to farmers for the productive management of crop residues. As per the situation, farmers use various straw management methods (Bisen and Rahangdale, 2017).

Crop Residue Management and Crop Water Productivity

Water resource conservation is the major challenge in present-day farming. After harvesting of rainy rice, retention of rice straw in the field efficiently conserves the residual soil moisture for subsequent crops, mainly in dry tracts (Chavan et al., 2010). Mulching using rice straw not only keeps the soil moist, but also helps to moderate the soil temperature, check the weed emergence, and, most importantly, increase the yield of wheat (Rahman et al., 2005). It has been reported that 84% of the residues are wasted from rice–wheat systems (Singh and Panigrahy, 2011). Keeping rice straw in zero-till wheat in IGP increases the wheat yield, monetary return, and resource use efficiency, as reported by Erenstein and Laxmi (2008) and Ladha et al. (2009). A happy seeder is used to spread loose rice residue uniformly after harvesting, and this instrument has been well adopted for conservation agriculture (Sidhu et al., 2009). Retention of rice residues lowers the crop water use by 3–11% and increases the water use efficiency by 25% as compared to a no-mulching situation (Chakraborty et al., 2010). They also reported that rice straw improves the wheat root length by 40% as a consequence of better soil moisture storage. The 13 years of the experiment reported that continuous rice residue incorporation enhanced the wheat yield by 34.89% as compared to residue burning due to the better resource use efficiency and soil health (Mandal et al., 2004).

Crop Residue Management and Soil Health

Rice and wheat are also exhaustive nutrient feeders and one of the major causes of poor soil health under the rice-wheat system is due to this excessive nutrient mining of soils. The quantity of nutrients derived from rice and wheat is greater than the quantity added and recycled by fertilisers. The preservation of residues increases the physical (i.e. structure, penetration rate, water ability available to plants), chemical (i.e. nutrient cycling, cation exchange capacity, soil reaction) and biological (i.e. SOC sequestration, microbial biomass C, soil biota activity and species diversity) quality of the soil (Singh et al. 2008, Bisen and Rahangdale, 2017).One of the safer crop production alternatives is the introduction of sustainable crop residue management activities (Raza et al., 2019). Indiscriminate combustion of crop residues has a significant effect on soil quality, the content of organic matter, plant micro- and macronutrients, and the microbial community (Raza et al., 2019, Nyanga et al., 2020). Numbers of possible crop residue management technologies such as conservation tillage, nutrient cycling, soil conversation methods, zero-tillage and residue mulching, use in animal feed, and vermicompost preparation are used in realistic field conditions in various parts of the world (Raza et al., 2019). Proper management of crop residue has a positive effect on improving efficiencies in input usage by controlling various biochemical properties of the soil (Sarkar et al., 2020).

Impact on physical health of soil

Soil physical properties such as soil moisture content, aggregate formation, bulk density and soil porosity are influenced by crop residue management practises. Incorporation and/or retention of crop residues in soils has decreased soil bulk density and compaction (Bellakki et al., 1998). The annual application of 16 t ha-1 of rice straw for 3 years reduced the bulk density in the 0-5 cm layer on a sandy loam from 1.20 to 0.98 g cm-3. Owing to the breakdown of the aggregates and the creation of the surface seal by the raindrop effect, the lower infiltration resulted in an increase in compaction and a decrease in the pore proportion of the surface soil. This issue is solved by residue preservation on the surface. Incorporation of crop residues decreased BD and increased infiltration rate as compared to no residue application, WHC, microbial population, soil fertility. The integration of residues with NPK fertiliser resulted in maximum production, nutrient absorption, increased residual soil fertility and the status of soil microorganisms (Singh et al. 2010). It has been shown that the incorporation of leguminous crop residues enhances the physical properties of the soil, such as water holding capability, soil permeability, etc. The addition of leguminous crop residues also improves crop growth and productivity by improving the availability of crop root zone nutrients (Smitha et al., 2019). In modern input-intensive agriculture, the use of heavy machinery and farm implements such as planters, zero-tillage implements, reapers, and combine harvesters is very common, and indiscriminate use of these heavy machinery pieces often leads to compacting the soil and hampering physical properties of the soil, such as infiltration rate, airflow, and water holding capacity (Smitha et al., 2019). Carlesso et al. (2019) stated that the use of crop residues from ryegrass and straw residues as well as mixed litter can significantly increase the porosity of the soil and the capacity to retain water, and can eventually make the soil more efficient. In order to boost soil aggregate and carbon storage in rice-based cropping systems, the application of crop residues along with conservation tillage has been documented (wang et al., 2019).

Impact on chemical health of soil

The pH of the soil is a deciding factor for the fertility of the soil, which is greatly affected by the residues of the crops in the soil. Long-term application of straw will establish the amount of soil organic matter and N reserves and will also enhance the supply of macro- and micro-nutrients. The 11-year study filed by Beri et al. (1995) on loamy sand soil showed that the introduction of residues from both crops into the rice wheat system increased the total P available P and K content in the soil over residue removal. Gupta et al. (2007) stated from the three year analysis that with the incorporation of crop residue over straw burned, inorganic and organic P, decreased P sorption, and increased P release increases. Approximately 50-80% of the micronutrients consumed by rice and wheat crops (Zn, Fe, Cu and Mn) can be recycled by incorporated residue. Crop residues affect the supply of micronutrients in rice, such as zinc and iron (Singh et al. 2005 and Gupta et al. 2007). The soil's chemical properties, such as pH, electrical conductivity, and cation exchange ability (CEC), as well as the conversion of various primary and secondary plant nutrients, can be improved effectively by sustainable crop management. A strong correlation with the application of crop residue is observed in the soil carbon pool (both complete and labile pool). The application of 10 Mg ha^{-1} wheat residue mulching along with the application of 75 kg N ha-1 is stated to significantly increase the total and labile carbon pool of an irrigated maize production system (Chatterjee et al., 2018). In order to improve system productivity, K usage efficiency and obvious K balance, adoption of conservation tillage in a rice-maize cropping system with residue management may be effective (Singh et al., 2018). Residue incorporation is also beneficial for the recycling of up to 15 percent of usable K soil, as well as the need for K external supply (Singh et al., 2018). Smitha et al. (2019) stated that the application of cluster bean crop residue before sacred basil transplantation (Ocimum sanctum Linn) significantly improved soil macronutrient SOC and availability.

Impact on biological health of soil

In particular, the availability of nutrients such as N, P, and S depends on soil microbial biomass (SMB) and microbial activity, which in turn depends on the soil's supply of organic substrates. The soil flora and fauna population is positively associated with the soil phyto-biomass current. Beri et al. (1995) and Sindu et al. (1995)[39] noted that soil treated with crop residues had 5-10 times more aerobic bacteria and either burned or removed 1.5-11 times more fungi than soil. The study by Verhulst et al. (2009)[40] showed that soil microbial biomass (C and N) decreased in the zero-till treatments in both rainfed and irrigated long-term trials with a decreasing amount of residue retained on the soil surface. The microbial biomass of the soil represents the ability of the soil to store and cycle nutrients (C, N, P and S) as well as organic matter and plays an important role in aggregate physical stabilisation. Crop residues are also known to increase nitrogen fixation by asymbiotic bacteria in the soil (Azotobacter chrococcum and A. agilis). The activity of soil enzymes responsible for the conversion of inaccessible to usable nutrient type also increases due to the increase in soil microbial population. Proper preservation of crop residues has been reported to have a major effect on soil microbial biomass control. Samui et al. (2020) recorded improved microbial activity in the top layer of soil through the application of crop residue mulching, which may be attributable to plant-soil microclimate modification, increased availability of water and nutrients, and soil temperature control. Chatterjee et al. (2018) observed comparable results and considered that soil microbial biomass carbon (MBC) increased significantly through the application of wheat crop residue. Incorporation of leguminous crop residues such as cluster beans before sowing the next crop has been documented in order to increase soil microbial biomass and dehydrogenase activity (DHA) compared to control treatment (using crop residue) Smitha et al (2019). CA residue retention has also been reported as beneficial in a wheat-soybean cropping system for the reduction of soil nematode population (Escalante et al., 2020).

Impact on soil fertility and productivity of soil

For the maintenance of soil fertility and the recycling of soil nutrients, judicious crop residue management is very beneficial. Rusinamhodzi et al. (2016) stated that good crop residue management not only helps improve soil productivity and nutritional status, but also helps improve the overall health status of farm animals. To increase soil productivity, C-pool and earthworm population productivity, long-term use of crop residues along with conservation tillage has been stated (Frazao et al., 2019). In global agriculture, crop residue is becoming increasingly important and is considered to be an excellent source of organic matter that helps to boost soil C stock, water conservation, nutrient recycling, and soil characteristics, and reduces residue burning patterns and the consequent environmental hazards upon retention (Fig. 2) (Liang et al., 2016). Most of the overall production of crop residues comes from cereals (74%), followed by sugar crops (10%), legumes (8%), tubers (5%) and oilseeds (3%) (Lal, 2005). In addition to C, depending on the crop species and soil fertility status, crop residue contains many mineral nutrients (Lal, 2005). However, it is very difficult to decide how many nutrients would be available to crops at the time of incorporation of crop residue, as it has been well known that, as a result of the high C:N ratio, crop residues initially immobilise the available soil N (Garai et al., 2020). In the long term, however, this activity is very successful for the availability of nutrients for subsequent crops along with the generation of high quality organic matter and encourages better production of food crops (Yadvinder-Singh and Timsina, 2005). After cereals, legume cultivation contains the most residues (Sombrero et al., 2010). Instead of quantity, legume residues are considered to be residues of good quality and have a significant amount of soil C for a long time (Sarkar et al., 2020). A systematic study of the application of crop residue in agricultural practises relating to soil fertility and productivity is discussed below.

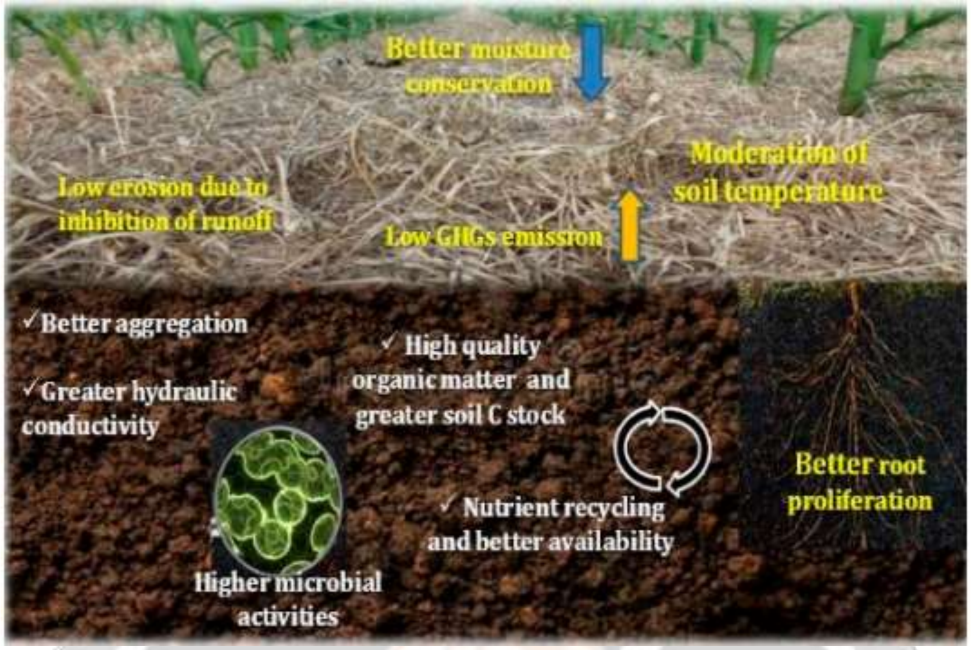

Fig. 2: Advantages of crop residue retention for improving soil fertility (Source: Sarkar et al., 2020)

Conclusion:

The most intensive method of production in the country is the rice-wheat cropping system. It occupies a commanding proportion of India's total cultivable land. The recycling of its residues has the great ability to get back to the soil a large amount of plant nutrients. The yield stagnation resulting from the decreasing organic carbon of the soil is a major threat to this system in particular. It is therefore a great challenge for farmers to effectively and efficiently manage rice residues in order to increase carbon sequestration and preserve the sustainability of production. There are both benefits and drawbacks to any management choice. It depends on a given set of conditions for soil, environment and crop management, consistent with the machinery available and socially and economically appropriate. It is important to evaluate and update the mechanised harvester technology for sustainable residue use in order to avoid residue burning in the rice wheat cropping system. Relevant conservation tillage methodology can be adopted for place and soil quality. If rice residues are properly handled, changes in soil physical, chemical and biological properties can be justified and rice-wheat cropping system productivity can be sustained.

References

- MoA. (Ministry of Agriculture). Govt. of India, New Delhi.2012. www.eands.dacnet.nic.in.
- Janaiah A, Hossain M. Farm-level sustainability of intensive rice–wheat system: socio-economic and policy perspectives. Addressing Resource Conservation Issues in Rice–Wheat Systems of South Asia, A Resource Book, Rice Wheat Consortium for Indo Gangetic Plains (CIMMYT), 2003.
- MNRE. (Ministry of New and Renewable Energy Resources) Govt. of India, New Delhi. 2009. www.mnre.gov.in/biomassrsources.
- Sarkar A, Yadav RL, Gangwar B, Bhatia PC. Crop residues in India. Tech. Bull., Project Directorate for Cropping System Research, Modipuram, 1999.
- Dobermann A, Fairhurst TH. Rice Straw Management. Better Crops International, Special supplement publication: Rice Production. 2002, 16.

- Singh Y, Singh B. Efficient Management of Primary Nutrients in the Rice-Wheat System. In: Kataki, P.K. (Ed.). The Rice-Wheat Cropping Systems of South Asia: Efficient Production Management. Food Products Press,New York, USA. 2001, 23-85.

- Bisen N and Rahangdale CP. Crop residues management option for sustainable soil health in rice-wheat system: A review. International Journal of Chemical Studies 2017; 5(4): 1038-1042.

- Gupta RK, Shukla AK, Ashraf M, Ahmed ZU, Sinha RKP, Hobbs PR. Options for establishment of rice and issues constraining its productivity and sustainability in eastern Gangetic plains of Bihar, Nepal and Bangladesh. Rice-Wheat Consortium Travelling Seminar Report Series 4. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. 2002, 36.

- Singh B, Shan YH, Johnson-beeebout SE, Singh Y, Buresh RJ. Crop residue management for lowland ricebased cropping systems in Asia. Adv Agron, 2008; 98:118-199.

- Bellakki MA, Badanur VP, Setty RA. Effect of long-term integrated nutrient management on some important properties of a Vertisol. J. Indian Soc. Soil Sci. 1998; 46:176-180.

- Singh SK, Kumar D, and Lal SS. Integrated use of crop residues and fertilizers for sustainability of potato (Solanum tuberosum) based cropping systems in Bihar. Indian J Agronomy. 2010; 55(3):203-208.

- Sindu BS, Beri V, Gosal SK. Soil microbial health as affected by crop residue management. In: Proc. Natl. Symp. On developments in soil science Ludhiana. Indian Society of Soil Science New Delhi. 1995; 2-5:45-46.

- Verhulst N, Sayre KD, Vargas M, Crossa J, Deckers J, Raes D. Wheat yield and tillage-straw management system x year interaction explained by climatic covariables for an irrigated bed planting system in northwestern Mexico. Field Crops Res. 2011; 124:347- 356.

- Gupta RK, Singh Y, Ladha JK, Singh B, Singh J, Singh G et al. Yield and phosphorus transformations in a ricewheat system with crop residue and phosphorus management. J American Soc Soil Sci. 2007; 71:1500-07.

- Beri V, Sidhu BS, Bahl GS, Bhat AK. Nitrogen and phosphorus transformations as affected by crop residue management practices and their influence on crop yield. Soil Use Manage. 1995; 11:51-54.

- Singh Y, Singh B, Timsina J. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. Adv Agron, 2005; 85:269-407.

- Smitha, GR., Basak, B.B., Thondaiman, V., Saha, A. Nutrient Management through Organics, Bio-Fertilizers and Crop Residues Improves Growth, Yield and Quality of Sacred Basil (Ocimum Sanctum Linn). Ind. Crop. Prod. 2019, 128, 599–606.

- Carlesso, L., Beadle, A., Cook, S.M., Evans, J., Hartwell, G., Ritz, K., Sparkes, D., Wu, L., Murray, P.J. Soil Compaction Effects on Litter Decomposition in an Arable Field: Implications for Management of Crop Residues and Headlands. Appl. Soil Ecol. 2019, 134, 31–37.

- Wang, X., Qi, J.Y., Zhang, X.Z., Li, S., Latif Virk, A., Zhao, X., Xiao, X., Zhang, H. Effects of Tillage and Residue Management on Soil Aggregates and Associated Carbon Storage in a Double Paddy Cropping System. Soil Tillage Res. 2019, 194, 104339.

- Kumar, V., Jat, H.S., Sharma, P.C., Balwinder-Singh, Gathala, M.K., Malik, R.K., Kamboj, B.R., Yadav, A.K., Ladha, J.K., Raman, A., et al. Can Productivity and Profitability Be Enhanced in Intensively Managed Cereal Systems While Reducing the Environmental Footprint of Production? Assessing Sustainable Intensification Options in the Breadbasket of India. Agric. Ecosyst. Environ. 2018, 252, 132–147.

- Chatterjee, S., Bandyopadhyay, K.K., Pradhan, S., Singh, R., Datta, S.P. Effects of Irrigation, Crop Residue Mulch and Nitrogen Management in Maize (Zea mays L.) on Soil Carbon Pools in a Sandy Loam Soil of Indo-Gangetic Plain Region. Catena 2018, 165, 207–216.

- Singh, V.K., Dwivedi, B.S., Yadvinder-Singh, Singh, S.K., Mishra, R.P., Shukla, A.K., Rathore, S.S., Shekhawat, K., Majumdar, K., Jat, M.L. Effect of Tillage and Crop Establishment, Residue Management and K Fertilization on Yield, K Use Efficiency and Apparent K Balance Under Rice-Maize System in North-Western India. F Crop Res 224. Field Crop. Res. 2018, 224, 1–12.

- Samui, I., Skalicky, M., Sarkar, S., Brahmachari, K., Sau, S., Ray, K., Hossain, A., Ghosh, A., Nanda, M.K., Bell, R.W., et al. Yield Response, Nutritional Quality and Water Productivity of Tomato (Solanum Lycopersicum L.) Are Influenced by Drip Irrigation and Straw Mulch in the Coastal Saline Ecosystem of Ganges Delta, India. Sustainability 2020, 12, 6779.

- Escalante, L.E., Brye, K.R., Faske, T.R. Nematode Populations as Affected by Residue and Water Management in a Long-Term Wheat-Soybean Double-Crop System in Eastern Arkansas. Appl. Soil Ecol. 2020, 157, 103761.

- Raza, M.H., Abid, M., Yan, T., Ali Naqvi, S.A., Akhtar, S., Faisal, M. Understanding Farmers' Intentions to Adopt Sustainable Crop Residue Management Practices: A Structural Equation Modeling Approach. J. Clean. Prod. 2019, 227, 613–623.

- Nyanga, P.H., Umar, B.B., Chibamba, D., Mubanga, K., Kunda-Wamuwi, C., Mushili, B. Reinforcing Ecosystem Services Through Conservation Agriculture in Sustainable Food Systems; Elsevier Inc.: Amsterdam, The Netherlands, 2020.

- Rusinamhodzi, L., Corbeels, M., Giller, K.E. Diversity in Crop Residue Management Across an Intensification Gradient in Southern Africa: System Dynamics and Crop Productivity. Field Crop. Res. 2016, 185, 79–88.

- Frazao, J., de Goede, R.G.M., Salánki, T.E., Brussaard, L., Faber, J.H., Hedde, M., Pulleman, M.M. Responses of Earthworm Communities to Crop Residue Management After Inoculation of the Earthworm Lumbricus terrestris (Linnaeus, 1758). Appl. Soil Ecol. 2019, 142, 177–188.

- Liang, F. Li, J., Yang, X., Huang, S., Cai, Z., Gao, H., Ma, J., Cui, X., Xu, M. Three-Decade Long Fertilization-Induced Soil Organic Carbon Sequestration Depends on Edaphic Characteristics in Six Typical Croplands. Sci. Rep. 2016, 6, 30350.

- Garai, S., Mondal, M., Mukherjee, S. Smart Practices and Adaptive Technologies for Climate Resilient Agriculture; Maitra, S., Pramanick, B., Eds.; New Delhi Publishers: Kolkata, India, 2020; pp. 327–358.

- Sombrero, A.; de Benito, A. Carbon Accumulation in Soil. Ten-Year Study of Conservation Tillage and Crop Rotation in a Semi-Arid Area of Castile-Leon, Spain. Soil Till. Res. 2010, 107, 64–70.

- Lal, R. World Crop Residues Production and Implications of Its Use as a Biofuel. Environ. Int. 2005, 31, 575–584.

- Yadvinder-Singh, B.-S.; Timsina, J. Crop Residue Management for Nutrient Cycling and Improving Soil Productivity in Rice-Based Cropping Systems in the Tropics. Adv. Agron. 2005, 85, 269–407.

- Sarkar S., Skalicky M., Hossain A, Brestic M, Saha S, Garai S, Ray K and Brahmachari K. Management of Crop Residues for Improving Input Use Efficiency and Agricultural Sustainability. Sustainability 2020, 12, 9808.

- Mandal, K.G., Misra, A.K., Hati, K.M., Bandyopadhyay, K.K., Ghosh, P.K., Mohanty, M. Rice ResidueManagement Options and Effects on Soil Properties and Crop Productivity. J. Food Agric. Environ. 2004, 2, 224–231.

- Chavan, M.L., Phad, P.R., Khodke, U.M., Jadhav, S.B. Effect of Organic Mulches on Soil Moisture Conservation and Yield of Rabi Sorghum (M-35-1). Int. J. Agric. Eng. 2010, 2, 322–328.

- Rahman, M.A.; Chikushi, J.; Saifizzaman, M.; Lauren, J.G. Rice Straw Mulching and Nitrogen Response of No-Till Wheat Following Rice in Bangladesh. Field Crops Res. 2005, 91, 71–81.

- Singh, C.P.; Panigrahy, S. Characterisation of Residue Burning from Agricultural System in India Using Space-Based Observations. J. Indian Soc. Remote 2011, 39, 423.

- Erenstein, O., Laxmi, V. Zero-Tillage Impacts in India’s Rice Wheat Systems: A Review. Soil Tillage Res. 2008, 100, 1–14.

- Ladha, J.K., Kumar, V., Alam, M.M., Sharma, S., Gathala, M., Chandana, P., Saharawat, Y.S., Balasubramanian, V. Integrating Crop and Resource Management Technologies for Enhanced Productivity Profitability, and Sustainability of the Rice-Wheat System in South Asia. In Integrated Crop and Resource Management in the Rice-Wheat System of South Asia; Ladha, J.K., Singh, Y., Erenstein, O., Hardy, B., Eds.; International Rice Research Institute: Los Banos, Philippines, 2009; pp. 69–108.

- Sidhu, H.S., Manpreet-Singh; Humphreys, E.; Yadvinder-Singh; Balwinder-Singh; Dhillon, S.S.; Blackwell, J.; Bector, V.; Malkeet-Singh; Sarbjeet-Singh. The Happy Seeder Enables Direct Drilling of Wheat into Rice Stubble. Aust. J. Exp. Agric. 2007, 47, 844–854.

- Chakraborty, D., Garg, R.N., Tomar, R.K., Singh, R., Sharma, S.K., Singh, R.K., Trivedi, S.M., Mittal, R.B., Sharma, P.K., Kamble, K.H. Synthetic and Organic Mulching and Nitrogen Effect on Winter Wheat (Triticum aestivum L.) in a Semi-Arid Environment. Agric. Water Manag. 2010, 97, 738–748.