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Trichoderma: A part of possible answer towards crop residue disposal

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Abstract
India is one of the leading countries in agricultural production and generate large volume of crop residue. Increasing demand for food grains due to growing population leads to generation of crop residues. Due to lack of proper disposal mechanism of crop residue, farmers burn the residue which release greenhouse gases (GHGs) into the atmosphere, and poses great threat to environment as well as human health. The residue burning causes greater carbon emission and nutrient losses which otherwise incorporated into the soil system may substantially improve the soil biodiversity. Besides several practices of crop residue management, the most feasible method for farmers is incorporation of residue into the soil with the inoculation of microbes. In soil system the ability of microbial community in degrading organic substances is well known. In the early stages of residue decomposition simple substrates like carbohydrates are degraded by bacteria, but in later stages degradation of complex constituents viz., cellulose, lignin needs microbes which are capable of secreting enzymes like cellulase, acting on complex organic substrates. In this context, cellulolytic micro organisms like *Trichoderma* have the potential and emerging as an important microbial inoculants to enhance the rate of decomposition as well as alleviate the effect of residue burning.

Keywords: Agricultural production, Crop residue, Disposal, GHGs

INTRODUCTION

In India, agriculture is accounted for considerable to the economy, and wide range of crops, especially food grains are cultivated which leaves bulk of residues after harvesting of economical part. Crop residue is the left over plant material after harvesting such as leaves, stalks and roots which is around 500 Mt in India (GOI, 2016). Crop residue burning is the common practice among farmers due to lack of proper disposal mechanism and high labour requirement which causes environmental pollution either by gaseous emission or nutrient losses from soil system, thus leading to the pollution and causing hazard to the health of animals and humans as well as damage to the ecosystem. Therefore suitable residue management practice is important for resource conservation and overall environmental sustainability. In this regard, crop residue generated in agricultural lands can be used for many purposes in order to get it disposed and also for recycling. This waste residue can be converted into most economical product by its recycling as fuel for domestic and industrial use, for thatching rural homes, as animal feed and composting (Devi *et al*., 2017).

Crop residue can also be utilized in the areas of bio thermal power plants, mushroom cultivation, paper production, bio-fuel production, vermicompost and bio-char preparation. But mostly farmers are not enthusiastic to adopt these practices because of scattered residue which is difficult to gather. In this situations the feasible, eco-friendly and recommendable method is residue incorporation and inoculation of cellulose and lignin degrading micro organisms which would add organic matter and nutrients to the soil. Some micro organisms viz., *Pleurotus, Trichoderma, Aspergillus, Azotobacter,* etc could not only degrade complex substrates but also release growth harmones and antibiotis. Crop residue degradation rate is enhanced by *Trichoderma* spp. by the production of enzymes like cellulases, hemicellulases, proteases, and â-1, 3-glucanase (Keswani *et al*., 2015), on the other hand *Trichoderma* spp. produce growth hormones such as gibberellic acid, indole-3-acetic acid and abscisic acid (Hassanein, 2012).

Crop residue generation in intensive cropping system: Crop residue is the portion of plant left in field, after harvest and consisting of stalks, stubbles and leaves. Agriculture is a crucial aspect for Indian economy which leaves huge quantity of crop residues. With the growth of increasing food demand and shortage of land area the world agriculture has intensified since 1960s. Shifting of traditional farm based crop cultivation to more advanced commercial crop management practises have led to more biomass generation in agricultural fields. The approximate production of crop residue per annum is 500 million tonnes (GOI, 2016) which is likely to increase. In India predominant cropping system is rice-wheat system which accounts approximately 25% of the residue production (Sarkar *et al*., 1999; Bisen and Rahangdale, 2017). The quantity of residue produced can be analysed by residue to crop ratio and dry matter portion of residue in crop biomass. The highest crop residue generation was estimated in Uttar Pradesh (60Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt). Crop residue generated through different crops can be categorised into cereals, pulses, oil seeds, sugarcane and fibre crops on the basis of crop type. More than half of the residue generated through cereals (59 %) followed by sugarcane (27%) and minimum by fibre crops (3%). The residues generated through different crops are shown in Fig.1.

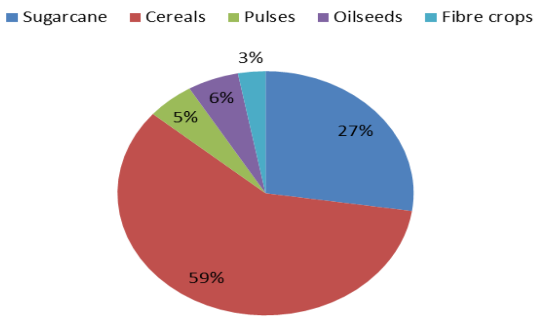

Fig 1. *Crop residue generation through different crops.Source: Ministry of Statistics and Program Implementation (MOSPI, 2013-14).*

Table 1. Agricultural field residue burning in selected countries.

Country	Amount of biomass burned in field (Mt)
Africa	49
Asia (Excluding China and India)	274
India	81
China	6
Latin America	85
Brazil	42
USA	36
Australia	7

Source: Yevich and Logan (2003)

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 and 80 across states and is maximum in Punjab, Haryana and Himachal Pradesh (80%) followed by Karnataka (50%) and Uttar Pradesh (25%) (Gupta *et al*., 2003; Jain *et al*., 2014).

Possible way out for utilization of crop residue: Traditional age old practice of crop residue disposal is to burn the crop stubbles in open fields. In India, crop waste burnt is around 18–30 % but along the Indo-Gangetic plain the figure is as high as 30-40% (Kumar *et al*. 2015). Crop residue burning is identified in many countries (Table 1) leads to hazardous environment.

As India is an agriculturally dominant nation, along with economic yield, sustainable utilization of farm resources is appropriate to improve standard of

Table 2. Management options for left over residue.

Residue management	Residue type	Exp. Details	References
Ethanol production	Corn	In USA, ethanol is produced through corn residue. For additional yeast nitrogen requirement protease enzyme is added to the mash.	Bothast and Schlicher, 2005.
Ethanol production	Bagasse	Ethanol is produced by oxidative delignification with peroxidase and 2% H_2O_2 at 20^o C for 8 hrs	Sun and Cheng, 2002
Macerating fluid by solid state fermentation	Orange peel	*Rhizopus oryzae* utilized orange peel under solid state fermentation conditions by secreting pectin lyase enzyme. Addition of NH_4NO_3 and NH_4Cl enhanced the process.	Hamdy *et al.*, 2005
Oyster mushroom	Rice and wheat straw	Rice straw (15%, 30%, 45%) and wheat straw (20%, 30% and 40%) as basal substrates for mushroom production found cost effective method.	Yang *et al.*, 2013
Shiitake mushroom cultivation	Wheat bran, rice bran, maize powder	In Bangladesh, mushrooms were provided with different levels of wheat bran, rice bran and maize powder supplementing saw dust. Wheat bran 25% supplementation showed highest number of fruiting bodies (34.8/500 g packet).	Moonmoon *et al.*, 2011
Briquette production	Rice husk	In Brazil, factory located at Mato Grosso state used rice husk as feed stock for briquette production by adopting mechanical piston technology.	Felfli *et al.*, 2011

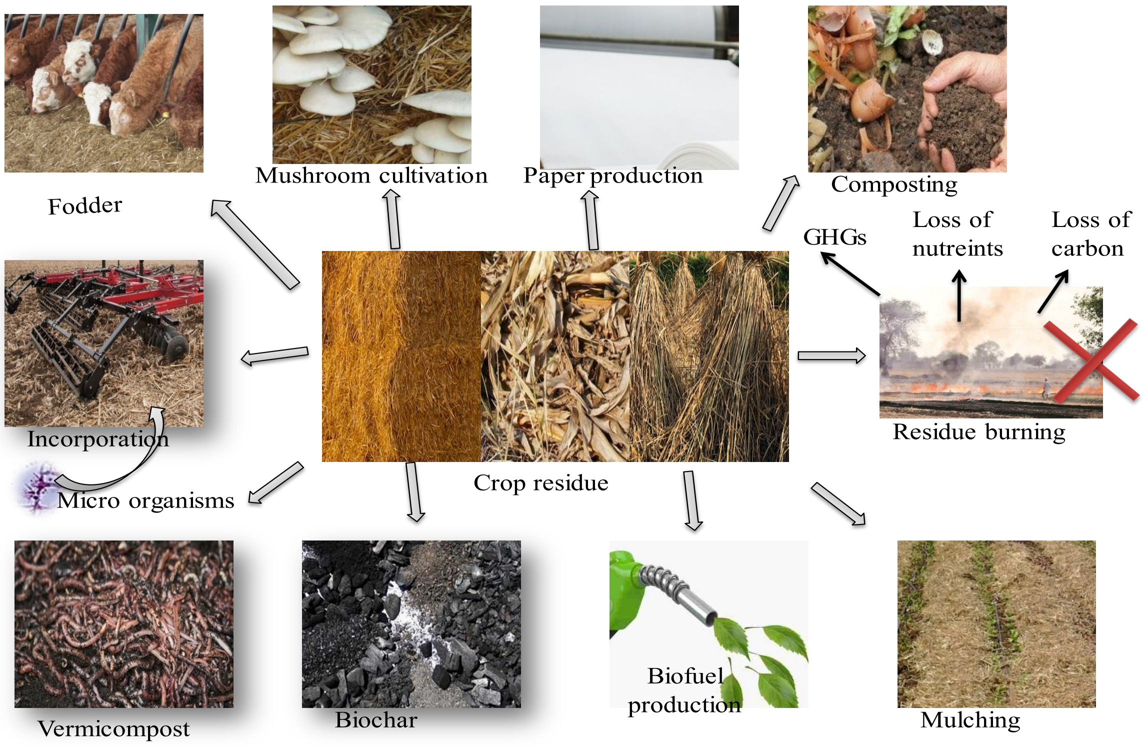

Fig 2. *Possible ways of utilization of crop residue.*

living. Appropriate mechanism for disposal of crop residues became a considerable issue, therefore the priority is on aerobic composting through which crop residue can be transformed into organic manure by microbiological process (Sharma *et al.*, 1999) instead of in-situ burning of residue. Rice is the most consumed food grain and is growing in large areas which generates huge quantity of residue in the form of straw, 668 t of straw can produce 708.7 litres of bio-ethanol (Kim and Dale, 2004; Devi *et al.*, 2017). To mitigate the complications due to residue burning, the possible approaches include crop residue as fodder, in bio-thermal power plants, in mushroom cultivation, production of bio-oil, as bedding material for cattle, paper production, bio-gas and incorporation of rice residue in soil, energy technologies and thermal combustion (Kumar *et al.*, 2015; Devi *et al.*, 2017). Some possible alternative uses (Fig. 2) of crop residue are:

Table 3. Degradation of various organic substrates by *Trichoderma* spp.

S.N.	Microorganisms	Substrates	Results	Authors
1.	*Trichoderma reesei, Humicola insolens*	Paddy straw	In an experiment conducted in Japan revealed Combined application of *Trichodermareesei*and*Humicolainsolens*enhanced the enzyme activity. Mixture of *Trichoderma* and *Humicola* in 75% : 25% (v/v) produced 79.8% hydrolysis ration is 10% higher than *Trichoderma* alone.	Kogo *et al*., 2017
2	*Trichodermareesei*	Filter paper	Whatman no.1 filter paper (from Maidstone, Kent, U.K) was hydrolysed by cellulolytic components produced by *Trichodermareesei* needed 20g per one filter paper for half maximal hydrolysis.	Nidetzky *et al*., 1994
3	*Trichodermareesei*	Cellulose	Cellobiohydrokases (CBH1 and CBH2) derived from *Trichodermareesei* showed synergistic effect in cellulose degradation.	Henrissat *et al*., 1985
4	*Trichodermareesei*	Cellulose	In an experiment conducted in Austria, the results revealed that concentration of protease derived from*Trichodermareesei* in extracellular fluid positively correlated with the protolytic cellulose degradation products.	Haab *et al*., 1990
5	*Trichodermareesei*	Cellulose	Transcripts of cellulase system CBH1 and EGL1 are present in uninduced cells of *Trichodermareesei* which are induced atleast 1100 fold in the presence of cellulose (Experiment was carried out in Brazil)	Carle-Urioste *et al*., 1997
6	*Trichodermareesei*	Hard wood	Hard wood pretreated with dilute sulphuric acid at high pressure and is subjected to complete enzymatic hydrolysis resulted in production of lignacious residue. During hydrolysis a significant amount of cellulase found to adsorbed.	Ooshima *et al*., 1990
7	*Trichoderma* spp.	Paddy straw	In a green house experiment pots with 6 inch diameter were inoculated with *Trichoderma* spores at 10^1, 10^2, 10^3, 10^4 and 10^5 per gram soil with the addition of rice straw segments of 1cm. control plot was maintained without inoculating with *Trichoderma*. After a month 60-70 % colonization of *Trichoderma* on paddy straw was noticed in pots with 10^5 counts, whereas in 10^1 to 10^3count, the observed colonization was 20%. The decomposition of paddy straw was faster when it was incorporated into the soil rather than leaving on the surface, when moisture content was optimum and inoculated with more spore count.	Cumagun *et al*., 2009
8	*Trichodermaviridae, Trichodermaharzianum*	Lignin	Laccase, manganese peroxidase and lignin peroxidase are produced by these fungi genera in basal medium with the use of tannic acid and ABTS (2, 2'azino-bis-3-ethylbenz-thiazoline-6-sulfonic acid) supplemented agar medium. These enzymes degrade lignin via extracellular action and oxidation. In tannic acid agar plate *Trichodermaviridae* shows highest solubilisation index and zone diameter during lignin decomposition.	Dabhi *et al*., 2017
9	*Trichodermapseudokoningii*	Hydroxyl groups present in the cellulose structure	Cotton fibres, treated with culture filtrate of *T. pseudokoningii* produces short fiber generating factor (SFGF) along with breaking of hydrogen bonds in cellulose. This results in rigidity loss of cellulose fibres and produces short fibres (SFGF) which are more prone to get hydrolysed by the cellulase actions.	Wang *et al*., 2003
10	*Trichoderma* spp.	Sugarcane trash, paddy straw and wheat straw	Bio-degradation of residue like sugarcane trash, paddy straw and wheat straw with the inoculation of *Trichoderma* studied for 3 months under pit conditions. Paddy and wheat straw has taken 60 days and sugarcane trash has taken 90 days for formation of quality compost with the activity of *Trichoderma*. At the end of the composting C : N ration is decreased substantially. This technique could be extended to insitu conditions.	Sharma *et al*., 2012

Biothermal power plants: One of the advisable management of crop residue is generation of electricity. At village Jalkheri, Fatehgarh Sahib, a power plant of capacity 10 MW running based on the biomass (paddy straw) was established in 1992 and is operative since 2001 (Kumar *et al*., 2015; Singh, 2017).

The fuel value of crop residue per Mg is around 16 $\times 10^6$ BTU (Weisz, 2004) which can be comparable to 2 barrels of diesel accounting for 18.6 $\times 10^9$ J or 3 $\times 10^6$ kcal of energy production (Lal, 2004). Heating value of stubbles is around 3×10^6 kcal/Mg which values the energy about 50% of that of coal and comparable to diesel it is around 33% (Larson 1979). Therefore a huge amount of biomass can be exploited for lowering the cost of electricity needed in rural household areas if used properly.

Paper manufacturing: Paper can be produced by paddy straw in combination with wheat straw in 4 to 6 ratio. Paddy straw is being used by more than 50% of pulp board mills with reference to the data furnished by PAU (Kumar *et al*., 2015; Singh, 2017).

Mushroom cultivation: Paddy straw can be used as bedding material for paddy straw mushroom cultivation which will assure economic and nutritional security. Wheat and rice straw are excellent bedding materials for *Agaricus bisporus* (white button mushroom) and *Volvariella volvacea* (straw mushroom) which are commonly cultivated.

Mulching: It is a process of utilizing farm left over to cover barren soil which incorporates organic matter and nutrients to the soil with the combined benefit of weed growth prevention.

Compost preparation: Crop residue can be used as cattle bedding material in cattle shed which would absorb 2-3 kg urine/ kg of crop residue and then heaping would be done in dung pits (Gupta *et al*., 2012).

Bio-fuel production: To ensure energy security, for replacement of imported crude oil and to reduce the dependency on fossil fuels, assuredly bio-fuel adoption is ecologically and commercially profitable approach. Cellulosic biomass could be utilized as feed stock for ethanol production which can either directly be used as fuel for vehicles or as gasoline additive.

Vermicompost: It is nutrient rich organic fertilizer and soil conditioner which will be prepared by the activity of earthworms to create a mixture of decomposing wastes.

Biochar: It is a fine grained, carbon rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperature (~350 ^{0}C – 600 ^{0}C) in an environment with little or no oxygen which would be produced with any type of residue. After conversion of plant biomass to bio-char, it constitutes recalcitrant and resistant pool of carbon, thus used as a carbon sequester in soil (Joseph and Lehmann, 2015; Bisen *et al*., 2017).

Residue incorporation: Instead of residue burning and removal, incorporation of residue into the soil enhances physical, chemical and biological properties of soil. Incorporation of residue avail the recycling of nutrients with a slight constraint of temporary immobilization of nutrients like nitrogen, hence additional nitrogenous fertilizer is required to mitigate high C : N ratio of incorporated residue (Singh *et al*., 2005; Singh *et al*., 2008).

In preference to residue burning, the discussed alternative transformations of crop residue has been practically demonstrated by many authors (Table 2) as indicated.

Trichoderma may be a partial answer: In order to remove the crop residue biomass without having major impact on climate change, the residue must be returned to soil in an eco-friendly manner. The incorporation of micro biome into soil or to crop residue leftover in fields not only assures the return of sufficient residue carbon to soil but also enhances soil microbial activity in long run. Impact of these practises can lead to good nutrient recycling in soil with improved soil health. Asper crop degradation is concerned the fungi among other microbes labelled as prominent biomass utilize. It's not because of their sizes but also their predominance in wider range of soil pH and efficiency to assimilate a large amount of organic carbon that is present in crop leftover.

Incorporating the crop residue remained after harvest is one of the feasible and beneficial alternative with a limitation of immobilization of nutrients like nitrogen at initial stages due to high C: N ratio which could be mitigated by inoculation of fast decomposing microorganisms like *Trichoderma.* It is a fungi belongs to Hypocreaceae family under Ascomycota phylum, has many strains that are capable of decomposing lignocellulosic waste materials in crop fields. It degrades complex substances of organic matter *viz*., hemicellulose and cellulose, so that the time taken for decomposition of residue can be shortened with the advantage of nutrient mineralization and checking soil borne diseases. Generally crop residue consists of 10% dry mass of which lignin accounts for 10–25% of lingo-cellulosic materials (Bisen *et al*., 2017).Major portion of the residue generated i.e., paddy, wheat straw and sugarcane trash could be transformed into valuable organic compost at insitu level, thus could enhance the physical, chemical and biological properties. Besides feeding upon dead cells the fungus also kills other fungal cells, a process known as myco parasitism in soil (Deacon 2006). *Trichoderma* is believed to be active cellulose decomposer (Domsch and Gams, 1969). Not only cellulosic materials but *Trichoderma* also produce lignin peroxidise and laccasefor ligno-cellulosic material degradation which helps in lignin degradation (Dabhi *et al*., 2017). Thus, *Trichoderma* spp. helps in delignification and cellulose biodegradation in nature. The fungi have good antagonistic and bio parasitic activities as *Trichoderma* produces many antifungal agents that help them to regulate other phyto-pathogens (*Yobo et al., 2011*).

Inoculation with a mixture of cellulolytic fungi viz., *Trichoderma viride* and *Trichoderma spiralis* fasten the degradation of sugarcane trash (Rasal *et al*., 1988; Singh *et al*., 2002), whereas *Trichoderma reesei* reduced the time period for decomposition in mixed residue (Sharma *et al*., 1999; Singh *et al*., 2002). *Trichoderma* spp are highly suitable for trash recycling into quality compost, however *Trichoderma harzianum* is much potent in residue degradation and enhanced N, P, K, S levels and decreased C : N ratio significantly over *Trichoderma viridae* (Sharma *et al*., 2012). Benefits of inoculated *Trichoderma* is more noticeable when residue is incorporated into the soil than when it is on the surface, as well as at optimum moisture conditions it decomposes the residue better and *Trichoderma* also be associated with disease management in rice based cropping system, thus reduces the cost involved in hazardous chemicals. It degrades cellulose into simple substrates such as glucose, cellobiose and xylose. Hence *Trichoderma* can moderately deal with the complications arising due to burning of crop residues.

Trichoderma ressei uses glucose, xylose, cellobiose to meet its carbon and energy requirement (Fig.3).

Success story: In current investigation, Trichoderma is one of the possible answer for biodegradation of residue generated. Some of the experimental details are mentioned regarding decomposing of organics by Trichoderma (Table 3.)

Conclusion

Wide range of crop production in India derives huge amount of crop residue which would ultimately subjected to burning, though it has immense economic value as fodder, in bio-thermal industries, in mushroom cultivation, compost preparation and as mulch. From region to region, management aspects of residue vary depending up on socio- economic demands. Burning of residue is a noticeable reason for environmental pollution, deterioration of soil physical and chemical characteristics. To alleviate this complication, the feasible and eco-friendly management practice for crop residue disposal is its incorporation into the soil along with inoculation of cellulolytic microbes such as *Trichoderma* could be possible alternative for proper recycling of farm waste. *Trichoderma* en-

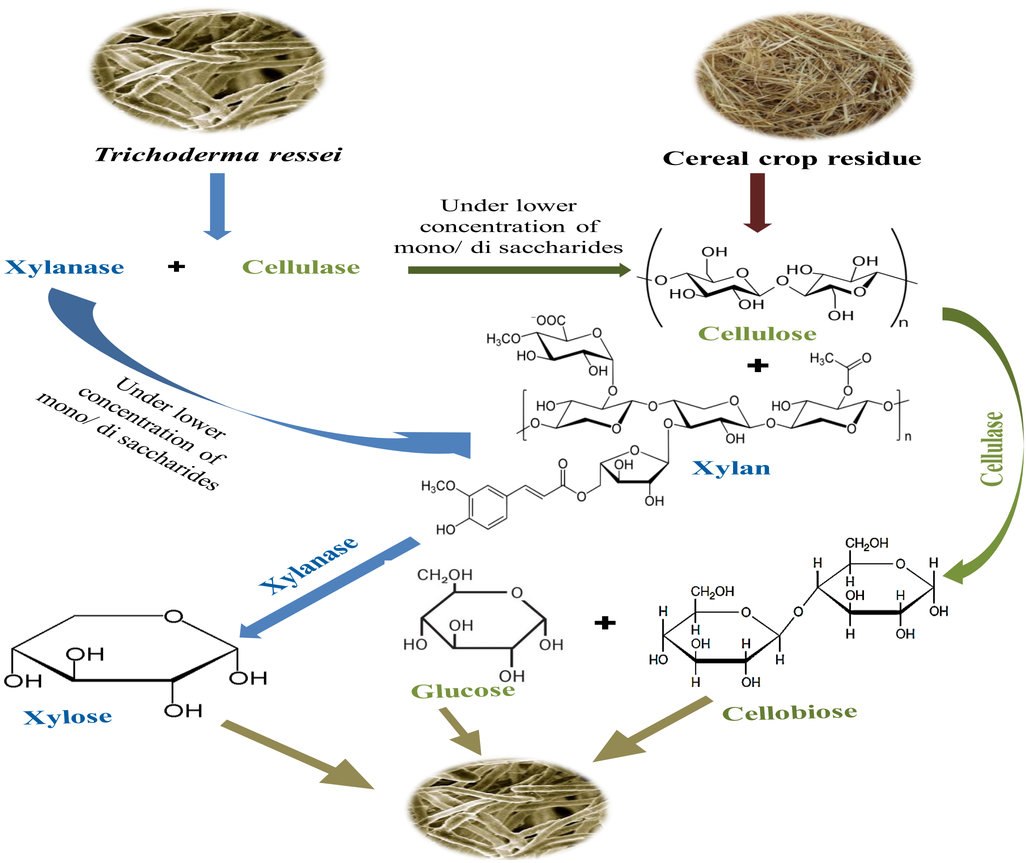

Fig. 3. *Simplified diagram of T. ressei mediated crop residue degradation.*

hance decomposition rate through degrading complex compounds like cellulose, hemicelluloses and lignin of residues and improves soil health with the added advantage of saving the environment against pollution due to burning of field wastes. The major constraint in adopting this technique is inadequacy of knowledge regarding benefits of this approach among farmers. The major difficulty is acquiring farmers realization towards this complication, hence inculcating knowledge among farmers by involving multi stake holders and targeting women and youth is crucial. Environmental destruction made the world to turn towards sustainability. In the current scenario, microbial inoculants is a major concern to maintain sustainability and have incredible scope in near future.

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