SUGARCANE-TRASH MANAGEMENT FOR SUSTAINING SOIL HEALTH AND DECREASING RISK OF SOIL-BORNE DISEASES, PARTICULARLY IN TROPICAL REGIONS

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Abstract. Sugarcane-trash management has now been widely applied in sugarcane cultivation systems. One of the sugarcane-trash managements is to return sugarcane bagasse to the land. In a tropical climate with humid and hot conditions, this practice would accelerate microbial activity to degrade the bagasse. This, further, results in providing the availability of organic matter in soil nutrients. However, bagasse is also an appropriate growing medium for soil-borne fungi such as *Sclerotium rolfsii*, *Rhizoctonia solani*, and *Xylaria warburgii*. These pathogenic fungi cause leaf midrib dry rot, ribbon midrib blight, and root rot diseases, respectively. Severe infection due to these pathogenic fungi would cause plant death and so decreased sugarcane production. Sugarcane-trash management that accelerates the decomposition process of sugarcane trash and suppresses the development of soil-borne diseases needs to be developed. Integrating the techniques to accelerate the decomposition rate with sugarcane-trash management should be considered. The techniques include inundation of primary decomposers, such as earthworms, addition of promoting substrates, and introduction of antagonistic microbes and decomposers, such as *Trichoderma* spp.
Keywords: *antagonistic microbes, bagasse degradation, microbial activity, organic matter, soil decomposer*

Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the world's major food-producing crops, providing about 75% of sugar produced in the world for human consumption (Souza et al., 2008) with total production in 2019 was more than 1.90 billion tonnes produced by 120 countries on areas of more than 26.27 million hectares (Souza et al., 2008; FAOSTAT, 2021) in subtropical and tropical region (FAO, 2005). The world consumption demand increased continuously, leading to crop yield focused on agriculture activities that ignore the sustainability of agro-ecosystems i.e.: biological and ecological process (Boincean et al., 2016). Therefore, agricultural intensification for a long period has degraded soil organic matters and ultimately resulted in the reduction in soil fertility (Kopittke et al., 2019) and favored the occurrence of soil-borne diseases (Krikun et al., 1982).

Sugarcane is a perennial crop planted from vegetative cuttings for 9-13 months. After harvesting, the shoots regrowing from the stump, known as ratoon cane. In some developing countries such as Indonesia, the ratoon cane could last for seven to 12 years (7-12 ratoon crops). Furthermore, sugarcane takes large amounts of nutrients from soil during its growth and development and requires to apply additional fertilizer to compensate the soil fertility to sustain sugar yields (Yadav et al., 2009). Therefore, sugarcane grown under the monoculture system for ten years decreased soil fertility

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significantly (Hartemink, 1998). During sugarcane growth, every ton sugarcane/ha will uptake 0.56-1.2 kg N, 0.38-0.82 kg P_2O_5 and 1.0-2.5 kg K, 0.25-0.60 Ca, 0.20-0.35 kg Mg, 0.02-0.2 Na, and 2.0-2.7 out of the soil (Zande, 1990).

Traditionally, in some sugarcane plantations mature sugarcane crops are burned before harvesting to help simplify the harvesting process which could reduce the labour cost or burning the sugarcane residues after harvesting before ratoon. The sugarcane trash (comprised of 54% of dry leaves and 46% of tops) was estimated at 10.7 t/ha (Franco et al., 2013) or even 8 to 30 t/ha (Carvalho et al., 2017). Burning of sugarcane trash is not environmentally safe, because it releases smoke and other toxic compounds that are harmful to human health and destroy the beneficial insects, such as parasitoids and predators, and reduces insect diversity. Also, the trash burning caused soil microorganisms, small florals, and faunas are killed (Rípoli et al., 2000). Sajjad et al. (2012) reported that population of sow bugs, spiders, ladybird beetles and ants numbers were reduced by 96%, 95%, 85%, and 61%, respectively, due to the effect of burning of sugarcane trash. Furthermore, silica contained in ash produced during the burning process polluted the surrounding areas and it could cause respiratory diseases (Le Blond et al., 2008). The organic matter and nutrients were also depleted, resulted in adversed soil conditions.

Considering the negative effects of clearing and managing of sugarcane plantation land by burning, some sugar industries implemented a trash management system to improve the soil's physical conditions, as well as to increase the soil productivity. This system allows sugarcane residues (dried leaves and litters) to be mulched or incorporated into the soil. However, humid and hot conditions of some sugarcane growing regions, like those in tropical area, are conducive for soil-borne fungal pathogens, which are able to live saprophytically, to perpetuate and be pathogen inocula to cause deseases on subsequent planted crops. Therefore, in this paper we propose the management of sugarcane-trash to sustain the soil health and to decrease the risk of soil-borne diseases, particularly in tropical areas.

Practices on sugarcane trash management

Research on trash management has been widely reported to have a good influence on sugarcane productivity, improve soil fertility, and would achieve sustainability. Trash management implemented included retaining the trashes combined with the addition of compost. These practices improved soil physical, chemical and biological characteristics as well as increased the germination of sugarcane setts and yield, controlled soil erosion, increased microbial and small fauna activities, retained moisture and reduced evapotranspiration. Reports on the positive effects of sugarcane trash management practices are presented in *Table 1*.

Germination of the setts was only 68% when planted in soil where the residues were burned, but the germination reached 82%, with average cane yield increased 12.8% when the trashes were plowed and enriched with *Trichoderma viridae* (Savitha and Suma, 2015). Munoz-Arboleda and Quintera-Duran (2009) reported that the effect of retaining the trash on the soil increased yield on eighth ratoon cane (RC), but not in plant cane (PC). The sugarcane yield in the PC was around 150 t/ha. The eighth RC yielded 80 t/ha when the trash was removed without addition of fertilizers. However, when the crops were fertilized, or the residues were mulched on soil, the cane yield increased by 30 t/ha. The yield increased even higher up to 160 t/ha when application of fertilizers was

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combined with mulching. Mulching sugarcane trash in alternate rows reduces weed growth and conserves moisture as well (Sivaraman, 2014). Sugarcane should be weed-free during tillering in the first two months. According to Hunsigi (1993), applying bagasse and or sugarcane trash at 3-5 t/ha between rows as mulch controlled weed.

Table 1. *Reports of the benefits of sugarcane trash management practices published on 1990s to 2021*

Management practices	Results	References
Baggase mulching 3-5 t/ha, applied between rows	Control weed growth	Hunsigi (1993)
Incorporated sugarcane trash for 23 weeks	Increased microbial biomass and activity, the numbers of free-living nematodes, and unknown predatory fungus, suppressed the plant-parasitic nematodes, so that reduced the sugarcane root infection by the parasitic nematodes.	Stirling et al. (2005).
Mulching the soil by retaining the trash combined with application of fertilizer.	Increase the 8th ratoon yield by 30 t/ha.	Munoz-Arboleda and Quintera-Duran (2009)
Mulching sugarcane trash in alternate rows	Reduced weed growth and conserves moisture.	Sivaraman (2014))
Retaining sugarcane trash	Accumulated carbon in the soil surface to 30-cm depth	Cerri et al. (2011)
Plowing sugarcane residue and enriched with *T. viridae*	Increased the germination of the sett by 82% and cane yield by 12.8%; increased organic carbon, nitrogen, phosphorus, and potassium in soil.	Savitha and Suma (2015)
In situ trash mulching coupled with microbial consortia application	Numerically higher single cane weight, cane height, cane girth and significantly higher number of millable canes and cane yield.	Tayade et al. (2016)
Tillage by tractor combined with trash shredding and composts.	Improved sugarcane ratoon productivity and sustained soil fertility, including increased the microbial biomass carbon, and arbuscular mycorrhizal fungi (AMF) population.	Pillai and Manickam (2015)
Continously retaining trash on the soil surface as a 'trash blanket'	Potentially reduce N fertilizer application rates to obtain 95% of maximum yields.	Meier and Thorburn (2016)
Mulching the green cane trash blanket on sugarcane soil in Australia	Increase overall microarthropod abundance including predatory mites (Mesostigmata)	Manwaring et al. (2018)
Mulching the soil by dried sugarcane leaves	Increased diversity of soil inhabitant of spring tails.	Rahardjo et al. (2019)
Shreddered trash spreading followed by trash mulching (119 t/ha)	High yield (124 t/ha) and high Commercial Cane Sugar (CCS) (15.78 t/ha).	Vajantha et al. (2021)

The other benefits of incorporating or mulching sugarcane trash are improvement of soil characters due to the restoring organic matter to the soil. This includes enhancing the role of organic matters and nutrient contents of the applied soils. The organic matters would stabilize soil aggregates, reducing soil erosion and water runoff, improving infiltration, water retention, and as chelating agent (Haynes et al., 1991; Johnston et al., 2009; Rossetto et al., 2014). The retained sugarcane trash would cause a higher accumulation of carbon in the soil surface to 30 cm depth (Cerri et al., 2011) and when applied as a mulch could act as a long-term source of N and C (Ferreira et al., 2015). A ton of sugarcane trash contains about 5.4 kg N, 1.3 kg P_2O_5, 3.1 kg K_2O, and small quantities of micronutrients which is equivalent to 0.35% N, 0.13% P_2O_5, and 0.65% K_2O

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(Singh and Solomon, 1995; Sivaraman, 2014). Carvalho et al. (2017) recommended that the minimum mass of sugarcane trash, at least 7 t/ha, should be maintained on the soil surface to provide agronomic and environmental benefits.

Returning sugarcane trash into the soil also increased micro-mesofauna and microbial populations, particularly fungal decomposer. Rachid et al. (2016) found that the fungal community was more influenced by the trash compared to the bacterial community. It could be understood that fungi were more capable of decomposing complex carbon chains from sugarcane trash, as fungi are commonly acted as primary decomposers. Sugarcane dried leaf mulch also increased the diversity of soil inhabitant collembola (*Brachystomella* sp., *Folsomides* sp., *Mesaphorura* sp., *Alloscopus* sp., and *Dicranocentrus* sp.) but not the population due to high predator population (Rahardjo et al., 2019). Meanwhile, Manwaring et al. (2018) reported that mulching sugarcane fresh leaf significantly increased the population of soil microarthropods, including mesostigmata, oribatid mites, and collembolans. Incorporated sugarcane trash for 23 weeks increased carbon, microbial biomass, microbial activity, numbers of free-living nematodes, and unknown predatory fungus, suppresses the plant-parasitic nematodes, such as *Pratylenchus zeae* and *Tylenchorhynchus annulatus* by 85% and 71%, respectively, as well as 95% reduction in root infection in sugarcane (Stirling et al., 2005).

Although the trash management practices provide benefits for improving soil characteristics, including improving the performance of soil micro inhabitants, the microclimate around and in the soil also provides opportunities for soil-borne pathogens to thrive, especially those which inhabited in trash as saprophytes, and acted as a disease inocula for the next season crop. In the following chapter we discuss about the soil-borne pathogens that could cause infection to the plant because of retaining and mulching sugarcane trash to the soil.

Soil-borne diseases incorporation with sugarcane trash and mulch into soil

The tropics areas are characterized by high humidity almost all over year. In agroecosystems with high humidity, many pathogens have been reported to cause diseases on sugarcane or become more virulent inocula causing crop diseases. Under optimal conditions of high humidity, the retained sugarcane trash could be a source of inocula that will cause severe disease in the subsequent sugarcane plantation. Debris-borne inoculum has been widely reported to play a role in maintaining the viability of fungal propagules (Viswanathan and Rao, 2011). For example, *Sclerotium rolfsii* Sacc requires high humidity for optimal growth and is an important disease-causing pathogen in several plant species, including sugarcane (Liamngee et al., 2015); isolates of *Rhizoctonia solani*, the pathogen causing soybean seedling disease, became more virulent at high soil moisture (Teo et al., 1988; Torres et al., 2004); and *Xylaria* sp. which generally survive as saprophytes on sugarcane stubs, and under humid condition caused root and basal stem rot on sugarcane (SRSD) (Maryono et al., 2020). We discuss specifically these three soil-borne pathogens associated with sugarcane trash and mulch into the soil.

Sclerotium rolfsii Sacc. (*Athelia rolfsii*)

Sclerotium rolfsii Sacc. (*Athelia rolfsii*) has not been considered as an important fungal pathogen in sugarcane plantation. The fungus usually infects leaf sheath and causes red rot (Ricaud, 2000) or dry rot of leaf sheath (*Fig. 1a*). However, recently, we observed that

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the fungus caused the failure of sugarcane setts germination in Malang, East Java, Indonesia (*Fig. 1b* and *Fig. 1c*) and in a new site of sugarcane plantation in Seram Island, Maluku, Indonesia. The new site was previously a cleared forest land, where some wood and leaf residues were remained on the ground. Bhuiyan et al. (2019) also reported that the fungus reduced sugarcane sett germination by more than 70%. On the other hand, in subtropical Karnataka, Savitha and Suma (2015) reported that plowing sugarcane residue and enriched with *T. viridae* increased the germination of the sett. We suggest that the microclimates of tropical and subtropical regions would affect *S. rolfsii* importance as a soil-borne disease of sugarcane.

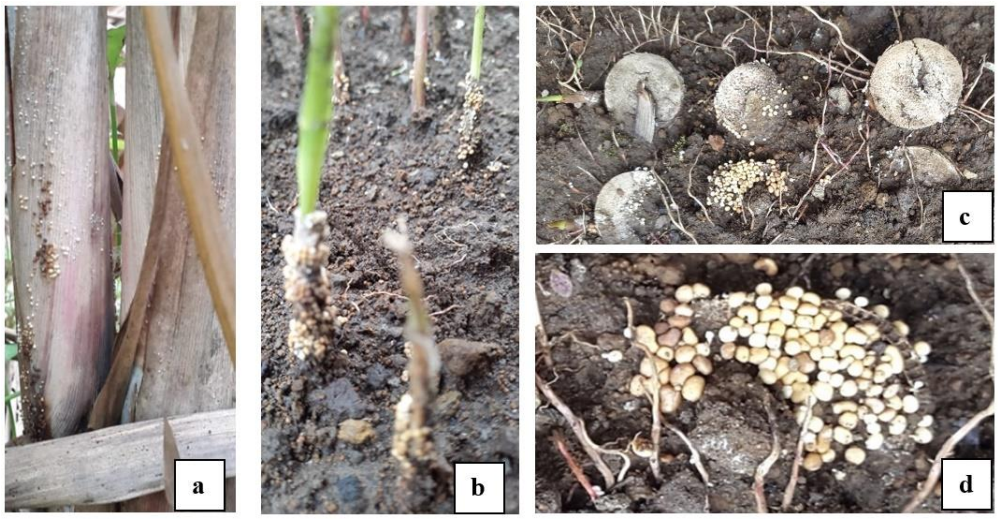

Figure 1. *Infection of S. rolfsii; (a) on mature sugarcane crop, (b) on sugarcane shoots, (c) on sugarcane setts, (d) sclerotia on the sett surface*

S. rolfsii is a necrotrophic soil-borne pathogen, able to survive on plant debris, and in the soil in the form of sclerotia (Punja, 1985). The sclerotia generally infect seedlings, the lower part of stems near or at the soil surface of a wide variety of host crop plants from vegetables, fruits, herbaceous, and woody plants (Mullen, 2000). The ability of the fungus to survive in plant debris, including sugarcane trash, should be taken into account when sugarcane-trash management is applied, especially in humid regions.

Rhizoctonia solani Kuhn

Rhizoctonia solani Kuhn (*Thanatephorus cucumeris* (Frank) Donk) also known as a soil-borne necrotrophic pathogen and has numerous host plants (Okubara et al., 2014). Sharma et al. (2022) and Safiudddin and Sheikh (2016) considered this fungus as an important fungal pathogen of sugarcane in India. Usually, *R. solani* infects the lower leaf sheath or leaf blade of sugarcane near the soil surface and then grown to the upper part. The *R. solani* would grow and caused disease in optimally humid condition.

In some sugarcane plantations in Indonesia (tropical regions), we observed some oval water-soaked yellow greenish spots appeared on lower leaf sheath or blades. This could be as an initial symptom of *R. solani* infection. The symptoms were more prominent when microclimate in the sugarcane plantation was very humid; and dense canopy of a 4-6-month sugarcane plants caused shade. The spots later developed as irregular lesions with grayish white centers surrounded by tan-brown margins, particularly in old leaves

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and known as sheath blight (*Fig. 2a*). The spot with light brown bordered with dark brown dry strips on leaf blade known as banded leaf blight (*Fig. 2b*). White to pale brown, mycelia would be seen growing and developing like spider webs on the leaf surface (*Fig. 2c*) and forming sclerotia on the dead, dried tissue (*Fig. 2d*). The severe infection could affect the stem resulting in dried rot and cracked stem (*Fig. 2e*). However, Safiudddin and Sheikh (2016) found different symptoms when *R. solani* infected sugarcane plant. In some districts of Uttar Pradesh sugarcane seedlings were killed by *R. solani* and caused stunting on infected older plant. When the fungus infected sugarcane leaves, it caused brown to dark brown dry rot leaves. However, the significant losses have not been reported.

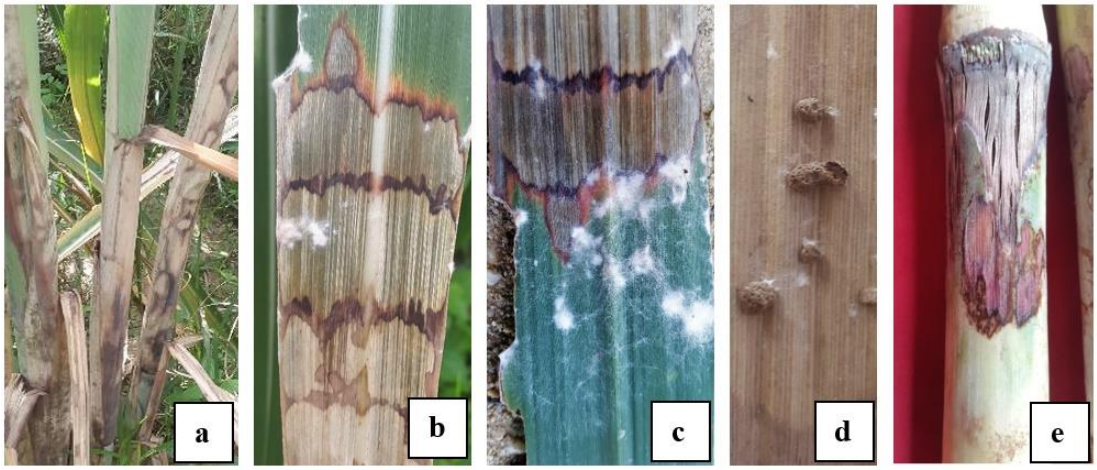

Figure 2. *Several symptoms of R. solani infection on sugarcane plant parts; (a) old leaves, (b) leaf blade, (c) leaf surface, (d) dried tissue, (e) stem*

Infected dried plant materials left on the field could be a source of inoculum for the next season, since *R. solani* could survive for a long period in plant debris and soil (Garrett, 1950). The fungus survived in form of sclerotia or pigmented hyphae (Sneh, 1991). The plant trashes such as maize litter, coconut fibers, compost pam, as well as biochar, peat, cellulose, glucose, fish meal, and sawdust increased the saprophytic growth of *R. solani.* The fungal sclerotia survived better in rice straws than that in soil and then caused severe damage to seedlings (Pusposendjojo, 1999). Furthermore, the green manure of Brassica species applied to the soil promoted the saprophytic activity of *R. solani* to cause damping-off in canola (Yulianti et al., 2005).

The survival of *R. solani* was reported being affected by the degree of temperature and humidity. *R. solani* sclerotia that survive on the soil surface or in association with plant debris are pathogenic structures that can become primary inocula that cause disease when environmental conditions, especially temperature and humidity, are favorable for them to grow. Tropical microclimate conditions provide optimal temperature and humidity for this fungal sclerotia to grow and cause plant infections. The fungus could survive in infected rice straw for 16 months when incubated at 4°C, however, its survival decreased to 50% and 35% when the temperature increased to 25°C and 36°C, respectively (Feng et al., 2017). The fungus also survived up to 10 months (100%) when the diseased rice straws were incorporated in wet or flooded paddy soils compared to those when incorporated in dry soil (75%).

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In sugarcane plantation, there is limited information regarding the capability of *R. solani* surviving in sugarcane trash. There were different results of the effect of implementing sugarcane trash residues management. As an example, Papavizas (1970) noted that addition of a high C/N ratio organic residues caused nitrogen competition among microbes and thus it could decrease the saprophytic activity of *R. solani* and its potential pathogenicity in long term period. In contrast, Bonanomi et al. (2020) found that high C/N ratio organic matters could increase *R. solani* inoculum in short-term due to its cellulolytic activity. However, in the long-term these organic matters could promote the activity of competitive microbes and cause the saprophytic activity of *R. solani* decreased. Hence, further study on the population dynamic of *R. solani* and its activity in sugarcane trash residue needs further examination.

Xylaria cf. *warburgii*

*Xylari*a cf. *warburgii* is a soil-borne pathogen causing root and basal stem rots of sugarcane in Sumatera Sugarcane Plantation, particularly in Palembang of South Sumatera and Lampung Provinces, Indonesia. It was found for the first time probably in 1993, and caused 12.3-15.4% yield losses (Sitepu et al., 2010). The disease was reported in Taiwan, Puerto Rico, and the United States (Hsieh, 1980; Fang and Lee, 2000). More than 700 ha of sugarcane plantations in Taiwan were infected by this pathogen and caused a loss of 5% on plant cane and up to 30% on ratoon cane (Fang and Lee, 2000). The infection of *X. warburgii* to the root system causes inhibition of nutrient transportation and triggering yellowish leaf symptoms. Infected plants usually grow slowly, stunted, thin, and the number of tillers reduced. Severe infection reduces sugar production and quality, even plant death (Sitepu et al., 2010).

The fungus survives in diseased stumps and infects ratoon crops in the following season (*Fig. 3*). In endemic areas, the symptoms appeared as yellow and dry planting patches. The genus *Xylaria* is classified as a white soft-rot fungus infected several woody plants (Akhtar et al., 2015) and also known as a soil inhabitant saprotrophic fungus capable in decomposing lignocellulose (Osono et al., 2011).

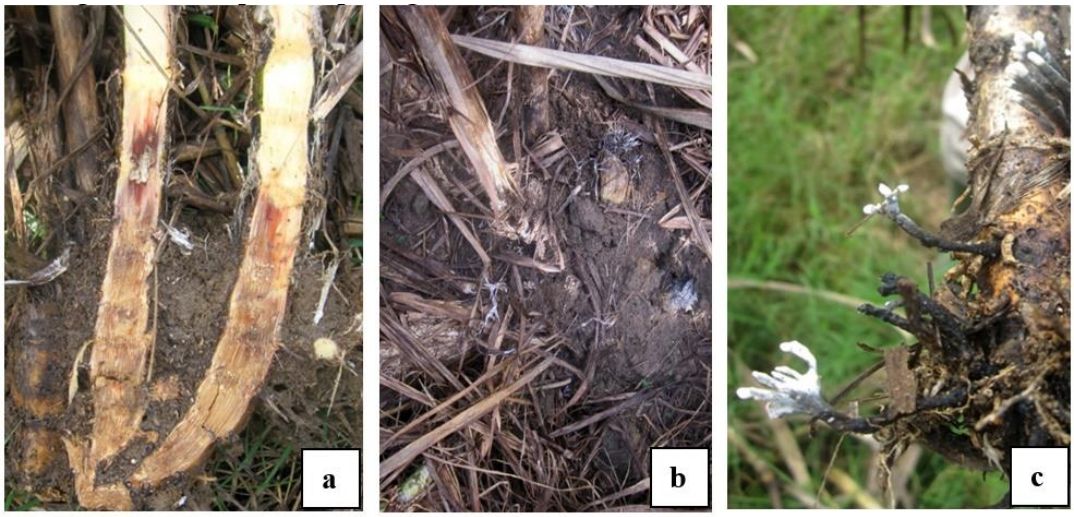

Figure 3. *Basal stem rot of sugarcane caused by X. warbugii; (a) Symptom of basal stem rot on sugarcane basal stalk, (b) Fungal mycelia mats on sugarcane trash, (c) Stroma of the fungus on sugarcane stubble*

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Similar to the two previous pathogens, *X. warburgii* as a decomposer is also be a pathogen that causes important diseases in sugarcane, if conditions are favorable. The most favorable environmental conditions are the optimal temperature and humidity for the fungus to develop into a pathogen.

Control method the sugarcane basal-stem rot has been studied intensively. Control using fungicides with the active ingredients of benomyl and carbendazim was not effective against *X. warburgii* infection in the field, although in laboratory tests with PDA media, these fungicides inhibited the growth of pathogens (Sitepu of GMP, personal communication). Winarno (2015) reported that hexaconazole 6 mL/L also inhibited the *in vitro* growth of the fungus. Currently, only varieties with low resistance to *X. warburgii* are available in Indonesia, namely PS 881, PS 864, PS 882, PSJT 941, and PSJK 922, which were developed by an Indonesian sugarcane company in South Sumatra. A study using an antagonistic fungi *Trichoderma* spp. conducted by Jati et al. (2022) showed that isolate T10 from the Indonesian Sugar Research Institute (ISRI) collection with a chitinolytic index value of 1.15 had the potential to be used as a biological control agent for *X. warburgii* in sugarcane. The development of control of *X. warburgii* in sugarcane should not only focus on suppressing the growth of pathogens and disease occurrence, but also needs to be considered to restore the balance of micro ecosystem in the soil, through a proper soil management, such as minimum tillage, solarization, the addition of silicon fertilizers, and organic manure enriched with the antagonist.

With the trash management program, i.e. returning crop residues to the soil, the presence of the biomass could provide these necrotrophic saprophytic pathogens, as mentioned above, to survive and develop, when microclimate, such as temperature and humidity, is suitable for the pathogen to grow and cause infection. A proper trash management should be applied to accelerate the decomposition process which would reduce the survival of the pathogens. We propose several techniques that can be integrated into the sugarcane management system. The decomposition acceleration techniques are through inundation of primary decomposers, addition of beneficial substrates, and introduction of microbial decomposers. Thus, all of the treatments would reduce infection as well as improve sugarcane growth.

Decomposition process of sugarcane trash

Although incorporating or mulching sugarcane trash returns nutrients and organic matter to the soil, it will take a long period of time or years to obtain the effects. By this period, specific necrotrophic saprophytic pathogens which are associated with such media, could take the opportunity to survive in the biomass. Therefore, a safe, appropriate, and faster process of sugarcane trash decomposition should be taken into account in the choosing trash management method.

Decomposition process of the sugarcane trash depends on the chemical composition of the trash, soil type, climate, water, and oxygen availability. Sugarcane trash mainly comprised of dry sheets and leaves with C:N ratio around 70-100:1 which caused the nitrogen immobilized and was not readily available for the next season crop (Robertson and Thorburn, 2007a; Ferreira et al., 2015). Mulching crushed sugarcane trash 10 t/ha on two types of only contributed 15% of nitrogen for the first six months, and then it declined slowly during 18 months (Kee Kwong et al., 1987). This meant that available N from the trash was fulfilled less than 10% of sugarcane need. Furthermore, Fortes et al. (2011) reported that the ratoon-cane plant was only used 20% nitrogen from the trash after

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incorporating residues to the field for three years. Even Robertson and Thorburn (2007b) claimed that nitrogen from the trash persisted in the soil around 80% after six years of incorporation. Therefore, nitrogen fertilizer was still required in the first six years after incorporation, because it is needed to decomposing cellulose, hemicellulose and lignin consisted in the trash (Welker et al., 2015) as the soil microbes took a longer period to degrade the trash content matters (Jenkinson and Ayanaba, 1977).

Degradation process of cellulose, hemicellulose, and lignin in sugarcane trash needs microbial consortia which produced enzymes for primary degradation and subsequent processes. Several species of cellulolytic, hemicellulolytic, and ligninolytic microorganisms including bacteria, fungi, as well as actinomycetes have been identified as decomposers associated with the sugarcane trash (de Vries and Visser, 2001; Dantur et al., 2015; Legodi et al., 2019).

The study of cellulase which plays an important role in the degradation process of cellulose has been known to be produced by cellulolytic microbes. Bacteria from the genera *Klebsiella, Stenotrophomonas, Microbacterium, Bacillus* and *Enterococcus* isolated from the intestines of sugarcane-fed larvae of the moth *Diatraea saccharalis* were reported by Dantur et al. (2015) to have a good cellulolytic activity correlated with high extracellular protein concentrations. While Pinheiro et al. (2015) reported that cellulosic enzymes produced by several bacteria found in the gastrointestinal tract of snail *Achatina fulica*, including those from the genus *Cellulosimicrobium, Microbacterium*, and *Agromyces* had the ability to degrade cellulose contained in sugarcane bagasse.

Degradation of hemicelluloses, such as glucan, xylan, arabinan, galactan, and mannan, requires several enzymes from microbes (fungi, bacteria, and actinomycetes) and also small faunas. For example, mannan could be degraded by β-endo-mannanases (β-mannanases) and β-mannosidases produced by *Aspergillus* (de Vries and Visser, 2001). Xylan esterases, ferulic, and p-coumaric esterases, α-l-arabinofuranosidases, and α-4-O-methyl glucuronidase, were further needed to hydrolyze xylans and mannans (Pérez et al., 2002). Whilst endoglucanase (EC 3.2.1.4), exoglucanase or cellobiohydrolase (EC 3.2.1.91) and β-glucosidase (EC 3.2.1.21), mainly produced by fungi, bacteria, and protozoans, were needed to hydrolyze polysaccharide cellulose (Immanuel et al., 2006). Endoglucanases (EGs) were usually produced by basidiomycetes, brown rot, and white-rot fungi and also from the plant pathogen *S. rolfsii* (Baldrian and Valášková, 2008). Legodi et al. (2019) reported that *A. fumigatus* produced β -glucosidase enzyme, *T. harzianum*, and *T. longibrachiatum* had cellulase and endoglucanase enzymes. Akhtar et al. (2015) found that *Bacillus subtilis* from composting materials were capable of degrading cellulose. There were also three bacteria (*B. macerans, Cellulomonas cartae,* and *C. uda*) found by Singh et al. (2008), which were able to degrade cellulose and lignin into fermentable sugar. One of the critical issues related to the implementation of enzymes to improve the biomass use in Brazil is to search for novel and potent strains producing lignocellulosic enzymes (Valencia and Chambergo, 2013).

Lignin has a complex structure, high molecular weight, and water insolubility make it is challenging to degrade (Pérez et al., 2002). Lignin also prevents the penetration of hemicellulose and cellulose degraded enzymes since it binds them to form a physical seal between them (Howard et al., 2003). Ligninolytic enzyme produced by *Phanerochaete chrysosporium*, a white rot fungus, removed 62.59% - 65.63% lignin on sugarcane bagasse (Ramesh et al., 2021). Ligninolytic enzyme decomposed lignin of sugarcane

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bagasse and enhanced both labile and stable components of soil organic (Phukongchai et al., 2022).

Decomposition of retained sugarcane trash in the field has a good impact on the soil, nonetheless it would cause soil-borne pathogens associated with it to become a serious disease problem, especially in tropical areas which bear high humidity. Accelerated decomposition process is expected to overcome this problem. We propose some techniques for accelerating the sugarcane degradation rate. Acceleration of sugarcane trash decomposition requires the induction of several microbial activities, mainly those that responsible for cellulose, hemicellulose, and lignin degradation. There are several alternative methods to boost the process, i.e., introducing of primary decomposers, addition of promoting substrates, and introduction of decomposer microbes.

Inundation of primary decomposers

Mesofauna, such as earthworms, collembola, and acarina, could break down the trash into smaller parts or excrete it as feces. Earthworms were capable of digesting complicated and resistant organic matter since they are symbiont with bacteria (Trigo and Lavelle, 1993). Lately, vermicompost are used to increase soil health status, also enhancing soil biodiversity. Vermicomposting is the degradation process by which earthworms ingest, digest, and absorb green wastes through their metabolic system, then biological activities of microorganisms and enzymes enhance the level of nutrients in the earthworm excrement (Cai et al., 2020). The vermicompost substantially improve microbial biomass (Hernandez et al., 2014). This microbial biomass provided a broad variety of antagonistic microbes in vermicast and served an efficient biocontrol of soil borne phytopathogenic fungi (Pathma and Sakthivel, 2002; Hernandez et al., 2014). Moreover, Gopalakrishnan et al. (2011) stated that vermicompost provided better soil porosity, thus induced more aerobic conditions, hold more water, and gave good drainage, produced enzymes, and growth stimulants for crops (Joshi et al., 2014). *B. subtilis* in vermicompost produced volatile compounds that inhibited the growth of pathogenic fungus *Botrytis cenerea in vitro* and also triggered morphological abnormalities of pathogenic fungi (Mu et al., 2017).

The primary decomposers which produced composts, such as vermicompost, provided media for microorganisms for further decomposition stage and also provided the antagonist microbials to play a role as effective inhibitors for the soil-borne pathogens to grow and cause diseases. Vermicompost was a source of antagonistic microbes, especially those from Actinomycetes (Gopalakrishnan et al., 2011), and is rich in chitinolytic bacteria and has a function as a soil suppressant (Yasir et al., 2009). *Eisenia foetida* and *Eudrilus eugeniae* are the two earthworm species that had been utilized for vermicomposting process (Dominguez et al., 2019; Cai et al., 2020; Biruntha et al., 2020; Sujatha et al., 2021; Sharma et al., 2022). Acceleration of decomposition rate by inundating the primary decomposers such as earthworm or other vermicompost producer species would be integrated in sugarcane-trash management.

Addition of beneficial substrates

Acceleration of decomposition rate could also be done by adding beneficial substrates into the trash piles. The substrates were used as a starter food for *in situ* or introduced microbes. The microbial food could be humid acid and yeast extracts, vinasse, and extract of composted rumen mixed with sugarcane stubble. Addition of the substrates were aimed to increase the population of decomposer microbes.

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Naidu et al. (2010) used humic acid and yeast extract at the rate of 4:7/100 g (w/w) as a starter substrate to increase the microbial population in tea compost. The bacteria, yeast, fungi, and actinomycetes reached ten to a hundred folds compared to control after six months period of storage. Humic acid had several functions, such as growth regulator for some bacteria and exocellular enzyme-producing fungi, a nutrition source of plants, living cell protectors from toxin (Tikhonov et al., 2010). Yeast extract was a processed yeast product, which commonly used for improving microbial grown in culture media since it contains vitamins, trace elements, growth factors, amino acids, and peptides (Ferreira et al., 2010).

Sica et al. (2020) stated that vinasse, a liquid bioproduct of sugarcane could be used as biofertilizer. Yamaguchi et al. (2017) obtained that the addition vinasse at the rate of 200.000 L/ha on top of 16-24 t/ha sugarcane straw (comprised of 75% dry leaves and 25% green leaves) boosted the decomposition process of the trash by 14-35%. Vinasse is an acidic organic sugar product that mainly contains glycerol, which accelerates the development of early decomposer fungi (Christofoletti et al., 2013). Vinasse can also be used as biofertilizer since it contained some nutrients such as N, P, K, Ca, Mg, S, Zn, Mn, Fe, and Cl (dos Santos et al., 2013). The Indonesian Government Estate for Sugarcane applied vinasse biofertilizer at the rate of 50.000 L/ha mixed with a standard dose of inorganic fertilizer increased the number of stalk/row by 142% and plant height by 111%.

Another substrate from an extract of sugarcane stubble mixed compost can be used to enhance the degradation rate of sugarcane trash. Shrestha et al. (2012) prepared the extract from a nine-month-old composted rumen mixed with sugarcane stubble in a ratio of 1:1. The mixture (3 kg) was placed in a cotton bag and then submerged in 30 L aerated water enriched with 1% (v/v) 'fish and kelp hydrolysate' and 0.5% (v/v) molasses at the ratio of 1:10 (v/v). After one month of incubation, the extract was sprayed twice at the rate of 200 L/ha on the sugarcane trash layer for six months. As a result, the CO_2 released total soil C and dissolved organic C increased. The *in situ* method for sugarcane trash composting has been studied by Dhanushkodi et al. (2019). Sugarcane trash was sprayed with 20 kg of bio-mineralizer microbes and provided frequent irrigation water accelerated the composting process increasing the organic carbon (0.42 to 0.45%), available N (317 to 331 kg ha^{-1}), P (14.5 to 16.1 kg ha^{-1}), and K content (520 to 551 kg ha^{-1}), increased 4.8% yield (92.5 t ha^{-1} over the control plot of 88.3 kg ha^{-1}), and increased gross income by 4.7% and benefit-cost ratio of 2.99 over control plot.

Introduction of microbial decomposer

Acceleration of sugarcane trash decomposition by introducing cellulolytic/ligninolytic microorganisms have been practiced worldwide. The decomposers are more effective when they possess antagonism properties to fungal pathogens. The most common decomposer, which also acts as an antagonist and plant growth promotor, is the genus of *Trichoderma* (Harman, 2000). Dhapate et al. (2018) reported that the application of decomposer fungi, such as *Trichoderma* sp., *Penicillium* sp., *Aspergillus* sp., *Paecilomyces* sp., and *Rhizopus* sp., enhanced the decomposition process of sugarcane trash, then actinomycetes and bacteria used released nutrition into the soil for further decomposition. A similar result also reported by Yadav et al. (2009), who inoculated *T. viride* in sugarcane trash mulch in ratoon cane. The inoculation increased the basal soil respiration, the soil bulk density, microbial biomass, soil organic carbon, and N, P, K uptake. As a result, it increased sugarcane yield by 12.8 t/ha compared to the plot where trash was removed without *Trichoderma* inoculation. The faster degradation of the

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sugarcane trash by *T. viride* also provided nutrition for *in situ* microbes (bacteria and fungi).

Amblyosporium sp. and two species of *Aspergillus*, as a lignocellulolytic consortium, mixed with sugarcane bagasse, filter cake, and manure as composts were reported to be effectively speeded up the composting process and which produced compost with C/N ratio of 9-22% (Rahmad and Nurmiaty, 2022). Previously, Dhapate et al. (2018) showed that a cellulolytic fungal consortium consisted of *Trichoderma* sp., *Penicillium* sp., *Aspergillus* sp., *Paecilomyces* sp., and *Rhizopus* sp. significantly accelerated the decomposition rate of sugarcane trash and improved the chemical and biological properties of the compost. Li et al. (2012) also found that cellulolytic consortium bacteria degraded wheat straw more effectively than individual isolate and also enhanced the decomposition rate. Our collection of decomposer and antagonist microbia consisting of 14 *Trichoderma* strains and *R. solani* have a capability to decompose the green sugarcane leaf.

Conclusion

Sugarcane-trash management by retaining the trash on the field is essential to be done. The retained trash will decompose naturally and then provide a vital major and minor plant nutrients, as well as essential soil organic carbon. Decomposition of sugarcane trash will improve overall soil productivity. Sugarcane-trash management involves microfauna and microbial decomposers which play an important role on decomposition process. The decomposers include soil-borne disease which on initial decomposition process act as saprophytes. However, when the climatic conditions are optimal, particularly in tropical regions with high humidity and temperature, pathogenic microbial soil-borne diseases can thrive. Therefore, acceleration decomposition techniques must be integrated into the sugarcane-trash-management system. Beneficial microorganisms primarily serve as antagonists to pathogenic microorganisms in the acceleration of degradation.

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