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Study of Fungal Glycoproteins Contributing to Soil Carbon Pool in Conservation and Organic Agriculture

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ABSTRACT: The assessment of the impact of agri-management on the microbial activities related to C sequestration was undertaken using two contrasting long term (2003-2020) agricultural managements in the rice-wheat rotation. The aim was to assess the role of microbial glycoproteins for carbon sequestration in agricultural soil, Soil microorganisms are key agents determining the fate of soil C and aid in its sequestration. This study evaluated the impact of agricultural management on microbial activities related to carbon sequestration in the rice-wheat rotation. The organic management approach involved a combination of farmyard manure, vermicompost, and biofertilizers, which resulted in significantly higher melanin and chitin content in the top 30 cm of soil. The results suggest that this approach has the potential to increase the soil labile carbon fraction. Additionally, the long-term conservation agriculture experiments showed that zero-tilled soils had higher fungal metabolites and precursors of recalcitrant carbon, indicating the potential for carbon sequestration. However, the effectiveness of using fungal glycoproteins for carbon sequestration in agricultural soils poses several challenges. One of the main challenges is the efficiency of the process, as sequestering carbon using fungal glycoproteins can be slow and require a significant amount of time. Another challenge is the varying effectiveness depending on soil type and environmental conditions. The cost of producing and applying glycoproteins is also a significant factor to consider. Further research is needed to fully understand the potential of microbial glycoproteins for carbon sequestration and to develop more efficient and cost-effective methods for their use in agricultural soils. Overall, the findings suggest that agricultural management practices can significantly impact soil microbial activities and carbon sequestration potential, and highlight the importance of sustainable management practices in mitigating climate change.

Keywords: Conservation agriculture, Soil carbon sequestration, Soil microbial indices, Microbial metabolites, Precursors of recalcitrant C.

INTRODUCTION

Carbon sequestration is the act of removing carbon dioxide from the atmosphere or diverting it away from emission sources and storing it in terrestrial settings (vegetation, soils, sediments), seas, and geological formations. Soil carbon sequestration is a critical measure in agriculture that has the potential to offset huge amounts of agriculturally produced methane and nitrous oxide emissions. Conservation agriculture was proposed as a resource-efficient agricultural crop production strategy based on integrated agroecosystem management and efficient input usage. Conservation agriculture encompasses a larger notion than conservation tillage, which involves covering more than 30% of the soil surface with crop leftovers. CA, according to the FAO, attempts to attain acceptable earnings, high and sustained production levels, and environmental conservation through three essential principles:

1. Minimum or no mechanical soil disturbance
2. Permanent soil cover (consisting of a growing crop or a dead mulch of crop waste) and
3. Diversified crop rotations

Lal, (2015) established a fourth key principle, namely, enhancing soil fertility through integrated nutrient management (INM) to convert biomass carbon into soil organic matter for good crop management.CA is currently practiced on approximately 180 million hectares (Mha) of land around the world, with tropical and temperate regions covering 85.3 Mha and 95.12 Mha, respectively. Conservation agriculture has been touted as a method of increasing agricultural sustainability while also having the potential to reduce greenhouse gas emissions. However, there are conflicting reports on the possibility for C sequestration through conservation agriculture practices (Lal, 2008).

"Organic agriculture is a holistic production management system that avoids the use of synthetic fertilizers, pesticides, and genetically modified organisms, minimizes pollution of the air, soil, and water, and optimizes the health and productivity of interdependent communities of plants, animals, and people", according to the Codex Alimentarius Commission. Crop rotations and greater crop diversity, varied combinations of livestock and plants, symbiotic nitrogen fixation with legumes & use of organic manure, and biological pest control are just a few of the strategies that organic agriculture farmers can use to fulfil these goals. Organic agriculture makes a significant contribution to climate change mitigation and adaptation, according to recent studies (Scialabba and Muller-Lindenlauf 2010).

The ability of organic agriculture to prevent climate change is largely based on assumptions about organic management's soil carbon absorption capability. In one study, enhanced carbon sequestration was only significant when organic farming was associated with no tillage, but not when organic farming was mixed with deep tillage (Tizio *et al.,* 2008). Another study found that an optimised conventional system with certain organic methods including cover crops, crop rotation, and mulches produced slightly higher sequestration without using mineral fertilizers. A comparative field trial in the United States found that the organic system had lower sequestration than the no-tillage system, although no statistical analysis was provided. The trial's sampling depth was barely 5 cm. Over the course of 20 years, two randomised long-term trials comparing organic and conventional farming practices revealed that the organic plots had much higher carbon content. In a field trial in the United States, organic systems sequestered around one ton per hectare and year more carbon than conventional systems.

Another 8-year field trial in the United States yielded similar results. Organic croplands have a global average sequestration potential of 0.9-2.4 Gt CO_2 each year, according to Niggli *et al*., (2009), which is equivalent to an average sequestration capacity of roughly 200 to 400 kg C per hectare and year for all crop lands. Aside from the soil carbon pool, organic agriculture promotes agroforestry and landscape integration, resulting in additional carbon sequestration in plant biomass. In addition, biomass burning, which is a major source of emissions, is prohibited in organic agriculture.

Agricultural management strategies to increase CO_2 sequestration include:

1. Reduce the quantity of soil disturbances or tillage to improve the physical protection of soil carbon in aggregates.
2. Increasing the quantity and quality of soil animal and plant inputs
3. Keeping soils covered with live plants throughout the year

Soil carbon stores on agricultural land are steadily diminishing. Alternative farming practices are being used to supply the ever-increasing demand for food while also reducing carbon losses and increasing soil carbon storage. Soil carbon in Indian tropical soils is low, despite the fact that it is an important determinant in soil health and fertility. Agricultural techniques and accompanying changes in soil microbial communities must be identified in order to aid in the accumulation of soil organic carbon levels and decrease C losses from soil, Soil microbial populations are influenced by agricultural management methods, which accounts for soil carbon sequestration.

Organic agriculture and conservation agriculture are said to promote natural resource efficiency and are gaining popularity around the world. Organic agriculture's primary techniques focus on closed nutrient cycles, such as recycling plant leftovers and livestock manure back to soil, resulting in considerable reductions in soil carbon losses or even higher soil carbon concentrations and net carbon sequestration over time. Conservation agriculture, on the other hand, relies on the use of crop residues as surface mulch, crop rotation, and minimal or no soil disturbance by avoiding tillage. Plant-microbe interactions are influenced by agricultural management. Conservation agriculture (CA) is a method of managing agro-ecosystems for greater productivity, earnings, and food security while protecting and enriching the natural resource base and the environment. To separate this more sustainable agriculture from the narrowly defined 'conservation tillage,' the term conservation agriculture was coined. Reduced tillage, the retention of acceptable amounts of crop residues and soil surface cover, and the utilization of crop rotations are the three core concepts of CA.

CA covers a total area of 156.99 million hectares worldwide. CA improves soil fertility and reverses soil deterioration by increasing water holding capacity, promoting better penetration of precipitation and strengthening ground-water storage, enriching soil organic carbon (SOC), and increasing microbial diversity in the rhizosphere. In India, the area under zero tillage is progressively expanding, with an estimated 2.2 million hectares in the rice–wheat cropping system (RWCS) in the Indo-Gangetic plains (IGPs). Direct-seeded rice (DSR) under puddled or un-puddled conditions, brown manuring, zero-till (ZT) wheat with or without residue retention, and zero-till summer mungbean are the key CA-based practices that have potential for implementation in the RWCS of the IGPs. Crop rotations that include legumes, which are common in organic and conservation agriculture, have a favourable influence on SOC. Due to increased organic matter mineralization, increased tillage reduces soil organic matter (SOM). In soils, the microbial community plays an important role in carbon cycle processes.

Carbon and nitrogen turnover in soil are intertwined, and microbial biomass drives both. the contribution of microbes to soil Microbial community dynamics Relationships between the amount of microbial biomass, microbial community structure, microbial byproducts, and soil qualities such as texture, clay mineralogy, pore-size distribution, and aggregate are all directly related to

C sequestration. The net result of microbial biomass turnover, rate of respiration, nitrogen and phosphorus mineralization is total organic carbon in soil at any one time. all of these processes are intertwined with soil microbiota, microbial metabolisms in regulating the carbon (C) mineralization and sequestration balance. Soil bacteria can have an indirect impact on C cycling by increasing soil aggregation, which protects soil organic matter physically. Some microbial metabolites have been identified as potential contributors to aggregation formation and stabilization, hence preventing carbon oxidation and loss to the atmosphere. Soil bacteria create a variety of chemicals that contribute to soil aggregation and carbon sequestration, including chitin, glomalin, melanin, Peptidoglycans, polysaccharides, ergosterol, and other substances are all identified as key contributors to SOM buildup, but glycoproteins are the most commonly implicated (Rillig *et al.,* 2015).

Fungus role in C-transformations. The principal source of energy in soil is plant carbohydrates, which are predominantly glucose from cellulose and xylose and arabinose from hemicellulose. Fungi are rich in mannose, fructose, and rhamnose. Glucose, fructose, mannose, galactose, rhamnose, and fructose are the most common sugars found in bacteria. These molecules can be used to estimate microbial development, but they can also accumulate in microbial products, particularly extracellular slimes and biofilms. They can also react with humic substances. In soils, the fungal: bacterial ratio has been linked to C sequestration capability, with higher fungal abundance being linked to more C storage (Strickland and Rousk 2010).

Evidence linking the fungal: bacterial ratio to C sequestration has mostly come from intensively and less intensively maintained systems, but there have been some discrepancies. Soil pH and C:N ratios can be used to predict fungal v/s bacterial dominance quite well. Higher C storage in fungal-dominated soils can be attributed to higher C use efficiency; longer retention of C in living biomass; and recalcitrant necromass resulting in longer resident time of C (Strickland and Rousk 2010). Higher C storage in fungal-dominated soils is due to higher C consumption efficiency, longer C retention in live biomass, and resistant necromass resulting in longer C resident time (Strickland and Rousk 2010).

These findings are, however, merely correlative, and whether fungal dominating populations improve soil C storage or if soil with high organic C favours soil fungus is still contested. Furthermore, because of their superior ability to breakdown resistant litter, fungi may have a negative impact on C storage. Autotrophic microorganisms are recognized to play a substantial role in CO_2 assimilation in aquatic systems, but their involvement in CO_2 fixation and sequestration in soils is less well understood. Microbial autotrophy has recently been hypothesized to account for up to 4% of the total CO_2 fixed by terrestrial ecosystems each year. Microbially mediated C storage or breakdown is influenced by soil structure. Microaggregate production and stability are aided by a variety of microorganisms.

These microaggregate fractions preferentially stabilize soil organic matter (SOM), and aggregate stability rises linearly with C input. Given that SOM breakdown is primarily a microbiological process, it's possible that varied substrates and surface qualities will favour microbial communities that are uniquely adapted. Soil-dwelling bacteria can be categorized into two ecological functional categories based on C mineralization potential and growth rates: copiotrophs (r-strategists) and oligotrophs (k-strategists). It's also been suggested that oligotrophic soils have low C turnover and, as a result, low CO_2 emissions and thus better C sequestration (Yuan *et al.,* 2012).

Polysaccharides are well-known for their function in aggregation, specific molecule, stable isotope probing can be used to evaluate fungal to bacterial ratios using N-acetylglucosamine of chitin in fungi cell walls and N-acetylmuramic acid in bacterial cell walls. Because certain lipids are connected with various microbial groups and their tracer concentrations can be easily quantified, lipids, such as free fatty acids and phospholipids, are of interest. GC-C-IRMS allows for the separation of 13-C labelled fatty acid-phospholipids (PLFAs), which are expected to occur solely in living cells. The limited number of peaks that distinguish main groupings of organisms, as well as their varied occurrence in cells, limit interpretation.

Lignins are usually destroyed by cometabolism and phenol-oxidase enzymes with little or no formation of microbial biomass or absorption into resistant SOM. The aromatic component of lignin molecules is frequently broken up during degradation while still linked to a bigger unit. Despite the fact that lignin is not a substantial component of SOM, it is nonetheless considered important when simulating litter dynamics. Amino sugars are significant C and N constituents of SOM, and when combined with resistant, melanic fungal ingredients from dark-colored fungi, they can withstand decomposition rather well. The development of soil macroaggregates, which protect plant-derived SOM, is predominantly attributed to fungal extracellular polysaccharides and hyphae. As a result of differences in fungal-mediated aggregate turnover, ecosystems with fungal-dominated soil communities (e.g., NT) may have higher C retention than ecosystems dominated by bacterial breakdown pathways (e.g., CT).

Microorganisms in the soil are not only decomposers, but also significant components of SOM. Although plant residue contributes the majority of carbon to soil, much of it ‘filters' through microbial biomass before being converted into SOM. The contributions of microbial biomass to SOM production appear to be significantly higher than the 1-5 % estimate now widely accepted. According to a recent study, living microbial biomass and necromass (microbial residue left over after cell death) account for 80% of soil organic C. Bacteria and fungi account for more than 90% of soil microbial biomass. Microbes also have a role in the production of soil aggregates and soil structure. Fungi, for example, aid in the formation of microaggregates by linking soil particles to their hyphae and extracellular components (Six *et al.,* 2006).

Carbon sequestration by saprophytic and symbiotic fungus. Metazoans such as earthworms and mites execute the physical breakdown of plant tissue, following which saprophytic fungi perform the early steps in the degradation of cellulose, lignin, and other complex macromolecules. Saprophytic fungi are often considered a key engine of the breakdown process since the resultant compounds will be subsequently digested by bacteria. Soil is a CO_2 source (soil respiration) and a sink (carbon sequestration), with soil respiration accounting for 20% of total CO_2 emissions to the atmosphere (Kumar *et al.,* 2017).

In nature, fungus is a nonchlorophyllous organism that is heterotrophic (needs an organic source of carbon), i.e., it derives its sustenance from either dead organic matter (saprophytic) or living organic matter (hyphal biomass) (Chaubey *et al.,* 2019). The saprophytic form of nutrition involved in decomposition is exemplified by *Agaricus, Aspergillus, Morchella, Mucor, Penicillium, Rhizopus, Saprolegnia*, and others. The addition of nitrogen fertilizer increases fungal biomass, which aids in carbon sequestration. A positive reaction is seen at an optimum dose (20 mg kg^{-1}), but a greater dose (40 mg kg^{-1}) has a detrimental impact on fungal root growth (Aliasgharzad *et al*., 2016).

Pesticides Have a deleterious impact on fungal diversity and carbon sequestration in soil, both directly and indirectly. Mycorrhizal fungi have a mutualistic relationship with plants, and large hyphal mycelia account for almost 30% of soil microbial biomass. Fungi are the major regulators of nutrient transformations among soil microbial communities (Willis *et al.,* 2013).

Temperature, moisture, texture, and structure, as well as tillage and cropping management, all have an interacting cumulative impact on carbon dynamics. Microbial degradation of external C sources applied to soil as agricultural waste results in the loss of 2/3 of the carbon. Although primary production plays a role in carbon sequestration in soils, it is the size and activity of the soil's microbial biomass that controls carbon accumulation through mineralization and immobilization of plant and microbially derived residues. Agricultural management practices influence AMF and thus account for soil carbon sequestration. For example, in a no-tillage system (NT), glomalin concentrations are observed to be substantially greater than in a conventional (CT) management scheme.

Physical protection by aggregates related to the reactive characteristics of clays is directly and/or indirectly used by a soil to safeguard microbial biomass and microbially produced organic matter. The efficiency with which microorganisms utilize substrate C, as well as the chemical composition of the by-products they produce, are both important factors in soil C stabilization. Partially processed organic C has a resident period of one month to one year, but organic C in clay minerals can have a residence time of more than 100 years. As a result, it's critical to comprehend the mechanics of long-term C sequestration in clay minerals. SOC-clay mineral interaction is required not only for C sequestration, but also for the stabilization of the aggregate architecture as a web for other organo-mineral interactions.

Microorganisms have the following benefits for CO_2 sequestration:

1. Rapid generation,
2. High photosynthetic conversion
3. High environmental bioremediation capabilities, such as CO_2 fixation from the atmosphere or flue gas bioremediation
4. Large production capacity for a wide range of additive products
5. It's simple to improve genetically.
6. Possibility of being evolved into a large-scale bioprocess
7. Can be grown in a reactor

In low-land rice ecosystems, the combined use of inorganic fertilizers, Sesbania aculeata, and Azolla orchestrates soil nutrient availability, biomass production, biochemical activities, and a favourable soil physical environment that facilitates successful carbon sequestration. SOM stability in the soil is aided by fungal hyphae and bacterial extracellular metabolites such as glycoproteins and polysaccharides.

The microbial contribution to soil C storage is directly related to microbial community dynamics and the balance between formation and degradation of microbial byproducts. Soil microbes also indirectly influence C cycling by improving soil aggregation, which physically protects soil organic matter, the microbial contribution to C sequestration is governed by the interactions between the amount of microbial biomass, microbial community structure, microbial byproducts, and soil properties such as texture, clay mineralogy, pore-size distribution and aggregate dynamics. The capacity of a soil to protect microbial biomass and microbially derived organic matter is directly and/or indirectly through physical protection by aggregates related to the reactive properties of clays. However, the stabilization of the soil C is also related to the efficiency with which microorganisms utilize substrate C and the chemical nature of the by- products they produce.

After conducting a preliminary search, it seems that there is currently a research gap in the specific area of soil carbon sequestration by fungal glycoproteins. While there is a significant amount of research on carbon sequestration in soil, particularly through the use of agricultural practices such as cover cropping and reduced tillage, there appears to be limited research specifically exploring the role of fungal glycoproteins in this process (Lal, 2021).

One potential area of research could be to investigate the mechanisms by which fungal glycoproteins contribute to soil carbon sequestration, as well as to examine the potential for utilizing these proteins as a tool for enhancing carbon sequestration in agricultural systems. Additionally, research could be conducted to assess the impact of different fungal species and strains on soil carbon sequestration, as well as to evaluate the effects of environmental factors such as temperature and moisture on the activity of these proteins in the soil. Overall, it appears that there is significant potential for further research in this area, particularly given the potential for fungal glycoproteins to contribute to the development of sustainable agricultural practices and to help mitigate the impacts of climate change (Behera *et al.,* 2020).

MATERIALS AND METHODS

Soil sample collection: The soil samples were collected from the field at the flowering stage and transported to laboratory in ice box. The samples were divided into two parts, for biological studies the field moist samples were stored at - 4°C. A study on abundance and activities of fungi present in these two systems was undertaken, and fungal signature molecules and enzymes active in C mineralization were studied.

Treatment details for Conservation agriculture:

T_1: ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops)

T_2: (WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops)

T_3: ZTDSR – ZTW – ZT Mungbean with 100 % RDN (both crops)

T_4: (MR + ZTDSR) – (RR + ZTW) – (WR + Mungbean) with 100 % RDN (both crops)

T_5: CTR – ZTW with 100 % RDN (both crops)

T_6: Farmers' practice (CTR – CTW) with 100 % RDN (both crops)

CTW: Conventionally tilled wheat
CTR: Conventionally puddled transplanted rice
BM: Brown manuring of Dhaincha at 25 days after sowing by 2,4-D/ Bispyribac sodium spraying
RR: Rice residue (40 %)
WR: Wheat residue (20 %)
MR: Mungbean residue (100 %)
RDN: Recommended dose of nitrogen (120 kg ha^{-1})

Crops

– Kharif season: Rice, variety PRH – 10
– Rabi season: Wheat, variety HD CSW 18
– Summer season: Mungbean, variety Pusa Vishal

Experimental design: Strip plot
Replication: 3
Variety: Pusa Basmati 1728(Rice), HD 3086 (Wheat), Pusa Vishal (Mungbean)
Year of start: 2003
Current season: Kharif 2020 and Rabi 2020-2021.

Treatment details for Organic cultivation. The experiment was laid out in a strip plot design with three replications which consisted of two rice-based cropping systems, i.e., Basmati Rice-Wheat-Sesbania (RWS) and Basmati Rice-Wheat-Mungbean (RWM) in strips and seven combinations of different organic materials and Biofertilizers (BF) preceding crop @ 3 t/ha for each rice, wheat and mungbean, VC+CR, FYM+CR+BF and VC+CR+BF, and control (no fertilizer applied) were applied in sub-plot. Pusa Basmati 1121, HD 2967 and Pusa Vishal varieties were used for rice, wheat and mungbean, respectively. Combinations of organic sources and biofertilizers were applied to both rice and wheat, whereas mungbean in rice-wheat-mungbean cropping system was grown on residual fertility. For biofertilizers, Blue green algae (BGA), Phosphate solubilizing bacteria (PSB) (*Pseudomonas striata*) and cellulolytic culture (*Aspergillus awamori, Trichoderma viride, Phanerochaete chrysosporium and Aspergillus wolulens*) used in rice, Azotobacter, PSB (*Pseudomonas striata*) and cellulolytic culture in wheat and Rhizobium + PSB in mungbean, and soil samples were collected after harvest of rice crop.

-Quantification of glycoprotein content and melanin in soil samples relative to the total C, microbial biomass C, labile Carbon.

-Mineralization studies of native C by estimating the enzymes active in the process (Philip *et al.,* 2018).

RESULTS AND DISCUSSION

An experiment on conservation agriculture treatments and organic cultivation followed by Rice-Wheat cropping system was conducted during 2020–21 at the research farm of the Indian Agricultural Research Institute (ICAR-IARI, New Delhi) India. Two sets of soil samples were collected after the wheat harvest from these long-term experiment field at 0-30 cm soil depth with a core sampler (7.5 cm diameter) using a soil auger according to treatments (6 in conservation agriculture treatments), (8 in organic cultivation) and cropping system (Rice-Wheat) at flowering stage. Each soil sample were divided into two parts: One part was kept in refrigerator for analysis of biological parameters and the other part was air-dried and processed for chemical analysis. Soil samples were examined for soil physical and/ or chemical parameters on rice & wheat crop. an experiment details given in material & methods were analysed for various parameters like Soil microbiological studies: Ergosterol estimation, FDA hydrolase activity, Soil respiration, Soil dehydrogenase activity, SMBC, β-glucosidase activity, Glomalin protein estimation (Wright and Upadhyaya 1999), PLFA analysis, Chitin estimation (Ekblad and Nasholm 1996) etc.

Organic agriculture soils

(a) Chitin estimation. Chitin is a polymer of N-acetylglucosamine that is found in most fungi cell walls and is used as a measure of total fungal biomass. The recalcitrance of C input, interactions with soil minerals, aggregate formation, and abiotic factor modulation are all mechanisms for C sequestration (Hättenschwiler and Vitousek 2000).

The Chitin content ranged from 0.14±0.019 to 0.2008±0.06 (mg N-acetyl glucosamine/g substrate) in the different treatments of organic cultivation R-W-M (Control), highest and lowest was found in FYM+CR+BF and VC+CR respectively, the order of activity was FYM+CR+BF>VC+CR+BF > VC+CR. The chitin content ranged from 0.084±0.009 to 0.128±0.023 (mg N-acetyl glucosamine/g substrate) in the different treatments of organic cultivation R-W-S (Control), highest and lowest was found in VC+CR and FYM+CR+BF respectively, the order of activity was VC+CR>VC+CR+BF > FYM+CR+BF (Table 1).

(b) Glomalin content. Glomalins are exclusively produced by symbiotic soil fungi and is directly correlated with C sequestration, and these are ubiquitous, thermostable, and tenacious glycoprotein found in significant levels in soils and thought to reflect soil health and quality. Glomalin, which is an important component of soil organic matter, contributes 27% of carbon to be stored in the soil (Zhang *et al.,* 2017).

Table 1: Quantitative estimation of the Chitin content as influenced by the organic agricultural practices in the Rice - Wheat cropping system.

Chitin estimation (mg N-acetyl glucosamine/g substrate)	
Treatments	**MEAN±SD**
T_1: R-W-M (Control)	0.19±0.02 ^{ab}
T_3: VC+CR	0.14±0.019 ^{cd}
T_5: FYM+CR+BF	0.2008±0.06 ^{a}
T_7: VC+CR+BF	0.1701±0.032 ^{bc}
R-W-S (Control)	
T_2: R-W-S (Control)	0.094±0.0099 ^{e}
T_4: VC+CR	0.128±0.023 ^{d}
T_6: FYM+CR+BF	0.084±0.009 ^{e}
T_8: VC+CR+BF	0.09±0.0099 ^{e}
LSD (P=0.05)	0.043

Glomalin-related soil protein (GRSP) and its contribution to soil organic carbon are influenced by soil depth and glomalin features and qualities, which are influenced by soil attributes and climate fluctuation (Wang *et al.,* 2017). The glomalin content ranged from 73.28±7.6 to 90.22±9.1 (mg/g) in the different treatments of conservation agriculture soils, highest and lowest was found in ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops) and ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) respectively, The order of activity was ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops) >CTR – ZTW with 100 % RDN (both crops) > (WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops) > (MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN > ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) (Table 2).

Conservation agriculture soils

(a) Chitin estimation. The chitin content ranged from 0.393±0.059 to 0.519±0.059 (mg N-acetyl glucosamine/g substrate) in the different treatments of conservation agriculture soils, highest and lowest was found in CTR – ZTW with 100 % RDN (both crops)and ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) respectively, The order of activity was CTR – ZTW with 100 % RDN (both crops) >(WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops) >ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops) >(MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN > ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) (Table 3).

(b) Glomalin content. The glomalin content ranged from 73.28±7.6 to 90.22±9.1 (mg/g) in the different treatments of conservation agriculture soils, highest and lowest was found in ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops) and ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) respectively, The order of activity was ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops) >CTR – ZTW with 100 % RDN (both crops) >(WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops) >(MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN > ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops) (Table 4).

The study of fungal glycoproteins in carbon sequestration holds great promise for the future. Here are some potential areas of research that could be explored, Identification of novel glycoproteins: Fungi produce a diverse range of glycoproteins with various functions. The identification of new glycoproteins that are involved in carbon sequestration could provide new targets for study. Understanding the role of fungal glycoproteins in carbon sequestration: Fungal glycoproteins have been shown to play a role in carbon sequestration, but the exact mechanisms by which they do so are not well understood.

Table 2: Quantitative estimation of the glomalin content as influenced by the conservation agricultural practices in the Rice - Wheat cropping system.

Glomalin (mg/g)	
Conservation agriculture soils	
Treatments	**MEAN±SD**
T_1: ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops)	90.22±9.1 ^{a}
T_2: (WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops)	78.01±7.4 ^{c}
T_3: ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops)	73.28±7.6 ^{e}
T_4: (MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN	74.65±7.1 ^{de}
T_5: CTR – ZTW with 100 % RDN (both crops)	87.78±8.3 ^{b}
T_6: Farmers' practice (CTR – CTW) with 100 % RDN (both crops)	68.54±6.5 ^{f}
LSD (P=0.05)	2.225

Table 3: **Quantitative estimation of the Chitin content as influenced by the conservation agricultural practices in the Rice - Wheat cropping system.**

Chitin estimation (mg N-acetyl glucosamine/g substrate)	
Conservation agriculture soils	
Treatments	**MEAN±SD**
T_1: ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops)	0.491±0.059 ^{ab}
T_2: (WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops)	0.508±0.06 ^{a}
T_3: ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops)	0.393±0.059 ^{c}
T_4: (MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN	0.46±0.06 ^{b}
T_5: CTR – ZTW with 100 % RDN (both crops)	0.519±0.059 ^{a}
T_6: Farmers' practice (CTR – CTW) with 100 % RDN (both crops)	0.1008±0.02 ^{d}
LSD (P=0.05)	0.044

Table 4: Quantitative estimation of the glomalin content as influenced by the conservation agricultural practices in the Rice - Wheat cropping system.

Glomalin (mg/g)	
Conservation agriculture soils	
Treatments	**MEAN±SD**
T_1: ZTDSR – ZTW with 100 % RDN (Rice & Wheat crops)	90.22±9.1 ^{a}
T_2: (WR + ZTDSR + BM) – (RR + ZTW) with 100 % RDN (both crops)	78.01±7.4 ^{c}
T_3: ZTDSR – ZTW – ZT mungbean with 100 % RDN (both crops)	73.28±7.6 ^{e}
T_4: (MR + ZTDSR) – (RR + ZTW) – (WR + mungbean) with 100 % RDN	74.65±7.1 ^{de}
T_5: CTR – ZTW with 100 % RDN (both crops)	87.78±8.3 ^{b}
T_6: Farmers' practice (CTR – CTW) with 100 % RDN (both crops)	68.54±6.5 ^{f}
LSD (P=0.05)	2.225

Further research could help to elucidate the mechanisms by which these glycoproteins contribute to carbon sequestration. Developing new biotechnological applications: Fungal glycoproteins have a range of potential biotechnological applications, including in carbon capture and sequestration. Research in this area could help to develop new technologies for carbon sequestration. Studying the interactions between fungi and other organisms: Fungi interact with a range of other organisms in the environment, including plants and bacteria. Understanding these interactions and the role that fungal glycoproteins play in them could provide insights into how carbon sequestration can be enhanced. Overall, the study of fungal glycoproteins in carbon sequestration has the potential to contribute significantly to our understanding of this important process, and to the development of new technologies for mitigating the effects of climate change.

CONCLUSIONS

Relation between fungal C mineralization and specific concentration of fungal metabolites (Glycoproteins, Chitins) in the soil C sequestration process, soil carbon stocks of agricultural land are experiencing a continuance declining trend. In order to meet the eve growing demand for food and simultaneously reduce carbon losses / increase soil carbon storage alternative agricultural methods are being adopted. In this direction, the organic agriculture and the conservation agriculture practices are reported to improve natural resource use efficiency and gaining popularity globally. The key practices of organic agriculture, are focussed on closed nutrient cycles by recycling plant residues and manures from livestock back to soil thereby significantly reducing the soil carbon losses or even to higher soil carbon concentrations and net carbon sequestration over time. Another approach, the conservation agriculture also relies on the input of crop residues as surface mulch, rotation of crops and minimum or no disturbance of soil by avoiding tillage, agricultural management play a critical role in plant -microbe interaction.

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Conflict of Interest. None.

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