Research Article

Study of Maize Residue Decomposition in a Silty Loam Soil of Pakistan: A Comparison of Mulched Versus Incorporated Residue Management Practice

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Abstract | Using harvested crop residues in different residue management strategies would help in refilling the soil nutrient pools, enhance soil organic matter levels, protect soils against erosion and improve water retention. This research was conducted in laboratory-controlled conditions using maize residues and a loamy soil from a sugarcane field to determine carbon mineralization patterns. Two different residue management practices were chosen for this study; mulched (soil covered by residues) versus incorporated (residue incorporated in surface soil layer). Carbon mineralization patterns under two treatments were unique from each other. The results showed that all treatments enhance the carbon mineralization in soil with addition of residues compared to control. Soil treatment with incorporated residues (using 1g of residues) resulted in fastest respiration rates followed by mulched treatment. The soil treatment with incorporated residues (using 0.5 g of residues) exhibited comparatively slower rates of respiration which was understandable owing to lesser amount of crop residues added to soil. Residues of mulched treatment accelerated the decomposition during latter half of the incubation experiment. Thus, the decomposition of residues was affected by their placement in soil and also by their quantity. Our results recommend using crop residues of harvest as mulch as sustainable practice to enhance soil quality while reducing the environmental degradation.

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Introduction

The agriculture sector of Pakistan is an essential component ensuring food security and generating overall economic growth since its foundation. The most important agricultural crops of Pakistan are wheat, rice, maize, sugarcane and cotton which are responsible to add 23.55 % value in overall agriculture and 4.67% of GDP; while the other crops, forestry, livestock and fishing contribute to rest of the sector, making agriculture the largest provider of employment i.e., 42.3 % of the country's total labor force (Azam and Shafique, 2017). Maize (*Zea mays* L.) is the most important crop among cereals after wheat and rice and is grown on area of 1030 thousand hectares with the total production of 3560 thousand tons, contributing 2.2% to the value in agriculture and 0.4 % to GDP of Pakistan (Tariq and Iqbal, 2010; Abid *et al*., 2014). Soil organic carbon (SOC) is an important constituent of the soil due to its capability to affect plant growth as both a source of energy and a trigger for nutrient availability, to plants and soil microbes, through mineralization (Andrews and Wander, 2011; UNEP, 2012). The soils of Pakistan are alkaline and low in organic matter (OM) and intensive cropping practices have resulted in depletion of many essential nutrients. Other causes of low OM include high temperature, low rainfall and removal of almost all the crop residues except the roots (Hussain *et al*., 2006). A traditional and common but expensive method of supplementing soil nutrients is the use of chemical fertilizers, which can increase crop yields by 30-50% (Shah *et al*., 2009; Azam and Shafique, 2017). Recent studies show that fertilizers are doing more harm than good for example; Nitrogen (N) and Phosphorous (P) rich fertilizers are the primary source of nutrient pollution from agricultural sources; they increase acid levels in the soil, impact underground water quality and cause eutrophication in lakes. There are alternatives that can reduce nutrient pollution, include nutrient and drainage water management, installation of plant buffers, livestock waste management, use of bio (organic) fertilizers, reducing tillage and cover crops by residual managements (Turmel *et al*., 2015; Liu and Lobb, 2021). Crop residues, including roots, leaves, stalks, are generally considered as waste material but actually they are a rich source of nutrients. The crop residues were used to burn as burning them was previously considered good for soil and plant health. But many studies explored that they can be used in many effective ways to manage water table, improve soil quality, control soil erosion, enhance soil fertility, replenish plant nutrients, and soil organic carbon pool (Iqbal *et al*., 2011). The nutrients in the residues (biomass) can be added to the environment by their decomposition in presence of soil microbes. It also reduces the volume of dead organism and resumes the process of nutrient cycling to enhance the soil fertility and plant growth. Using crop residues in mulched or incorporated form may retain soil moisture, improves soil quality, reduces crop waste, reduces fertilizer pollution and helps to get the sustainable agriculture. Different comparative studies have been carried out to evaluate the effects of different crop residue managements. Resource conserving technologies (RCTs) like zero tillage and residue retention have emerged over the past 2-3 decades as a means of achieving the sustainability of intensive cropping systems (Sharma *et al*., 2012). These practices not only help to reduce the cost of cultivation and energy inputs but also help to get stable yields by improving soil fertility through increased carbon accumulation and biological activity (Meena *et al*., 2015). The crop residues after harvest as substitute for chemical fertilizers can either be incorporated in soil surface or mulched in soil for biological decomposition. Both strategies provide soil cover, reduce soil disturbance, enhance microbial activities, enhance crop yields and reduce negative impacts of synthetic compounds on environment. A study by Lal (2004) stated that biological N fixation, recycling from subsoil, aerial deposition, use of bio solids, and use of crop residues are among the several sources of nutrients for C sequestration. Same study declared that one ton of cereal residue contains 12 to 20 kg N, 1 to 4 kg P, 7 to 30 kg K, 4 to 8 kg Ca, and 2 to 4 kg Mg. The report also stated that 3 gigatons (Gt) of residues of grain crops are produced globally which if recycled rather than removed for fuel and other uses would improve soil quality and sequester C (Lal, 2004). In a comparative study carried out in Nigeria to evaluate the effect of different crop residue managements, it was found out that soil condition was much more improved with enhanced nutrients in mulched treatment as compared to non-mulched treatments or the treatments without using crop residues (Mbah and Nneji, 2011). In another field study, Choudhary *et al*. (2011) reported that crop residue incorporation in saline sodic soils positively affected plant height, number of tillers, panicle length, number of grains, straw and paddy yield (Iqbal, 2011; Ali *et al*., 2012). In another study done in the West Africa showed that mulched crop residues increased up to 73% of cereal production, high water content due to increased microbial activity while lowering the temperature in an acidic agricultural field (Buerkert *et al*., 2000). Similarly, mulched soil with sugarcane residue increased soil C, microbial activity and numbers of free-living nematodes, and suppressed parasites *Meloidogyne javanica* and *P. zeae* to a greater extent than incorporating the residue into soil (Stirling *et al*., 2011). The objective of this work was to determine the degree of decomposition of crop residues in soil by comparing two different residue management strategies i.e., incorporated versus mulched.

Materials and Methods

Description of the study area

A lab experiment was conducted at the Environmental Science department, Forman Christian College (A Chartered University) Lahore to study the carbon mineralization pattern of maize residues on loamy soil. Two different residue management practices were chosen for this study; mulched (soil covered by residues) versus incorporated (residue incorporated in surface soil layer).

Soil sampling

The silty loam soil (Sand:36%; Clay:10%; Silt:54%) was sampled from an agricultural field located near Renala Khurd city in district Okara (30.8782° N, 73.5954° E), Pakistan during August 2018. The soil was sampled at 10cm of depth from sugarcane field cultivated with reduced tillage. The soil samples were sealed in Polyethylene zipper bags and transported to laboratory. Sampled soil was sieved at 2mm and stored at 4º C until experiment was initiated in September, 2018. The soil moisture content (9.32% of dry soil) was determined using oven drying by gravimetric method. The soil water content was adjusted to 60% of soil water holding capacity by adding distilled water. Water holding capacity was determined by cutting ring method. Briefly, PVC pipe cylinders (3cm diameter and 1.5 cm height) to which nylon cloth was fixed on one side were used to fill soil and doing saturation. The rings were placed on a wet tray for 5-6h and weighed after sufficient saturation had occurred. Then all the soil was taken out of the ring and oven-dried at 105 °C for 48 hours. The dried soils were re-weighed to estimate the mass of water absorbed by the soil. Other physical and chemical properties of soil were estimated after following standard laboratory protocols. For instance, soil texture (silt loam) was estimated through soil hydrometer method (Bouyoucos, 1962). Briefly, 50g of soil was placed into a soil dispersing cup and the weight was recorded to at least 0.1g accuracy. The cup was filled up to two inches of the top with distilled water and 5mL of 1M sodium hexametaphosphate was added. After 15 minutes of agitation, suspension was transferred to sedimentation cylinder filled to 1000mL mark with distilled water. The suspension was thoroughly mixed and the hydrometer was placed into suspension; to note reading after 40 seconds and 2 hours. After final reading, hydrometer was removed, and a thermometer was carefully lowered into the suspension to record the temperature (°C). A blank cylinder with water and sodium hexametaphosphate was also run for both these readings. Soil pH was 8.2 and was measured in water at 1:5 (soil to water) suspensions using a pre-calibrated pH meter (Thermo Scientific Orion star A111) and electrical conductivity was 146.3 S/m. Electrical conductivity was determined by calibrated EC meter (Thermo Scientific Orion Star A112). Soil organic matter of soil was estimated by loss-on-ignition method using muffle furnace.

Maize residues

Fresh maize residues were collected from a field near Okara district. All samples were sealed in polyethylene zipper bags and transported to the laboratory for experiment. In the lab the maize crop residues were prepared for experiment. They were oven dried at 60°C for 3 days. Dried residues were cut with scissors into smaller pieces (~ 1cm) and stored at room temperature.

Incubation experiment

Airtight glass jars (500 mL) were used for incubation experiment. Two different residue management practices were chosen for this study. A control treatment (soil without crop residue addition) was also launched to calculate soil respiration. In every treatment same amount of the soil was taken which was 75 g dry-equivalent. An incubation experiment was conducted with a total of four treatments, i) Mulched treatment: Soil sample in glass jar was covered with 1 gram of maize residues; (ii) Incorporated (1) treatment: 1 gram of crop residues were incorporated in the surface layer of soil in jar; (iii) Incorporated (0.5) treatment: 0.5 grams of residues were incorporated in the surface layer of soil in jar; and (iv) Control treatment: Soil sample was taken in jar without crop residues. Samples for all treatments were prepared and conducted in duplicates. In addition, two blank jars were also used in the incubation experiment for correction of soil respiration. These jars (10 jars in total) were placed carefully inside the low temperature incubator (NB-2201F, N-Biotek Co., Ltd. Korea) at 25°C and monitored for a period of 59 days in dark. During this period, soil moisture content was maintained at 60% of water holding capacity. Small glass vials carrying 1 M NaOH were placed inside each jar to trap CO_2 released by microbial respiration. NaOH traps were replaced at day 1, 3, 7, 14 and then weekly until end of experiment. Carbon mineralization in soils was estimated after titrating NaOH with 0.5M Hydrochloric Acid (HCl). The CO_2 produced in the incubation was absorbed in 10 ml NaOH (1 mol L^{-1}) after the following reaction:

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

Then, the excess alkali was determined by titration with HCl (0.5 mol L^{-1}) in the presence of phenolphthalein (Dilly, 2003). All required solutions were prepared freshly in the laboratory with carefully calculations and handling of chemicals. Cumulative carbon mineralization of crop residues was estimated after subtracting mineralization of soil carbon from the total mineralization (soil mixed with crop residues). After incubation, organic matter of treated soils was also estimated using loss-on ignition method. Soil samples were combusted at 550°C using an electrical muffle furnace for 6 hours. For mulched treatment, residues were carefully separated from the soil. For incorporated treatments, two layers were separated; the upper layer contained soil mixed with incorporated residues and the lower layer was soil placed beneath the incorporated layer. All samples were weighed, oven dried and placed in muffle furnace for organic matter estimation to see the effect of treatment on them.

Data analysis

All incubation treatments were carried out with two repetitions and all results were presented as averages and standard deviations. Respiration of soil (C-CO_2 mg kg^{-1} day^{-1}) was based on the quantitation of total CO_2 rate per day. Respiration was used as a proxy for microbial activity, following the addition of the crop residues to soil.

Results and Discussion

Soil respiration

Quantity of crop residues and management strategy had strong influence on soil microbial respiration (Figure 1). All residue management treatments had mineralized more ($P<0.05$) compared to control treatment with any residue addition. Carbon mineralization during first 3 weeks was greatest in treatment with 1g of crop residue incorporated in the soil followed by mulched treatment and was lowest in treatment with 0.5g of residues incorporated in soil. Afterwards, cumulative mineralization in soil with mulched residues increased and was greatest by the end of incubation experiment. Total cumulative mineralization after 59 days of incubation experiment was 3939±56 mg C-CO_2 kg^{-1} dry soil in mulched treatment followed by soil treatment with 1 g incorporated residues i.e., 3739±81 mg C-CO_2 kg^{-1} dry soil. The soil treatment incorporated with 0.5g showed lower cumulative mineralization (2320±13 mg C-CO_2 kg^{-1} dry soil) which was almost 60% of the mineralization showed by other two residue management treatment. Total cumulative mineralization in control soil without any residue addition was lowest i.e., 1255±3 mg C-CO_2 kg^{-1} dry soil. Here the quantity of residues, placed in the treatments, played an important role.

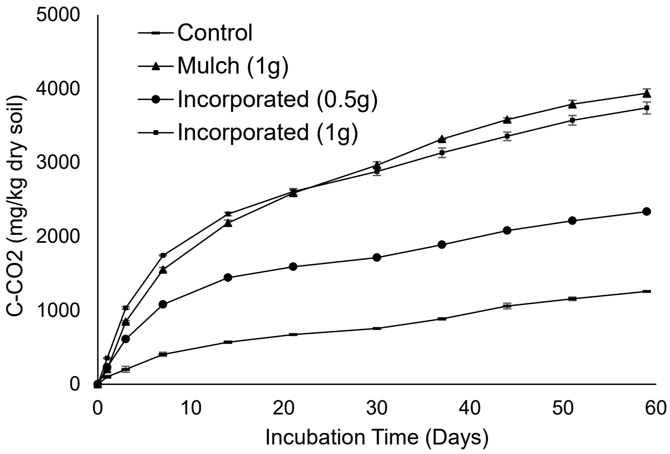

Figure 1: *Soil respiration (Cumulative) in soil without crop residues (control) and soil amended with maize crop residues during incubation experiment. Data are shown as averages of two replicates ±standard deviations.*

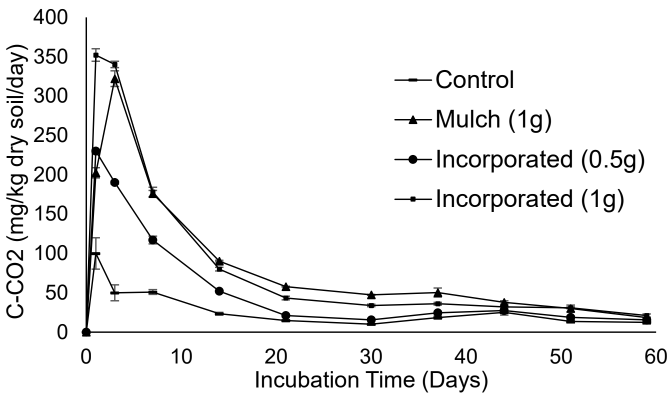

Figure 2: *Soil respiration rates of soil without crop residues (control) and soil amended with maize crop residues during incubation experiment. Data are shown as averages of two replicates ±standard deviations.*

The net carbon mineralization in soil was also affected by the quantity of crop residues as well as their placement i.e., mulched versus incorporated (Figure 2). Our results showed that fastest respiration rates were in soil where 1g of maize residues were incorporated followed by soil where we incorporated 0.5 g of residues. Interestingly, soil respiration was slower at day1 in mulched treatment. At day 1, respiration rates were 352±8, mg C-CO_2 kg^{-1} dry soil day^{-1}, 230±2 mg C-CO_2 kg^{-1} dry soil day^{-1}, 202±6 mg C-CO_2 kg^{-1} dry soil day^{-1}, and 100±20 mg C-CO_2 kg^{-1} dry soil day^{-1} in Incorporated (1g), Incorporated (0.5g), Mulched and control treatments respectively. Afterwards, soil respiration rates increased in mulched treatment and were maximum after day 14 of sampling and remained fastest until end of the incubation experiment.

Dynamics of maize residue C

Figure 3 shows the cumulative mineralization of maize residue carbon added as mulch or incorporated in soil. The line representing the decomposition of the mulched residues shows that this treatment contributed 45.5% of added C. It must be noted that this line goes smoothly exponentially as compared to other two. Initially the mulched treatment is showing the least amount percentage of residues decomposition. It is due to the reason that in mulched treatment residues are spread over the soil surface. There is less chance of interaction between soil microbes and mulched crop residues. But later on, after 20 days of incubation may be due to the suitable condition. Microbes get activated and increased the rate of decomposition of provided residues. Thus, this decomposition added the carbon content to soil. The line representing the decomposition of the residues in incorporated 1g shows that this treatment contributed 42.2% of added C. The line representing the decomposition of the residues in incorporated 0.5 g shows that this treatment contributed 35.9% of added C. For the first two weeks the lines of incorporated 1g and incorporated 0.5 g treatments are overlapping. That is, they are contributing similar percentage of total C added. But after this time the incorporated 1 g treatment shows higher decomposition of its residues than the incorporated 0.5 g residues. One reason may be the fact that in the incorporated 1 g treatment soil is in direct contact with large amount of residues. That means that the soil microbes can get more chance of their faster activity as they are getting more food.

The organic matter was also measured after the whole experiment of incubation to see the impact of incubation on each treatment. The highest OM was found in soil of incorporated 1g treatment, which was about 0.22g per 1000g of soil. The OM of Incorporated 0.5g treatment soil was estimated about 0.21g per in 1000g of soil. The OM in mulched treatment was estimated about 0.20g per 1000g of soil. The OM in control soil was about 0.15g per 1000 g of soil.

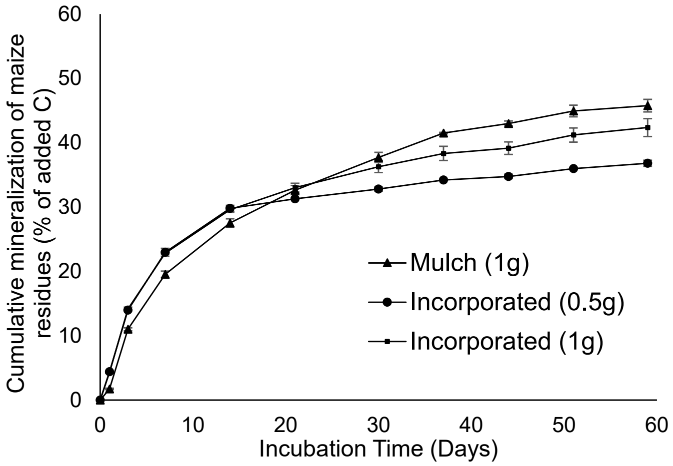

Figure 3: *Cumulative mineralization of organic carbon derived from maize crop residues in soil (% of added carbon). Data are shown as averages of two replicates ±standard deviations.*

The soil of mulched treatment was simply covered with the layer of crop residues whereas in the incorporated treatments the crop residues were mixed in the upper layer of soil and were spread over the soil underneath. Our data showed that in the beginning of the incubation, residues of incorporated treatments mineralized at faster rate but then slowed down as the time passed. The rate of mineralization of the residues in the mulched treatment increased after 20 days which was slower at the beginning of incubation. Faster mineralization in incorporated treatment is mainly attributed to the fact that soil microorganisms had greater access to residue compared to surface covered residues in mulch treatment (Aslam *et al*., 2014; Coppens *et al*., 2007). Resultantly with the passage of time, the rate of incorporated residual decomposition slowed down, also resulting a decrease in cumulative mineralization. By contrast, in mulched treatment, soil microbes had much less exposure surface place residues and therefore mineralization was slower in beginning of the incubation (Coppens *et al*., 2007). The increased microbial activity and population with time enhanced decomposition of mulched residues (Abiven *et al*., 2005). After microorganisms could access the residues, they used it as substrate and decomposed it. Feeding on the residues might have released the trapped nutrients and increased the soil nitrogen, carbon and phosphorus levels.

Our data presented in Figure 2 showed that the incorporated treatment (1g) had the highest peak, (~360 mg C-CO_2/ Kg dry soil /day) for soil respiration rates which may be attributed to two main reasons; one is that it had the greatest amount of crop residue to decompose and second is, it is mixed with soil increasing the surface area for microbial activity (Bertrand *et al.*, 2006). The incorporated treatment 0.5g had half the amount of crop residue than the incorporated 1g treatment, that is the reason it exhibited almost half (~240 mg C-CO2/ Kg dry soil/day) soil respiration rates than incorporated (1g) treatment. The mulched treatment showed the slower rates of soil respiration in the beginning because it had crop residues spread over the soil surface rather than incorporated within soil. The soil particles and microbes were not in direct contact with the residues thus decomposition rate was much slower but then increased with the increase in microbes' population. The control showed nearly the half of soil respiration compared to incorporated (0.5g) treatment i.e. (~120 mg C-CO2/ Kg dry soil /day). Soil organic carbon was also found greater in incorporated 1g treatment, this again supports that the cumulative mineralization was higher in this treatment. This organic matter in soil can be used to enhance the fertility of soil in an eco-friendly and healthy way which is also economical (Iqbal *et al.*, 2013; Abiven *et al.*, 2005). Anthropogenic activities and chemicals have altered the natural processes; which has led us to the degradation of land ecosystems. This world is straightforwardly depended on the plants, which are the only primary producers. All the food chains and the food webs are to feed the entire groups of living organisms and to protract the ecosystem. At this stage living beings needs to adopt the natural ways to protect and gain the eco system services. Using crop residues management strategies in the fields to protect soil and enhance productivity, would not only reduce the curse of pollution but also manage our solid waste, reduce the use of chemicals, reduce the production cost and eliminate the hunger and poverty while providing us with a healthy and clean environment. This is the win-win situation and a step towards sustainable agriculture.

Conclusions and Recommendations

This study conducted under controlled conditions demonstrated that crop residue management has unique impact on soil properties. The results showed that the impact of residues on each treatment is different from each other depending upon their placement in soil and also by their quantity. Microbial activities were faster in incorporated treatment as compared to mulched treatment as evident by soil respiration rates. In the incorporated treatments, residues were in direct contact with the soil particles and soil born microorganisms which allows the faster rate of decomposition. We conclude that residue management and organic matter dynamics in soil are inter-linked. It is not only influencing the carbon decomposition and nutrient release but also influences water retention, water and nutrient transport and leaching.

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Novelty Statement

This study for the first time reports the impact of crop residue management (mulched versus incorporated residues) practices on residue decomposition, soil respiration and organic matter content in a silty loam soil of Pakistan.

Author's Contribution

Saman Rizwan: Experimentation, data analysis, writing and editing
Sohaib Aslam: Conceptualization, supervision, review and editing

Conflict of interest
The authors have declared no conflict of interest.

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