



RESEARCH NOTE

REVISED Root mass may affect soil water infiltration more strongly than the incorporated residue [version 2; referees: 1 approved with reservations]

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Abstract

Crop residue incorporation increases stable soil pores and soil water infiltration and reduces surface water runoff and soil erosion. However, few studies have examined the relationship between crop residue incorporation and water infiltration. A previous study showed that water infiltration increases depending on the quantity of applied wheat straw. In this study, we examined whether the relationship is applicable to different crop residues in a crop rotation. We grew corn, rose grass, and okra in crop rotation under plastic film houses and measured the water infiltration rate at the time of ridge making. A strong correlation was found between the quantity of applied residue and the soil water infiltration rate ($r = 0.953$), although there are outliers in the case of no prior crop. However, aboveground biomass of the prior crop showed a stronger correlation with water infiltration rate ($r = 0.965$), without outliers. Previous studies have revealed the exponential relation between plant root mass and soil erosion. Our data also show a positive relationship between resistance to erosion and root mass when assuming that aboveground biomass is proportional to the underground biomass. The result also showed that the effect of the prior crop root mass disappears within the next crop period. Our results indicate that maintaining a large root biomass is crucial for reducing soil erosion.

Keywords

Crop residue, Crop rotation, Soil erosion, Soil water infiltration, Sustainable agriculture

Open Peer Review

Referee Status: ?

Invited Referees

1

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1 **Kae Miyazawa**, University of Tokyo, Japan

Any reports and responses or comments on the article can be found at the end of the article.

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Competing interests: No competing interests were disclosed.

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REVISED Amendments from Version 1

Following comments from the peer-reviewers, the manuscript was revised as follows.

Clarification of the content, including [Supplementary Figure 1](#), was added to explain the objective and methodologies.

The term "soil moisture levels" change to "mulching treatment".

The period of corn residue drying was corrected "a month" to "two months".

See referee reports

Introduction

Soil degradation is a major constraint of food security (Gomiero, 2016; Lal, 2015), and soil erosion represents one of the crucial intervention points for reversing soil degradation (Karlen & Rice, 2015). The no-tillage method is a major approach to tackle erosion; however, tillage remains a major management approach on arable land. What is the point of preventing soil erosion in practical? The Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) is the standard for estimating erosion. The equation shows that the risk of erosion is reduced when a crop has covered soil surface. This emphasizes the importance of preventing erosion in the early stage of crop growth. In general, it is rare for rain intensity to exceed $30 \text{ mm } 10 \text{ min}^{-1}$ (Kouhei *et al.*, 2011). Therefore, surface runoff after tillage almost never occurs if the infiltration rate of a field is larger than $30 \text{ mm } 10 \text{ min}^{-1}$. Finally, technologies increasing the infiltration rate higher than the precipitation rate are needed to prevent soil erosion in tillage systems.

Tillage makes soil porous, but the physical properties are rapidly lost (Strudley *et al.*, 2008). However, organic matter application increases the stability of soil pores (Turmel *et al.*, 2015). Potter *et al.* (1995) reported that water infiltration of soil was higher under no-tillage than tillage conditions when the residue input was low, but the opposite result was shown when the residue input was high. The soil erosion decreased according to the degree of water infiltration (Potter *et al.*, 1995). Just after residue incorporation, rill erosion rates were significantly reduced (Brown *et al.*, 1989). A previous study reported that surface water runoff under normal subtillage reduced up to the applied wheat straw quantity, as the water infiltration increased with the quantity of applied straw (Russel, 1940), although the relation between the quantity of applied residue and infiltration rate has been less studied. Conversely, it is known that plant root mass is related to rill and ephemeral gully erosion (Gyssels *et al.*, 2005). The effect of residue incorporation is unclear.

Our research aims were as follows: 1) to determine whether the relation between residue incorporation and infiltration holds under crop rotation, and 2) to determine whether the remaining underground root mass influences this relation. To address these questions, we determined water infiltration rates for different biomass levels under even amounts of residue incorporation in crop rotation.

Methods

Study site and treatment

We conducted the experiment in two plastic film houses at the Japan International Research Center for Agricultural Sciences experimental field (24.38°N and 124.19°E) on Ishigaki Island. The climate is subtropical. The soil type was Ultisol (Soil Survey Staff, 2014) and the texture was sandy clay loam. The house was 5 m wide and 18 m long. We made three soil ridges (0.2 m high and 1 m wide) with a 0.5 m path on each side. We divided these ridges into three plots with 0.8 m paths between each plot. In this way, we created nine plots ($1 \text{ m} \times 5.2 \text{ m}$) in each film house and randomly assigned them with nine treatments (3×3 factorial design). These treatments comprised three nitrogen levels (0, 10, and 40 kg N ha^{-1} ; slow-release-type urea only, no other fertilizers were used) and three mulching treatment (unmulched, weed barrier fabric, and black plastic film mulch). Although both nitrogen application and mulch treatment have some impacts, we expected the changes in top-root ratios.

We replicated the treatments using two film houses (A and B). We cropped corn (*Zea mays*) without fertilizer before the experiment and collected the residue, then chopped the residue into approximately 3 cm pieces using a chopper and dried it for two months under a roof. We adjusted the soil moisture of the house at a suitable level for tillage by irrigating (25–40 mm) with mist irrigation tubes (Kiriko; Mitsubishi Chemical Agri Dream Co., Ltd., Tokyo) and then removed the tubes. We scattered 2 Mg ha^{-1} of the corn residue, tilled by a rotary tiller, made the ridges, measured the soil water infiltration, set the irrigation tubes again, set the mulch films, transplanted rose grass (*Chloris gayana*) seedlings with fertilizer, and irrigated up to the field capacity. Additional irrigation was not provided. After harvesting rose grass, we repeated the processes using rose grass residue in the same way for okra (*Abelmoschus esculentus*). All the crop residues were collected in each house then evenly returned to the plots (each plot received the same amount of residue for the next crop per house; the amount was different between the houses). The growing season of corn, rose grass, and okra were 7 June to 10 August 2016, 14 October 2016 to 11 January 2017, and 12 January to 14 April 2017, respectively. An interval of 65 days was provided between the corn harvesting and the rose grass planting. There was no interval between rose grass harvesting and okra planting. (Supplementary Figure 1).

Infiltration rate measurement

We measured the soil water infiltration rate with Mariotte's bottle (20 cm high, 10 cm in diameter), with two holes in the bottom. Mariotte's bottle is a device that delivers a constant rate of flow. We inserted a plastic ring of the same diameter into the ridge to a 10 cm depth and then watered from a 1 m height to the ring at a 60 mm min^{-1} rate. We recorded the time needed to waterlog 50% of the soil surface area. We measured infiltration on the ridge at the initial stage (before the rose grass; with incorporated corn residue), after the rose grass (with incorporated rose grass residue), and after the okra (with incorporated okra residue).

Determination and analysis

The effect of the soil moisture difference treatment was determined at the end of okra cropping by extracting soil core samples from 0 to 5 cm soil depth on the ridge. Aboveground biomass was calculated by multiplying the plot's whole fresh biomass weight to the average moisture content of the air-dried samples' in each house. We performed Pearson's product moment correlation analysis of the infiltration rate for the quantity of applied residue or for the aboveground biomass (dry weight) using the "CORREL" function of MS Excel 2016. The correlation coefficients were calculated for the mean values of nitrogen levels and for that of the mulch levels. The mean values of nitrogen levels show the effects of aboveground biomass, which averaged out the effect of soil moisture. By contrast, the mean values of mulch levels show the effect of soil moisture.

Results

The incorporated residues of each house were 2.0 and 2.0 Mg ha⁻¹ for the initial stage (before seeding the rose grass), 3.8 and 4.7 Mg ha⁻¹ after the rose grass, and 0.8 and 0.8 Mg ha⁻¹ after the okra. The corresponding infiltration rates were 45 and 36 mm, 97 and 123 mm, and 32 and 47 mm, respectively. There was a strong correlation between the quantity of incorporated residue dry weight and soil water infiltration rate ($r = 0.953$) in terms of nitrogen level treatment, although initial corn residue showed outliers (Figure 1a). However, aboveground biomass of the prior crop showed a higher correlation with soil water infiltration rate ($r = 0.965$), without outliers (Figure 1b). The correlation coefficient of the infiltration rate and the aboveground weight decreased to $r = 0.872$ for the mulch level treatment (Figure 1c). The soil moisture (0–5 cm) of the N0, N1, and N4 treatment at the end of okra cropping was 8.3% ($\pm 1.6\%$), 7.2% ($\pm 1.0\%$), and 7.8% ($\pm 1.7\%$), respectively

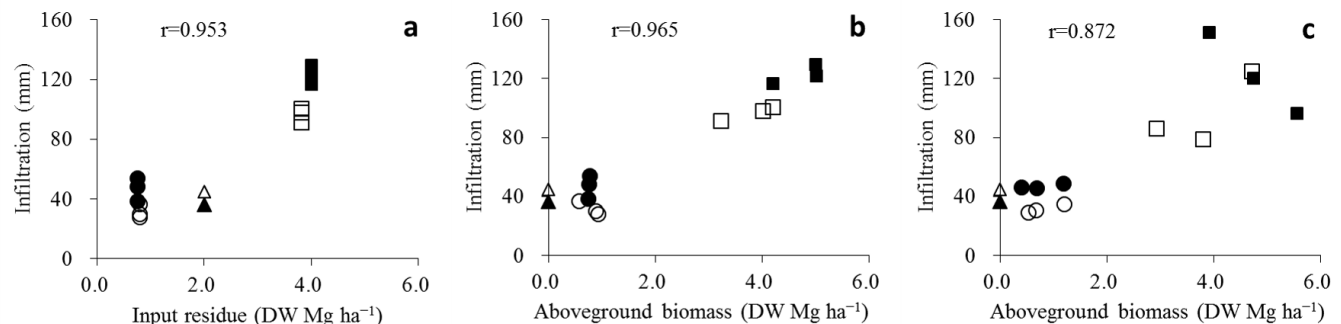
(Oda *et al.*, 2018). The soil moisture of the unmulched, the fabric, and the film treatments were 6.5% ($\pm 0.7\%$), 7.6% ($\pm 0.8\%$), and 9.7% ($\pm 0.9\%$), respectively (Oda *et al.*, 2018).

Discussion and conclusions

We found a strong correlation between input residue and the infiltration rates for the nitrogen-level treatment (Figure 1a). However, the average infiltration rate of initial stage was almost the same as that of after okra, although the input quantity of the initial stage (2.0 Mg ha⁻¹) was a 2.5-fold higher than after okra (0.8 Mg ha⁻¹). By contrast, the correlation for the aboveground biomass had no outliers (Figure 1b). This reveals that aboveground biomass affects infiltration rate more than the applied residue. A previous study has shown that the decrease in water erosion rates with increasing root mass is exponential, although infiltration was not mentioned (Gyssels *et al.*, 2005). Our data show a positive relationship between resistance to erosion and root mass when assuming that aboveground biomass is proportional to the underground biomass.

The mulch treatment data shows that correlation between the aboveground weight and infiltration rate was erratic (Figure 1c). The soil moisture difference caused large differences in aboveground growth. In addition, the unit performance of infiltration was not stable. The difference of soil water content at most 3.2% (6.5% of the unmulched and 9.7% of the film) in top 5 cm was negligible against the 25–40 mm of applied water before measurement for making the ridge. Therefore, it is considered that the outliers did not come from the difference of soil moisture but came from the difference of root mass, which was affected by the soil dryness.

We should consider the duration of the "after-effect" of the prior crop, such as the roots of rose grass on the soil water infiltration



△: Initial (after Corn) House A, ▲: Initial (after Corn) House B, □: After Rose grass House A, ■: After Rose grass House B, ○: After Okra House A, ●: After Okra House B.

Figure 1. Correlation between input residue or aboveground biomass and the soil water infiltration rate. (a, b) Means of the nitrogen-level treatment. (c) Means of the mulch-level treatment. Crop rotation was conducted as follows: corn, rose grass, and okra in plastic film houses. An interval of 65 days was provided between the corn harvesting and the rose grass planting. There was no interval between rose grass harvesting and okra planting. Houses A and B are replicates. We measured the soil infiltration rates on the ridge using artificial rainfall equipment on the day of making the ridge. The values are the mean of three plots.

rate measurement of after okra (Wischmeier & Smith, 1978). Two facts support the observation of a small after-effect. Firstly, the infiltration rates were very small (32 and 47 mm) after okra, although they were very large (97 and 123 mm) after rose grass. Secondly, the correlation between the aboveground biomass and the infiltration rate was stable and less was affected by a prior crop. Therefore, we conclude that the effect of the prior crop root mass almost disappears within the next crop growth period under the experimental conditions.

Finally, the key finding of this study is that the effect of above-ground residue quantity, more precisely root mass, was stronger than the incorporated residue. Although the residue quantity was the main factor determining the infiltration rates at tillage, the fairly low performance of initial corn residue is remarkable. This is likely to be because interval between harvesting corn and rose grass planting was very high (65 days). The soil pores would have been decreased. From a physical viewpoint, the area of residue surface is far smaller than that of the root surface. And the gap is easily clogged by sediment caused by rainfall. Therefore, the improvement of soil water infiltration probably comes from

root mass (Gyssels *et al.*, 2005). This suggests the importance of sequential cropping in tropical regions.

Data availability

Raw data of this article are presented in figshare: <https://doi.org/10.6084/m9.figshare.6741890.v1> (Oda *et al.*, 2018).

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Grant information

The author(s) declared that no grants were involved in supporting this work.

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Supplementary material

Supplementary Figure 1. Timeline of the experiment. Cropping days and the residue input.

[Click here to access the data](#)

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Open Peer Review

Current Referee Status: ?

Version 2

Referee Report 06 March 2019

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Kae Miyazawa

Graduate School of Agricultural and Life Sciences, University of Tokyo, Tokyo, Japan

Introduction:

- I could see some improvement in the introduction structure, however, it is still not structured enough to explain the importance of this research. For example, there is no explanation in the introduction about why it is important to investigate whether or not the relationship between residue incorporation and infiltration holds "under crop rotation" (which is stated as one of the aims of this research). I could not find from where this aim came from by reading this introduction. Similar comment for the other aim; the reference cited about wheat straw quantity and infiltration relationship under sub-tillage is way too old, and the description of plant root mass effect is unclear to support the importance of the second aim. Which kind of effect are you talking about by describing "that plant root mass is related to rill and ephemeral gully erosion"? Also what do you mean by "the effect of residue incorporation is unclear"? If it is not clear, then how do you define and evaluate whether or not 1) "the relation between residue incorporation and infiltration" holds under crop rotation, and 2) whether or not root mass influences "this relation"?
- Also the authors are mainly writing about no-tillage results in the introduction, and failed to summarize enough references that have investigated the effect of residues under tilled conditions. There are many papers on this topic (for example, the effect of organic matter or green manure application under tilled cropping system).

Methods:

- The experimental design has to match the aims stated in the introduction. For the 1st aim, it is necessary to compare the relationship between plant residue and infiltration rate under different cropping sequences (for example, consecutive corn cropping vs. corn-rose grass-okra cropping is necessary). For the second aim, factorial design of different amounts of root mass, and different amounts of crop residue incorporation is needed. The experimental design described here is not suitable for the aims stated in the introduction.

Results, discussion and conclusions:

- The same comments as the first review.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: soil science, vegetable cultivation

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 08 Mar 2019

Masato Oda, Japan International Research Center for Agricultural Sciences (JIRCAS), Japan

Thank you for the prompt response. However, I'm sorry that you didn't give me a response to our question about the outliers.

"the authors are mainly writing about no-tillage results in the introduction"

MO: I have no idea why you think so. We mentioned only about the tillage system in the second paragraph.

The importance of the water infiltration study of "under crop rotation" is not described. And, the reference is too old.

MO: The reference cited about wheat straw quantity and infiltration relationship is the only paper that we could find for "incorporated residue quantity and infiltration rate" although there are many papers on the effect of organic matter or green manure application under tilled cropping system. The study is for mono-crop, instead, our study is for the crop rotation.

Which kind of effect are you talking about by describing "that plant root mass is related to rill and ephemeral gully erosion"?

MO: This question was probably caused by the bad sentence. The following changes in those sentences will make it easy to understand:

"The relation between the quantity of applied residue and infiltration rate has been less studied, although, it is known that plant root mass is related to rill and ephemeral gully erosion (Gyssels et al., 2005)."

The last sentence is no longer needed.

For the 1st aim, it is necessary to compare ...(for example, consecutive corn cropping vs. corn-rose grass-okra cropping is necessary).

MO: I don't agree with you. It means that there is a relation in crop rotation if the relation was found in crop rotation. The same thing can be said to the cited study.

For the second aim, factorial design of different amounts of root mass, and different amounts of crop residue incorporation is needed.

MO: We did. Unless, how can we show the figure 1 a)? However, we need to explain the outliers. The answer is figure 1 b).

Competing Interests: No competing interests were disclosed.

Version 1

Referee Report 07 February 2019

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Kae Miyazawa

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This is a short report to investigate the infiltration rate under different treatments, conducted in 2 green houses. The treatments were 3 levels of urea input, and 3 ways for mulching. They have grown corn, rose grass, and okra, and incorporated them after each cropping season, and measured infiltration rates. Their conclusion is that the root mass affects infiltration more than incorporated residue amount, but it's flawed (details below).

Introduction:

- The introduction has to be revised. Right now, two paragraphs that are supposed to give the background for your research aim are not structured well. Right now, you have just put related information without considering logical order. It can be improved, for example, if the first paragraph is structured like this;
 1. Erosion is a major problem for the soil degradation.
 2. Erosion starts when rain hits the bare soil and form a crust by braking aggregates, which decreases infiltration and increase surface runoff.
 3. Therefore, to reduce soil erosion, protecting soil surface and improving infiltration rate are important.
- Then, in the second paragraph, you can talk about how to do that (no tillage, putting residues, incorporating organic matter etc.). Also at the end, or the next paragraph, you can talk about what is still lacking and needs to be investigated to show the originality of this report.
- In the last paragraph of the introduction, you put your research aim. 1), and 2) are understandable, but the last sentence is not clear. Why can "ensuring growth of different crops for the same amount of input residue with different nutrition levels and different soil moisture levels" provide answer for those two questions?

Methods:

- You have N fertilizer treatment, and "soil moisture" treatment, but putting as "three soil moisture levels (un-mulched,)" is not really exact naming for your treatment, since you are not really controlling soil moisture alone (covering with mulch has a lot more effect other than soil moisture). Probably "mulching treatment"?
- Second paragraph: Please put the information in order. You are talking about the end of Okura cropping, then going back to the corn cropping next. Please make it easy for readers to understand by putting them in logical manner.
- "we repeated the above processes": What are the processes? There are so many processes in "above". Do you mean all including corn cropping?
- It is not clear whether you returned residues evenly among plots within the house, or across the houses.

- Data analysis: Since this experimental design is 2 factor, 3 levels, randomized block design with 2 replication (block), please conduct 2-way anova accordingly.

Results, Discussion and conclusions:

- If you use the 2-way ANOVA results, you might find something interesting. Since the residue amount increases as the crop biomass and crop root biomass increases, these results are basically showing the same thing. When you had more residue (for example, when you have grown rose grass), you also had more above ground and root biomass. So the Figure 1a result is concomitant with the crop biomass (and root biomass), and not purely showing the effect of the residue amount. If you want to compare the residue incorporation effect and crop biomass (and root biomass), you need to have plots with uniform root biomass condition, and incorporate residues in different levels.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

No

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

No

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: soil science, vegetable cultivation

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 22 Feb 2019

Masato Oda, Japan International Research Center for Agricultural Sciences (JIRCAS), Japan

First of all, we respect you for bravely participating in the open review. As you know, the open review has not been popular in our field of sciences. We are deeply thankful to you. And it is our pleasure to enjoy the discussion with you. We are also thinking that your comments are on behalf of many other readers. We understand that the discussion presents them with a correct understanding of our results by improving the manuscript.

Comment 1:

Introduction:

The introduction has to be revised. Right now, two paragraphs that are supposed to give the background for your research aim are not structured well. Right now, you have just put related information without considering logical order. It can be improved, for example, if the first paragraph is structured like this;

- 1. Erosion is a major problem for the soil degradation.**
- 2. Erosion starts when rain hits the bare soil and form a crust by braking aggregates, which decreases infiltration and increase surface runoff.**
- 3. Therefore, to reduce soil erosion, protecting soil surface and improving infiltration rate are important.**

MO: Yes, you are right. We need to revise the introduction. However, the order is different. We showed the importance of the infiltration rate from the holistic view of preventing soil erosion practically. For that purpose, we are referring USLE. From this point of view, we showed that erosion is a problem of mainly combined with tillage. We added a sentence as follows: "What is the point of preventing soil erosion in practical?". Although it is another story, we changed the duplicate use of "Therefore" to "Finally".

Comment 2:

Then, in the second paragraph, you can talk about how to do that (no tillage, putting residues, incorporating organic matter etc.). Also at the end, or the next paragraph, you can talk about what is still lacking and needs to be investigated to show the originality of this report.

MO: We agree with you. The second paragraph had not followed the previous paragraph. We think the problem is the first sentence and the last sentence. We deleted the first sentence and added the following sentence at the end of the paragraph: "The effect of residue incorporation is unclear".

Comment 3:

In the last paragraph of the introduction, you put your research aim. 1), and 2) are understandable, but the last sentence is not clear. Why can "ensuring growth of different crops for the same amount of input residue with different nutrition levels and different soil moisture levels" provide Response for those two questions?

MO: Yes, we agree with you. We need to describe more clearly the aim of the treatment rather than the treatment itself here. We revised the sentence as follows: "we determined water infiltration rates for different biomass levels under even amounts of residue incorporation in crop rotation."

Comment 4:

Methods:

You have N fertilizer treatment, and "soil moisture" treatment, but putting as "three soil moisture levels (un-mulched,)" is not really exact naming for your treatment, since you are not really controlling soil moisture alone (covering with mulch has a lot more effect other than soil moisture). Probably "mulching treatment"?

MO: You are right. We changed to "mulching treatment". We are also thinking about the same thing that you have mentioned. We added the following sentence at the end of the first paragraph: "Although both nitrogen application and mulch treatment have some impacts, we expected the changes in top-root ratios."

Comment 5:

Second paragraph: Please put the information in order. You are talking about the end of Okura cropping, then going back to the corn cropping next. Please make it easy for readers to understand by putting them in logical manner.

MO: We added a supplemental figure of the timeline. We moved the first sentence to the determination section.

Comment 6:

"we repeated the above processes": What are the processes? There are so many processes in "above". Do you mean all including corn cropping?

MO: Thank you for the suggestion. We cut the word "above" and added the "using rose grass residue" after the word "okra".

Comment 7:

It is not clear whether you returned residues evenly among plots within the house, or across the houses.

MO: See the sentence "(each plot received the same amount of residue for the next crop per house; the amount was different between the houses)". We think many readers will have the same question; however, now the added sentence at the end of the introduction and the supplemental figure will help their understanding.

Comment 8:

Data analysis: Since this experimental design is 2 factor, 3 levels, randomized block design with 2 replication (block), please conduct 2-way anova accordingly.

MO: This study conducted correlation analysis, and the strong correlation means significance. We believe, anova is not needed because the correlation analysis of this study gives much information.

Comment 9:

Results, Discussion and conclusions:

If you use the 2-way ANOVA results, you might find something interesting. Since the residue amount increases as the crop biomass and crop root biomass increases, these results are basically showing the same thing. When you had more residue (for example, when you have grown rose grass), you also had more above ground and root biomass. So the Figure 1a result is concomitant with the crop biomass (and root biomass), and not purely showing the effect of the residue amount. If you want to compare the residue incorporation effect and crop biomass (and root biomass), you need to have plots with uniform root biomass condition, and incorporate residues in different levels.

MO: Thank you for the important question! You mean that both the amount of residue and the above ground biomass is significant, don't you? We knew. We also knew they are concomitant. However, how do you think about the outlier? To tell the truth, we had expected that returning plant residue is effective for preventing soil erosion; however, it denied in another experiment (unpublished data). "the average infiltration rate of initial stage was almost the same as that of after okra, although the input quantity of the initial stage (2.0 Mg ha⁻¹) was a 2.5-fold higher than after okra (0.8 Mg ha⁻¹)". The DM amount, 2.0 Mg ha⁻¹ is a considerable amount. The necessity of having plots with "uniform root biomass" is quite agreeable for us too. Therefore, we titled our research as "may affect". This Research note discusses only unexpected results that come from an experiment that was carried out by our resources.

Competing Interests: No competing interests were disclosed.

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