BRIEF REPORT

Use of the K factor from the Universal Soil Loss Equation can show arable land in Palau [version 1; peer review: 1 approved with reservations]

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Abstract
Palau is an island in the Micronesia region of the western Pacific Ocean. The island receives heavy rainfall and has steep slopes, so 92\% of the land is categorized within the most erodible rank, with a T factor of 5. A recent study reported that the water infiltration rate is proportional to the root mass of the crop soil; therefore, we attempted to evaluate the performance of root mass for preventing soil erosion. We covered parts of the land, with a slope of 15.4° (13.4°–17.3°), with weed control fabric to prevent the growth of grass and roots, then removed the fabric, cultivated the land, planted sweet potatoes, and compared the amount of soil erosion with other areas. Surprisingly, there was no erosion at all in the test plots, although there were 24 rainfall events that caused erosion. For the parameters of the Universal Soil Loss Equation (USLE) equation used in the present study, only the K factor was not actually measured. This means the K factor was larger than the actual value. Land at low risk of soil erosion and suitable for agriculture can be found by measuring K factor locally, even if the area is categorized as unsuitable.

Keywords
Babeldaob, hillside farming, island, tillage, mulching, USLE equation

This article is included in the Agriculture, Food and Nutrition gateway.
This article is included in the Climate Action gateway.

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Author roles: Oda M: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft Preparation; Nwe YY: Investigation, Resources, Writing – Original Draft Preparation; Omae H: Investigation, Project Administration, Writing – Original Draft Preparation

Competing interests: No competing interests were disclosed.

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Introduction

Palau forms part of the Micronesia region in the western Pacific Ocean. There are open agricultural fields that were once utilized by the Japanese, prior to World War Two. The redevelopment of these fields is starting to occur. Generally, fields with inclines of more than 8° are unsuitable for growing crops, but most of the agricultural fields in Palau have slopes of more than 8°. As well as having steep slopes, the island is also subject to heavy rainfall, therefore 92% of the land is categorized within the most erodible rank, having a T factor of 5 (more than 5 tons per acre per year) (Smith, 1983). In recent studies, the estimated risk of soil erosion from agricultural land was reported to be from 720 to 813 tons per ha per year (USDA Natural Resources Conservation Service, 2003). No-tillage farming is effective for preventing soil erosion (Zuazo & Pleguezuelo 2009), but the use of herbicides is unfavorable in Palau from an ecological perspective. Therefore, either tillage or the use of weed control fabric is necessary. The problem of tillage is the early stage of the crop of small vegetation coverage (Wischmeier & Smith 1978). It is essential to increase the water infiltration rate at this stage. The water infiltration rate is positively proportional to the root mass of the crop soil (Oda et al., 2019). Here, we clarified the risk of erosion in a field with an incline typical for Palau. In addition, we clarified the aftereffects of using weed control fabric, because the use of these fabrics can reduce root mass in the tropics and may result in erosion (Oda et al., 2019).

Methods

Site description

The experiment was conducted at the Palau Community College Research and Development Station (N7.53, E134.56). The soil here comprises “Ngardmau-Bablethuap Complex”, which is characterized as a very gravelly loam with low organic matter content of between 1% and 4% (Smith, 1983). The T factor is more than 5 tons per acre per year, although the permeability is moderately rapid (15–50 cm/hr) and very well drained. The available water capacity is between 0.05 and 0.10 cm/cm (Smith, 1983). The previous crop grown on the land was taro (Colocasia esculenta). The slope is 15.4° (13.4°–17.3°).

Treatments

We conducted the experiment from January to July 2019. The treatments were plants (with or without) × ridge (with or without) × 2 replications. We set these eight plots (2 × 10 m) randomly on the field (Table 1, Figure 1 and Figure 2). We tilled the field using a hand tractor on 22 January, leveled the field, and covered half the plots with weed control fabric (polypropylene, 0.4-mm thick, 120 g m⁻²; I-Agri Corp., Tsuichiura) on 28 January. We cut weeds on 16 April, blew off the residue, removed the weed control fabric on 17 April (Figure 3), then tilled each plot using the hand tractor up and down so that the soil did not mix. The average thickness of the soil tilled was 16 cm. We made a 70 cm width of the monitoring areas in the center of the plots by ridges or wooden boards (for the no-ridge treatment). We transplanted sweet potatoes (Ipomoea batatas) at 70 cm intervals on 17 April (Figure 4). We dug trenches at the upper end of the fields to prevent rainwater inflow. We embanked the lower ends and added 1-m lengths of weed control fabric to trap any eroded soil. Fertilizer was not applied. Hand weeding was conducted on 21 May and 6 June.
Determination
Following every heavy rainfall event, we collected any soil that had been eroded. We collected precipitation data every 5 minutes via a weather station in the Palau Community College Research and Development Station. The condition of the fields was recorded using an automatic camera.

Analysis
We identified rainfall events that caused severe erosion (more than 3 mm/10 min) (Onaga, 1969) and compared the amount of eroded soil of each events.

We estimated erosion using the Universal Soil Loss Equation (USLE) equation (Wischmeier & Smith 1978).

\[
A = R \times K \times L S \times P \times C \text{ metric ton ha}^{-1} \text{ year}^{-1}
\]

\[
E = 210 + 89 \log_{10} I_{30} \text{ 100 metric ton ha}^{-1}
\]

\[
I_{30} \text{ cm h}^{-1}; \text{ maximum rainfall in 30 min multiplied to 60 min; rainfall less than 1.27 cm is omitted, and the maximum value is 7.62 cm.}
\]

\[
A = EI \times K \times L S \times P \times C \text{ metric ton ha}^{-1}
\]

\[
K = 0.15
\]

\[
LS = \left(\frac{10}{20.0}\right)^{0.5} \times (68.19 \sin 15.4^\circ + 4.75 \sin 15.4^\circ + 0.068) = 4.34
\]

\[
P = 1.00; \text{ vertical ridge}
\]

C =1.0; Tillage

\[
EI = \frac{(E \times I_{30})}{100}
\]

Plot area = 7 m²

Results
Precipitation
The field site received regular rainfall, with total precipitation of 992 mm during the experimental period, from 17 April to 15 July (Figure 5). There were 46 days of erosive rainfall more than 3 mm per 10 min (Figure 6). The rainfall threshold where surface runoff occurs is 2–3 mm per 10 min on a 15° slope, although these values vary according to different soil characteristics (Onaga, 1969). There was a highly erosive rainfall event on day 7 after planting (2 May). Following weeding, an erosive period, a heavy rainfall event of 17 mm per 10 min occurred on the next day after weeding took place. The second weeding was conducted after seven days of intensive rainfall, with a further erosive rainfall event of 7 mm per 10 min that occurred just after weeding took place. Thus, the rainfall conditions during the experimental period were expected to result in severe soil erosion.

Estimated erosion
There were 24 rainfall events that could have caused erosion during the observation period (Table 2). The estimated erosion was 0.57 kg of erosion per plot on day 7, the first rainfall event, after transplanting. That was 2.82 kg after first weeding.
Figure 5. Daily precipitation.

Figure 6. Erosive rainfall events. The blocks show a rainfall event of more than 3 mm/10 min and the amount of precipitation. The colors distinguish the events.

Soil erosion
Despite the severe rainfall conditions, none of the plots had any erosion at all through the experimental period (Figure 7).

Vegetation coverage
Most of the soil surface was bare by day 14 (1 May). The surface of the soil was covered by small weeds on day 21 (8 May), the day of the first weeding. The vegetation coverage by visual inspection ranged from 15–85% on day 54 (10 Jun), after the second weeding. The vegetation coverage was 100% by day 89 (15 July) (Figure 8).

Discussion and conclusion
The experiment was conducted under severe conditions, with a slope of approximately 15° and vertical ridge. The treatment with weed control fabric was expected to erase the effect of root mass for preventing soil erosion. There were many intensive rainfall events during the experimental period. Nevertheless, no soil erosion occurred. This means that the risk of soil erosion was low for the experimental soil in fields with slopes of less than 15°. Tillage is available. Although the use of mulching material may erase the effect of root mass for preventing soil erosion, still the use of mulching material is available.

The results were unexpected. The vertical ridge may affect the result because a vertical ridge without a catch canal is less erosive (Shima et al., 1988).

For the parameters of the USLE equation in the present study, only the K factor was not actually measured. This means that the K factor was larger than the actual value. Low erosion land for agriculture can be found by measuring erosion locally, even if the area is categorized as being unsuitable for field crops. The
Table 2. Estimated erosion following each rainfall event.

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>$I_{95}$ cm h$^{-1}$</th>
<th>$E$</th>
<th>$E_{T}$ cm $^{-1}$</th>
<th>A t/ha</th>
<th>Erosion kg/plot</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-Apr</td>
<td>-9</td>
<td>1.76</td>
<td>232</td>
<td>4.08</td>
<td>0.89</td>
<td>0.62</td>
<td>(Before planting)</td>
</tr>
<tr>
<td>24-Apr</td>
<td>7</td>
<td>1.64</td>
<td>229</td>
<td>3.76</td>
<td>0.82</td>
<td>0.57</td>
<td>1st rain</td>
</tr>
<tr>
<td>26-Apr</td>
<td>9</td>
<td>1.36</td>
<td>222</td>
<td>3.02</td>
<td>0.65</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>1-May</td>
<td>14</td>
<td>2.76</td>
<td>249</td>
<td>6.88</td>
<td>1.49</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>2-May</td>
<td>15</td>
<td>2.84</td>
<td>250</td>
<td>7.11</td>
<td>1.54</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>6-May</td>
<td>19</td>
<td>1.52</td>
<td>226</td>
<td>3.44</td>
<td>0.75</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>9-May</td>
<td>22</td>
<td>1.68</td>
<td>230</td>
<td>3.86</td>
<td>0.84</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>10-May</td>
<td>23</td>
<td>2.92</td>
<td>251</td>
<td>7.34</td>
<td>1.59</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>12-May</td>
<td>25</td>
<td>3.52</td>
<td>259</td>
<td>9.10</td>
<td>1.98</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>18-May</td>
<td>31</td>
<td>2.92</td>
<td>251</td>
<td>7.34</td>
<td>1.59</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>24-May</td>
<td>37</td>
<td>6.56</td>
<td>283</td>
<td>18.55</td>
<td>4.02</td>
<td>2.82</td>
<td>After weeding</td>
</tr>
<tr>
<td>2-Jun</td>
<td>46</td>
<td>1.56</td>
<td>227</td>
<td>3.54</td>
<td>0.77</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>3-Jun</td>
<td>47</td>
<td>2.68</td>
<td>248</td>
<td>6.65</td>
<td>1.44</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>5-Jun</td>
<td>49</td>
<td>2.68</td>
<td>248</td>
<td>6.65</td>
<td>1.44</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>8-Jun</td>
<td>52</td>
<td>0.76</td>
<td>199</td>
<td>1.52</td>
<td>0.33</td>
<td>0.23</td>
<td>After weeding</td>
</tr>
<tr>
<td>8-Jun</td>
<td>52</td>
<td>2</td>
<td>237</td>
<td>4.74</td>
<td>1.03</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>17-Jun</td>
<td>61</td>
<td>1.72</td>
<td>231</td>
<td>3.97</td>
<td>0.86</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>21-Jun</td>
<td>65</td>
<td>1.12</td>
<td>214</td>
<td>2.40</td>
<td>0.52</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>27-Jun</td>
<td>71</td>
<td>1.96</td>
<td>236</td>
<td>4.63</td>
<td>1.00</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>29-Jun</td>
<td>73</td>
<td>1.6</td>
<td>228</td>
<td>3.65</td>
<td>0.79</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>2-Jul</td>
<td>76</td>
<td>1.04</td>
<td>212</td>
<td>2.20</td>
<td>0.48</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>10-Jul</td>
<td>84</td>
<td>5.36</td>
<td>275</td>
<td>14.73</td>
<td>3.20</td>
<td>2.24</td>
<td></td>
</tr>
<tr>
<td>13-Jul</td>
<td>87</td>
<td>2.44</td>
<td>244</td>
<td>5.97</td>
<td>1.29</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>14-Jul</td>
<td>88</td>
<td>4.32</td>
<td>267</td>
<td>11.52</td>
<td>2.50</td>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>15-Jul</td>
<td>89</td>
<td>2.44</td>
<td>244</td>
<td>5.97</td>
<td>1.29</td>
<td>0.91</td>
<td>(End of observation)</td>
</tr>
<tr>
<td>19-Jul</td>
<td>93</td>
<td>1.96</td>
<td>236</td>
<td>4.63</td>
<td>1.00</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>19-Jul</td>
<td>93</td>
<td>2.36</td>
<td>243</td>
<td>5.74</td>
<td>1.25</td>
<td>0.87</td>
<td></td>
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<tr>
<td>25-Jul</td>
<td>99</td>
<td>3.04</td>
<td>253</td>
<td>7.69</td>
<td>1.67</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>26-Jul</td>
<td>100</td>
<td>2</td>
<td>237</td>
<td>4.74</td>
<td>1.03</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>27-Jul</td>
<td>101</td>
<td>5.4</td>
<td>275</td>
<td>14.86</td>
<td>3.22</td>
<td>2.26</td>
<td></td>
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<tr>
<td>28-Jul</td>
<td>102</td>
<td>4.28</td>
<td>266</td>
<td>11.39</td>
<td>2.47</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>30-Jul</td>
<td>104</td>
<td>1.4</td>
<td>223</td>
<td>3.12</td>
<td>0.68</td>
<td>0.47</td>
<td></td>
</tr>
</tbody>
</table>

Sum of observation period (Day 7 to 89) 32.23 22.56
Figure 7. Actual erosion of the first rainfall event after transplanting. The estimated erosion was 0.57 kg per plot.

Figure 8. Vegetation coverage. Top panel: day 14, Upper middle panel: day 21 (before the first weeding), Lower middle panel: day 54 (after second weeding), Bottom panel day 89.
risk of erosion should be clarified for other soil types, and the
effect of the previous crop type too. For taro, the previous crop
in these fields, the roots might be left in the soil; although, we
took a fallow period. Land suitable for agriculture and at low
risk of soil erosion can be found in Palau by determining
site-specific K factor measurements.

Data availability
Underlying data
figshare.11769909.v1 (Oda et al., 2020). Data are available
under the terms of the Creative Commons Zero “No rights
reserved” data waiver (CC0 1.0 Public domain dedication).

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Publisher Full Text
Open Peer Review

Current Peer Review Status: ?

Version 1

Reviewer Report 30 April 2020

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Kathleen B. Boomer

1 Foundation for Food and Agriculture Research, Washington, DC, USA
2 CBP Scientific Technical Advisory Committee, Washington, DC, USA

Technical Review: Use of the K factor from the Universal Soil Loss Equation can show arable land in Palau by Oda et al.

General Comments:

The investigators report the results of measured and estimated soil erosion in the Micronesia region of the western Pacific Ocean. To compare how plantings and micro-tilling affects soil detachment and transport to field edges, they established eight plots within a single field, following as closely as possible (presumably) the original protocol of the USLE. Although the title indicates a focus on soil erodibility (K), the study design is more relevant to understanding practice effects on erosion. Given the importance of subsistence agriculture and the lack of studies specific to promoting sustainable practices in this region, this work calls attention to a critical information gap.

The manuscript requires extensive revisions to clarify and substantiate its contributions. It lacks a “story arc” that enables the reader to readily understand why this work is important, how the researchers tackled this knowledge gap, and how their results compare or contribute to the existing body of research. For example, the authors might consider highlighting the importance of subsistence farming to the region and the challenge of soil erosion to sustainable agriculture, but the lack of technical guidance specific to the region. The USLE, which is based on a phenomenal US dataset, is a widely accepted tool to evaluate erosion potential based on landscape setting and management, but the empirical model ideally requires local testing and refinements for application to areas outside of its original US study area. The research objectives and methods also require clarification. Finally, the limited number of plots (8) and fields (1) raises concerns about the power of the study to detect differences among field practices. Given the difficulty and expense of field studies and the realities of scant data, however, the publication may be valuable.
Specific Comments:

- A large portion of the introduction includes study site information, which should go in the Methods section.
- Use the international system for classification of soils to describe site conditions.
- Define “T factor”.
- In the site description, add information about the landscape setting, outside of the study site boundaries. A study site topographic map would be helpful. Information about the distribution of croplands on the study island, as well as a brief description of how the island compares to others in the region, would be helpful to thinking about the value of information beyond the study site.
- In the methods section, add a paragraph describing how and where rainfall data were collected. Include this location on the study area map.
- It is not clear how tilling, even if by hand, does not mix soils.
- Elaborate on how soil erosion was measured. Reference methods to the extent possible.
- Elaborate on USLE application and parameterization. Use previous publications as examples.
- In the “Estimated erosion” section, define “That” in the last sentence on page 3.
- Consolidate Figure 6 into one panel.
- In the Discussion and Conclusions section, paragraph 1, reference to site conditions seem contradictory: “experiment was under sever conditions, with a slope of ... 15°” vs “risk of soil erosion was low for the experimental soil”.
- Convert Table 2 to graphical form. For example, plot A vs EI, observed vs predicted, grouped by practice.
- The pictures are difficult to interpret.
- The discussion needs to follow the same “story arc” presented in the introduction and used to organize the methods and results sections. The discussion also needs to compare the study results with the existing body of literature to assess whether findings to reinforce or challenge existing paradigms. The authors also need to acknowledge the limitations of their study design and ideally, discuss the relevance of their findings to management recommendations.

Is the work clearly and accurately presented and does it cite the current literature?
No

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

Are sufficient details of methods and analysis provided to allow replication by others?
No

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: Hydrology, soil biogeochemistry, and watershed modeling

I confirm that I have read this submission and 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 25 May 2020
Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Thank you for the constructive comments.

We will accept almost of all the comments; however, before submitting a revised manuscript, may I clarify the following points?

1) Consolidate Figure 6 into one panel.
   Is that mean combine Figure 6 and Figure 5?

2) Convert Table 2 to graphical form. For example, plot A vs EI, observed vs predicted, grouped by practice.
   This is less effective because the practical data were all zero.

   Competing Interests: No competing interests were disclosed.

Author Response 02 Jun 2020
Masato Oda, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Define “T factor”.
Now, I understood that I misunderstood the meaning of the "T factor". Thank you so much.

**Competing Interests:** No competing interests were disclosed.

Author Response 19 Jun 2020

**Masato Oda**, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan

Clarified the “story arc” of the paper including the lack of technical guidance specific to the region, the research objectives, and methods.

1. The description of Palau was moved to the Methods section.
2. The international classification of soils was added.
3. Define of the “T factor” was corrected.
4. A Google map link was added as an alternative of the topographic map
5. The information on the experimental field was added.
6. The distance of the weather station was added.
7. The link of a picture of the hand tractor is added.
8. The method of collecting eroded soil was clarified more.
9. The application and parameterization of USLE were clarified more.
10. “That” in the last sentence on page 3 was clarified.
11. We couldn't understand the meaning of “Consolidate Figure 6 into one panel”.
12. We improved the readability. The first paragraph pointed out a contradiction and interpreted that in the second and the third paragraph.
13. No erosion was observed so the changing Table 2 to graphical form is ineffective.
14. We corrected estimated → predicted, actual was zero.
15. The discussion section was improved.

**Competing Interests:** No competing interests were disclosed.
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