Comparison of organic material application methods at “Majuro Atoll”

Abstract

The climate of Majuro Atoll is stable, and the soil is coral sand which has low levels of organic matter and nutrients and high percolation rates. This relatively stress-free climate and simple soil environment provides ideal conditions for the study of organic material application methods. In this study, I examined the efficiency of organic material application methods in five experiments using sweet corn crops. I obtained the following results: 1) Biomass output was correlated with residue input; however, input/output ratios converged to 0.5 at 15 Mg ha^{-1} a year (3 Mg ha^{-1} per crop). 2) The most efficient residue application rate was 2–3 Mg dry matter ha^{-1} crop^{-1}. 3) In terms of organic material application methods, scattering was the most effective, followed by incorporation. Cutting, short-term fermenting, mulching, and crop bed were not effective because of the areas humid climate and low levels of soil organic matter.

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Introduction

Numerous studies have been conducted concerning methods of organic materials application. For example, we can find many studies comparing tillage and non-tillage (Entry, Mitchell & Backman, 1996; Bolinder, Angers & Dubuc, 1997; Huggins et al., 1998; Clapp et al., 2000; Bolinder et al., 2007). However, relatively few of these studies have concerned the performance of organic material application methods in general. This is important because, for the farmer who decides to incorporate organic matter into the soil by tilling, he/she might still want to know: 1) how much organic matter to add, 2) the condition of the organic matter, and 3) which method is the most efficient. We cannot say that non-tillage is better than tillage without accounting for the effects of the application method itself. In fact, recent study revealed that no-till response is variable (Pittelkow et al., 2015). In practice, however, this can be difficult to determine because the results of organic material application methods also depend on climate and soil conditions.

Majuro Atoll, the capital of the Republic of the Marshall Islands, is located in the Pacific Ocean near the Equator. The climate is stable. The maximum monthly average temperature is 27.9 to 30.5 ℃, and the minimum temperature is 25.4 to 25.7 ℃. The average monthly precipitation is 192 to 337 mm, and the annual precipitation is 3,236.5 mm (National Oceanic and Atmospheric Administration. Retrieved 11 March 2015). The stable climate, in addition to the coral sand, provide a kind of natural growth chamber in which we can clearly observe the effects of differing organic material application methods. Coral sand has low organic matter levels (OC 0−15 cm: 46.9 g kg^{-1}, 15−45 cm: 10.8 g kg^{-1}), low nutrient levels (TN 0−15 cm: 4.25 g kg^{-1}, 15−45 cm: 1.35 g kg^{-1}) (Deenik, 2003; Deenik and Yost, 2006), and high percolation rates ($1.4–3.5 \times 10^{-3}$ m/s) (Hunt & Peterson, 1980).

The Laura District is an agricultural area on this atoll. Chemical fertilizer application is forbidden in this area to prevent contamination of the atoll's precious pure water lens. Therefore, copra cakes are a commonly used fertilizer. Copra cakes were at one time free of charge, but this has now changed. It will be useful, therefore, to identify effective organic material alternatives to copra cokes.

The aim of this study was to identify the most efficient methods for applying organic materials to crops. Specifically, the objectives were to:

1. Determine whether plant residue is a suitable alternative to copra cake.
2. Determine whether less weeding improves soil fertility by increasing total biomass.

3. Identify differences in cultivation conditions caused by crop bed and mulching.
4. Identify differences in yields among plant residue application methods when scattering, incorporation, cutting, and fermenting.
5. Identify how much plant residue should return to fields based on the output/input ratio, or what we call the law of diminishing returns.

Materials and Methods

Site description and common management conditions

The experimental field was located at Laura Farm (7° 8' 34" N, 171° 2' 9" E), which belongs to the Department of Research and Development of the government. The field was fallowed more than 6 months before starting the experiments. Water-soluble NO_3-N was not detected (less than 0.016 g soil^{-1}) by nitrite test strip (QUANTOFIX® Nitrate / Nitrite test strips, Macherey-Nagel GmbH & Co., Düren, Germany). Irrigation was not conducted, and fertilizers or chemicals were not used for all experiments. Weeds on the experimental field were collected on October 29, 2013. The unit fresh biomass of the weed was 26 Mg ha^{-1} (3.0 Mg ha^{-1} in dry weight). All of those weeds were pulled out and shredded by shredder, then fermented for 4 weeks under the shelf. The first experiment was started on November 25, 2013.

The plot size was 1.2 m × 6.0 m, and the experimental field consisted of two sets of 6 plots. The field size was approximately 12.5 m × 7.2 m. Sweet corn was seeded in 2 rows in 0.5 m intervals. Seeding was conducted on the same day as land preparation. However, nitrogen starvation was never observed. Hand weeding was performed twice at approximately 2 and 5 weeks after sowing (except for the treatment plots that were not weeded).

Experiment 1: Examining whether plant residue is a suitable alternative to copra cake

I divided the experimental field into 4 parts (consisting of 3 plots) having the same fertility, which was based upon an assessment of the original vegetation. The first part was applied fermented weed chips (6.3 Mg ha^{-1} in fresh weight; 5.0 Mg ha^{-1} in dry weight); the second part was applied copra cakes (10.0 Mg ha^{-1} in fresh weight; 5.3 Mg ha^{-1} in dry weight), the conventional method used by farmers; the third part was applied both weed chips and copra cakes (in short, 9.5 Mg ha^{-1} in dry weight), and the fourth part was the control (no organic material was applied). I cultivated all fields with a cultivator and mixed organic materials into soils. Sweet corn was seeded on November 26, 2013 and harvested on February11, 2014 (77 days after seeding). Accidentally, weeding was not completed.

Experiment 2: Evaluating the effect of crop bed, mulching, and weeding

Eight plots were examined, consisting of a 2 x 2 x 2 factorial design for 3 factors: crop bed, mulching (using 1/4 of the plant residue), and 2nd weeding. Sweet corn stems and leaves from the previous experiment were first collected and shredded, then fermented for 6 days until fungi started propagating. A cultivator was used to incorporate corn residue (5.0 Mg ha^{-1} in fresh weight; 3.7 Mg ha^{-1} in dry weight) into all plots. Three-quarters of the residue was incorporated into the mulching plot, and the remaining residue was scattered on the surface. Additionally, 2 plots with no residue were set for crop bed and no bed as reference. Sweet corns were seeded on February 17, 2014 and harvested on May 8 (80 days after seeding). This experiment was retried exchanging weeding treatment plots. Sweet corn stems and the leaves from the previous experiment were first collected and shredded, then fermented for 7 days until fungi started propagating. Corn residue (2.0 Mg ha^{-1} in fresh weight; 1.5 Mg ha^{-1} in dry weight) was incorporated into all plots. Sweet corns were seeded on May 16, 2014 and harvested on July 28 (73 days after seeding).

Experiment 3: Evaluating the differences in the application method

The experiment used an L_{12} orthogonal array design (Taguchi, 1986). The factors were: fermenting (5 days), cutting, scattering, and incorporation. Plots were located randomly. Sweet corn stems and leaves from the previous experiment were collected and corn residue (4.7 Mg ha^{-1} in fresh weight; 2.2 Mg ha^{-1} in dry weight) was incorporated into all plots. Sweet corns were seeded on August 4, 2014 and harvested on Octorber 21, (78 days after seeding).

Experiment 4: Evaluating the effect of quantity of the incorporated material

Plant residue from the previous experiment was incorporated into each plot by the same methods of scattering and incorporation. In other words, the quantity was different according to the preceding crop growth of each plots. Sweet corns were seeded on October 28, 2014 and harvested on January 9, 2015 (73 days after seeding).

Determinations and analysis

Whole fresh kernels from each plot were weighed. The total biomass of sweet corn was calculated from the fresh kernel weight by multiplying by 0.36 (standard value of total DM /kernel fresh weight index from present study: Miura & Watanabe, 2002). Weed DM was determined from the fresh weight by multiplying by the dry matter ratio of the sample in experiment 1. The aftereffect of the preceding crop was examined by significant difference test for the Pearson product-moment correlation coefficient.

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Results

Climate conditions and aftereffect

The precipitation days for each 73 to 80 days of crop period were 45, 67, 62, 58, and 54, respectively. There were no irregular climate conditions.

There was no aftereffect of the preceding crop except in experiment 5. Specifically, the p-values of correlation for each of the crops were 0.55, 0.79, 0.16, and 0.00, respectively. The aftereffect of previous corn was considered to be small when the residues were taken out because the proportion of root in corn is only 0.16 at physiological maturity (Amos & Walters, 2006). The exception, in the case of experiment 5, the whole plant residue of the preceding crop was incorporated into the plot. In addition, most of the water-soluble substances would be wash out by frequent rain falls.

Experiment 1

There were no significant differences in total biomass among treatments (Figure 1). The incorporation of weed residue resulted in the same amount of biomass output as the copra cake. On the other hand, a doubling of the biomass input did not double the output. Weed occupied 39 to 71% of the total biomass because weeding was not carried out in half of the field, by accident.

Experiment 2

There was no significant difference in total biomass among the treatments; however, weeding tended to increase crop yields (Figure 2). Weeding increased the crop biomass by 41% in the first trial and by 9% in the second trial. The effect of weeding was low in the retrial because weeds decreased with continuous cropping.

Experiment 3

Scattering increased the yield by 28%, while incorporation increased the yield by 21% (Figure 3). Cutting and fermenting makes no difference.

Experiment 4

Organic material (sweetcorn residue) input strongly (r = 0.94***) correlated with biomass output under the same application condition (Figure 4). The maximum biomass output was less than half of what it was in experiment 1.

Discussion

Is weed residue a suitable alternative to copra cake?

Yes. Weed residue is a suitable alternative to copra cake because there were no significant differences in total biomass production based on the type of organic material that was incorporated into the soil (Figure 1).

Does weeding less often provide an advantage?

No. Weeding is advantageous because total biomass production is limited and is shared by crops and weeds; therefore, weeding increases the biomass produced by crops by reducing weed biomass. The result of experiment 1 (Figure 1) shows diminishing returns as the quantity of inputted rich organic materials is increased. On the other hand, the result of experiment 4 (Figure 4) shows that biomass production can also be limited when organic material inputs are low. The strong correlation suggests that weeds should not be allowed to grow. Weeds present no advantage to production, whether organic material is in excess or is deficient.

Differences among the cultivation conditions

Crop bed and mulching has no effect (Figure 2). The large percolation rate of coral sand is considered to diminish the effect of the bed for preventing excess soil moisture. On the other hand, frequent rainfall diminishes the effect of the mulch for keeping soil moisture. Bear in mind that these results are specific to the environment of Majuro Atoll and may not be applicable to other locations.

Differences among the application methods

Cutting and fermenting makes no difference. This is useful information for farmers because it can reduce their labor. The effect of incorporation is understandable by common sense. However, that scattering produced a larger effect than incorporation is interesting. One possibility is the difference in aeration of organic material. Coral sand is extremely well-aerated; however, the aeration is lost inside the mass of organic material. The frequent rainfall in Majuro Atoll is considered a strength in terms of the anaerobic fermentation. The same thing can said for the surface of a bed. The products of the aerobic process stimulated the root extension, whereas the anaerobic fermentation yielded products which inhibited growth (Lynch, 1977, 1978). Further study is needed for this point.

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How much plant residue should be returned?

There is a strong correlation ($r = 0.94^{***}$) between input biomass and output biomass when the application method is same (Figure 4). On the other hand, the above correlation shows diminishing returns under conditions of rich organic material input (Figure 1). Figure 5 shows the output/input ratio for all the experimental results. The results indicate that around 2–3 Mg ha^{-1} input produces the most efficient return under these experimental conditions. Figure 6 also shows the output/input ratios as a function of total biomass input for each of the experimental plots for all experiments. The output/input ratios converge at 0.5 at 15 Mg ha^{-1} a year (3 Mg ha^{-1} per crop), although those experimental plots include unfavorable cultivation conditions. The ratio is equal to the ratio of the double input treatment in experiment 1.

Conclusions

1) The same amount of organic material input made no significant difference in terms of biomass output for both plant residue and copra cake; therefore, plant residue is a suitable alternative to copra cake in Majuro Atoll.

2) Weeding increased the biomass of crops by reducing weed biomass, because total biomass is limited and is shared by crops and weeds.

3) In terms of the method of organic material application, scattering is the most effective method, followed by incorporation. Cutting, short term fermenting, mulching, and crop bed are not effective in the humid climate and low organic matter soil of Majuro Atoll.

Acknowledgement

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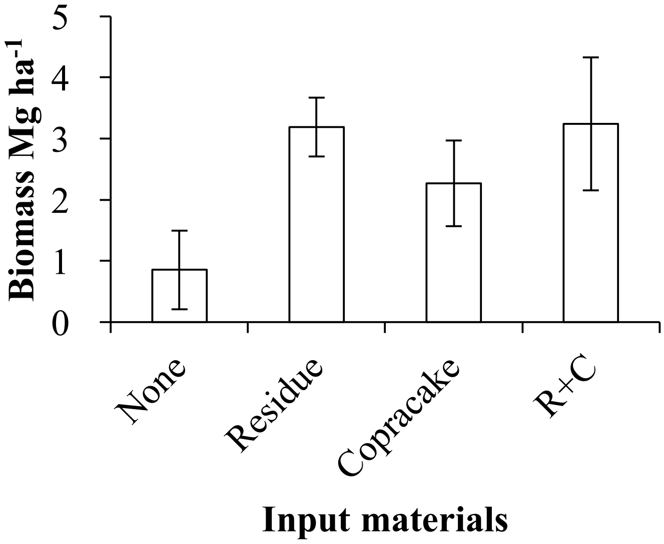

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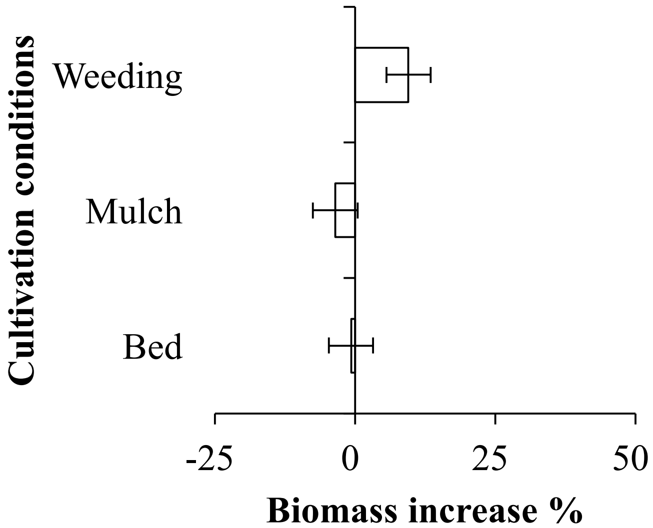
258 Figure 1. Biomass production based on the type organic material input.

259 Bar is Standard Error of sample mean (n=3)

260 W+C: Both weed and copra cake



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262 Figure 2. Percent biomass increase based on cultivation conditions.

263 Bar is Standard Error of sample (each sample size is 4)

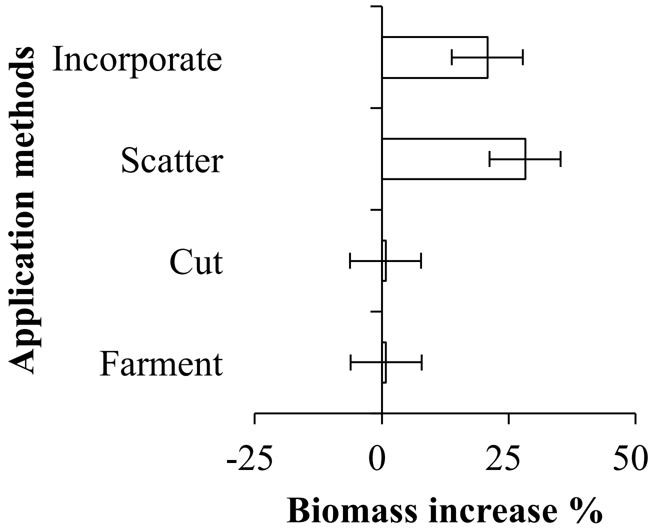


Figure 3. Increase in biomass based on residue application method.
Bar is Standard Error of sample (each sample size is 6)

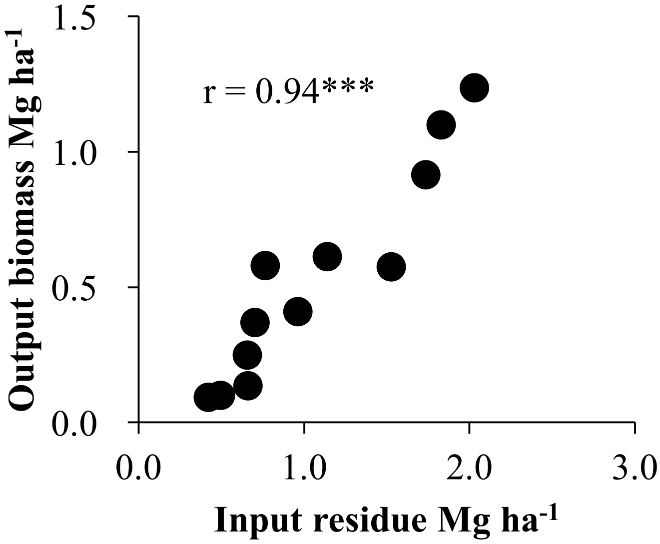
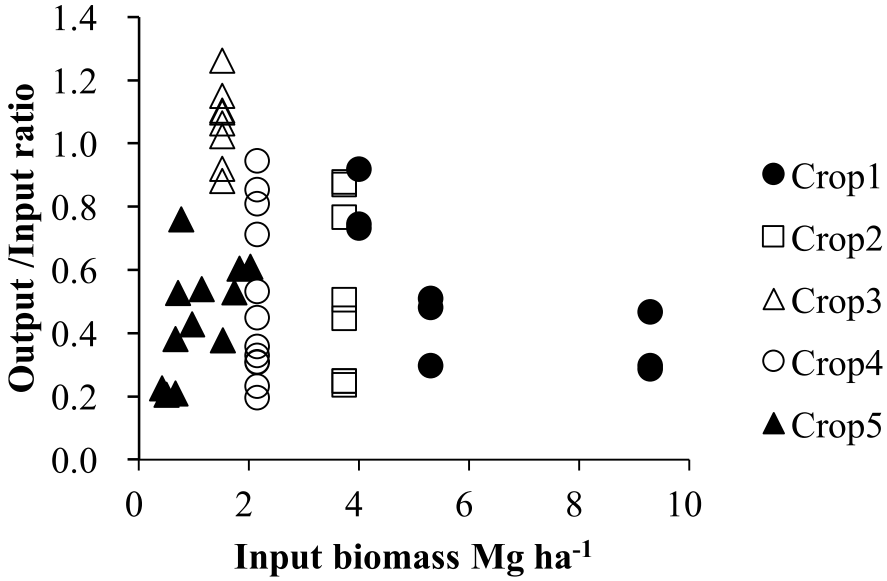


Figure 4. Biomass output based on the quantity of corn residue input.
r: significant difference test for Pearson product-moment correlation coefficient.
***: 0.1% significant



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272 Figure 5. Input biomass and output/input ratio for all crops.
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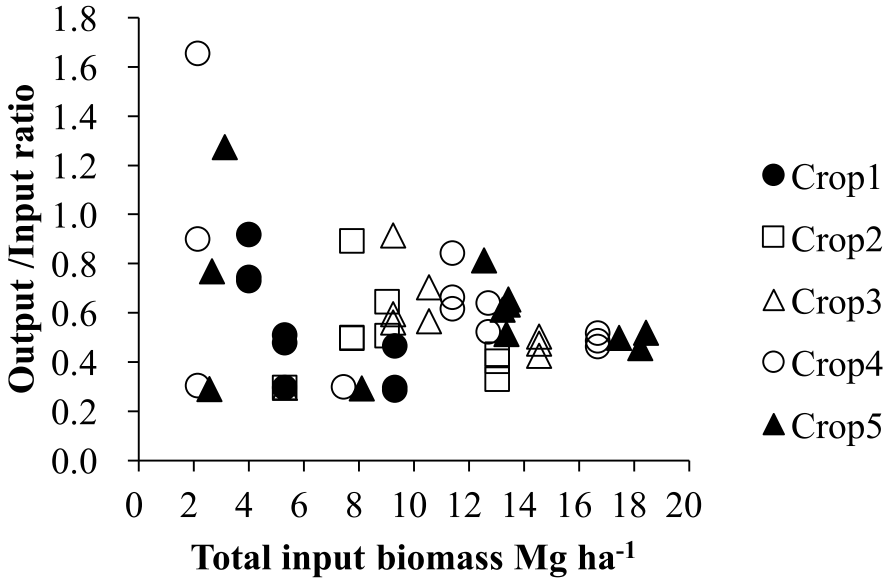

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275 Figure 6. Total input biomass and output/input ratio for all plots.
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