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The effects of composted pineapple residue return on soil properties and the growth and yield of pineapple

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Abstract:

A field experiment was conducted to investigate the influence of composted pineapple residue return (CPRR) on soil bio-chemical properties and the growth performance of next-cropped pineapple plants. The results suggested that CPRR markedly decreased the soil bulk density and increased the contents of available P and K. CPRR significantly increased the abundance of bacteria and actinomycetes, and the activities of catalase, acid phosphatase and invertase in the soil were notably heightened. Growth characteristics, including the plant height, length of leaves and roots, leaf width, number of leaves and fresh weight of the aboveground and belowground parts were significantly increased by CPRR. The contents of chlorophyll, soluble sugars, and soluble protein, as well root vigor were also markedly increased. CPRR also increased the fruit transverse and longitudinal diameters, weight and yield of next-cropped pineapple.

Keywords: Pineapple, residue return, compost, soil properties, growth performance

1. Introduction

Plant residue, a by-product of plant production systems, is an important biological resource, comprising approximately 50% of the total biomass of crops. It is estimated that a total of approximately 2 billion tons of residue are produced annually worldwide. The return of residue to the field is a useful cultural practice to improve both soil fertility and soil organic carbohydrate storage (Aynehband *et al.*, 2010; Lou *et al.*, 2011).

Composting, as one method of residue return, is a widely acceptable alternative for converting waste into a more useful eco-friendly fertilizer and is known to improve soil fertility (Gaind and Gaur, 2003; Tejada and Gonzalez, 2006). With the increasing demand for organic fruits and vegetables, the return of composted residue to fields as organic manure has recently attracted attention from farmers and scientists due to the positive effects of soil amendment while reducing the use of synthetic fertilizer (Chikae *et al.*, 2006; Gabhane *et al.*, 2012).

Due to the cellulose in plant residue, returning this material as compost decreases the bulk density, promotes the formation of soil aggregate structure, and increases the efficiency of water in soil (Edwards *et al*., 2000; Tejada and Gonzalez, 2003). There were certain amount of carbohydrate, N, P, K, and other nutrients in residues, the compost applied to soil was transferred to organic matter and enhanced the soil fertility level (Zayed and Abdel-Motaalet, 2005; Benito *et al*., 2006; Ribeiro *et al*., 2007; Roca-Pérez *et al.*, 2009). Due to the increase in the organic matter content and improvement of the physical-chemical properties, residue returned as compost supplies a better soil environment and an abundant carbohydrate and nitrogen source that benefits the growth of beneficial microorganisms (Zayed and Abdel-Motaalet, 2005; Ros *et al*., 2006; Bougnom *et al.*, 2010). Therefore, residue returned as compost results in enhanced soil enzyme activity by increasing the amount of enzymes and their substrates in the soil (Ros *et al.*, 2006).

Owning to the benefits on soil fertility, enzymes and microorganisms, residue returned as compost improves the condition of agricultural soils and increases root vigor and such other physiological characteristics as the chlorophyll content, photosynthetic rate and carbohydrate content of plants (Joshi *et al*., 2009; Yogev *et al*., 2009). Accordingly, composted residue return increases the growth rate, stimulates plant performances and enhances the yield and quality of crops (Abdelhamid *et al.*, 2004; Tejada and Gonzalez, 2006; Roca-Pérez *et al.*, 2009).

Pineapple [*Ananas comosus* (L.) Merr.] is an important fresh fruit that is widely cultivated in tropical and subtropical areas, with approximately 90~150 tons of by-products (leaves and stems) generated after fruit harvest per hectare. A preliminary study suggested that fresh pineapple residue contains 678.6 g kg^{-1}organic matter, 10.75 g kg^{-1} total N, 0.83 g kg^{-1} P_2O_5 and 11.4 g kg^{-1} K_2O 65.5 g kg^{-1}. Furthermore, the rational utilization of pineapple residue resources is becoming an inevitable requirement for the sustainable development of agriculture and the economy. It has been reported that more than 35 weeks was required for the decomposition of pineapple residue when the material was directly shredded and incorporated in the soil (Tam and Magistad, 1935). In some areas, pineapple residues are burned in situ prior to being returned to the soil (Ahmed and Husni, 2010); however, this process results in the loss of plant nutrients and pollutes the environment (Heard *et al.*, 2006). Therefore, many growers compost the pineapple residue before returning it to the soil.

To date, there is little available information about the effects of composted pineapple residue return on the bio-chemical properties of soil and the growth performance of the next-cropped pineapple plants. Accordingly, the purpose of this work was to examine the influence of composted pineapple residue return (CPRR) to the field on the physical-chemical and biological properties of soil, including fertility, enzyme activity and microbial diversity. Additionally, we examined the effects on the growth characteristics and physiological parameters of the next-cropped pineapple plants and fruit yield.

2. Materials and Methods

2.1. Site description

A field experiment was conducted in 2011-2012 at a commercial orchard located in the Shenwan region of Zhongshan (22°11′N-22°47′N; 113°09′E-113°46′E), Guangdong Province, P. R. China, to investigate the effects of pineapple residue returned as compost on the bio-chemical properties of soil and growth performance of pineapple plants and fruits. The local climate is characterized by a southern subtropical monsoon climate, with a mean annual precipitation of over 1791 mm that mostly occurs from March to September, and an average annual air temperature at approximately 22.2 °C. The monthly average temperature reaches a high of approximately 28.5 °C between July and August, and the low monthly average occurs from

December to February at approximately 13.6 °C. The soil type of the experimental area is a sandy loam soil of pH 4.0, with 15.0 g kg^{-1} organic matter, 91.05 mg kg^{-1} available N, 18.55 mg kg^{-1} available P and 27.0 mg kg^{-1} available K at 0~15 cm depth.

2.2. Composting

The pineapple residue was uprooted in February 2011 and machine broken into pieces of 3~5 cm in length and width on March 2, 2011. The next day, the obtained pieces (2 000 kg) were mixed with a commercial straw-rotting microbial mixture (2 kg) to accelerate the composting process. The composting pile was stirred manually and covered with plastic film after the initial water content was adjusted to approximately 65%. The moisture content was maintained at approximately 60% throughout the active composting period. The temperature was monitored each day and was controlled to not exceed 60~65 °C by adding water as necessary and turning the mixture manually to maintain porosity. The composting process ended on April 14, 2011, after the temperature decreased below 30 °C and did not increase, and the compost was exposed to sunlight for drying.

2.3. Experimental treatments

The experiment was conducted on April 18, 2011 and was arranged as a random block design with three replications and two treatments. Treatment CPRR consisted of pineapple residue compost (40 000 kg ha^{-1}) evenly spread over the field and raked into the topsoil (0~30 cm), whereas no compost was applied in treatment CK (control). One block was a replication, and each block was approximately 15 m^2 in area (1 m×15 m). The composted pineapple residue contained 30% water, 232.1 g kg^{-1} organic matter, 12.2 g kg^{-1} total N, 7.1 g kg^{-1} P_2O_5 and 13.8 g kg^{-1} K_2O.

At approximately 35 cm in height, sucker seedlings of pineapple cultivar 'Shenwan' were transplanted to the experimental field on April 18, 2012. The plant-to-plant distance within the rows and between the rows was 40 cm each. A total of 70 plants were cultivated in one plot. No other fertilizer was applied during the entire post-planting period.

2.4. Sampling and measurement of parameters

The soil and plants were sampled on September 26, 2011, approximately 160 days after the initiation of experiment. To assay the soil properties, two soil samples were randomly sampled from every block at 0~15 cm depth. The soil for the bulk density determination was sampled using a ring sampler (ring diameter of 6 cm and sampling depth of 2 cm) and was preserved in an aluminum specimen box prior to transport to the lab. The soil samples for the enzyme and microbial parameter measurements were preserved in refrigerator at 4 °C prior to the measurements. On the same day, the pineapple plants were randomly sampled from every block to determine the growth performance characteristics and physiological parameters of the leaves and roots. The leaf samples for the physiological parameter measurements were sampled from the mid part of the 10th to 15th leaves, as counted from the center of the pineapple plants.

The organic matter content of the soil was determined by oxidation with $K_2Cr_2O_7$ (LY/T1237-1999). The available N, P and K contents of the soil were determined based on standard assays (LY/T1229-1999, LY/T1233-1999/5, and LY/T1236-1999, respectively). The urease activity in the soil was determined according to Shi (1995) and was expressed as milligrams of ammonium released per kilogram of soil per hour (mg kg^{-1} h^{-1}). The catalase activity was measured by titration with 0.1 mol L^{-1} $KMnO_4$ (Soil Microbial Research Lab, Institute of Soil Science, Chinese Academy of Sciences, 1985). The activity was expressed as milliliters of $KMnO_4$ used per gram of soil per hour (mL g^{-1} h^{-1}). The determination of the acid phosphatase activity was based on that of Zhao and Jiang (1986), and the activity was expressed as micrograms of paranitrophenol used per gram of soil per hour (μg g^{-1} h^{-1}). The activity of invertase was determined based on a titration with 0.1 mol L^{-1} $Na_2S_2O_3$ (Soil Microbial Research Lab, Institute of Soil Science, Chinese Academy of Sciences, 1985), and the activity was expressed as milliliter of $Na_2S_2O_3$ used per kilogram of soil per hour (mL kg^{-1} h^{-1}). The diversity of bacteria, fungi, and actinomycetes in the soil was measured by the dilution-plate method of Zhang (2007). The bacteria were cultured using beef cream-peptone culture medium. The fungi were cultured using Modified Martin Agar Medium, and the actinomycetes were cultured using Gauze's Medium No.1.

The plant height, leaf length and width, and root length were measured using a ruler. The leaf length and leaf width referred to the length of the longest leaf and its width of the middle part, respectively. The fresh weights of the aboveground and belowground parts were determined using a steelyard balance and electronic balance, respectively. The number of leaves and roots reflected the fresh leaves and roots.

The content of chlorophyll was determined using the method reported by Li *et al*. (2005), ethanol-acetone solution (*v*/*v* 1:1) extraction. The soluble sugar and soluble protein contents were evaluated according to Li (2000). The root vigor detection was based on TTC reduction according to Zhang (2007).

On July 3, 2012, fifteen pineapple fruits with similar degrees of maturity (shell color) were harvested from each block. The transverse and longitudinal diameters of the fruits were determined using a vernier caliper, and the weight per fruit (without crown) was measured using an electronic balance. The yield per plot referred to the fresh weight of all the harvested pineapple fruits in each block (kg per plot).

2.5. Statistical analysis

The data were tested for statistical significance using the analysis of variance package included in Microsoft Excel 2003 and SPSS Statistics 17.0. Mean comparisons were performed using the t-test. A probability level of $p \leq 0.05$ was considered significant.

3. Results and Discussion

3.1. Soil physical-chemical properties

The bulk density of soil characterizes the weight, degree of curing and content of organic matter. Soil with a low bulk density has a higher total porosity and respiration rate, with a higher water holding capacity, providing a better condition for crops. As presented in Table 1, the bulk density of the CPRR soil (1.01 g cm^{-3}) was significantly decreased when compared with the CK soil (1.68 g cm^{-3}). This result confirmed that the return of residue as compost decreased the bulk density of the soil (Edwards *et al*., 2000; Abdelhamid *et al*., 2004; Evanylo *et al*., 2008).

With respect to the soil chemical properties, the organic matter content of CPRR was 21.5 g kg^{-1}, 19.4% higher than CK at 18.0 g kg^{-1}. Similarly, the available N, P and K contents of CPRR increased by 10%, 59.8% and 145.1%, respectively, when compared with CK. Statistical analyses showed that the available P and K contents of the CPRR soil were significantly heightened ($p<0.05$). These results suggested that the CPRR treatment enhanced the fertility of the soil, an observation in agreement with previous studies (Kowaljow and Mazzarino, 2007; Courtney and Mullen, 2008; Sommer *et al*., 2011) reporting that residue returned as compost increased the organic matter and N, P and K contents of soil. However, a significant difference was not observed for the organic matter and available N when compared with CK in the present work. The most likely reason for the lack of marked increase is due to the enhanced microbial consumption of the high amount of C and N in the returned pineapple compost.

Table 1 Effects of CPRR on soil physical-chemical properties

Treatment	Bulk density ($g\ cm^{-3}$)	Organic matter ($g\ kg^{-1}$)	Available N ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)
CPRR	1.01±0.01*	21.5±2.1	440.0±11.5	163.0±29.7*	1148.7±174.8*
CK	1.68±0.06	18.0±1.7	400.0±111.3	102.4±4.4	468.7±139.7

Note: Values with * within a column are significantly different by the t-test ($p = 0.05$)

Table 2. Effects of CPRR on the abundance of soil microorganisms

Treatment	Bacteria ($\times 10^6$ cfu g^{-1})	Fungi ($\times 10^4$ cfu g^{-1})	Actinomycetes ($\times 10^4$ cfu g^{-1})
CPRR	4.29±0.88*	9.75±6.94	7.99±5.66*
CK	0.95±0.41	5.30±0.96	0.008±0.0003

Note: Values with * within a column are significantly different by the t-test ($p = 0.05$)

3.2. Soil microorganisms

Bacteria are responsible for the decomposition of organic matter of soil. Fungi are engaged in the decomposition of organic matter and the transformation of proteins into soluble N nutrients, amino acid and ammonium, which can be taken up by plants. Actinomycetes are known to decompose the recalcitrant components of plant and animal matter to humus and to transform plant and animal debris into organic matter. With respect to microorganisms (Table 2), the CPRR bacterial abundance was 3.51 times higher than that of CK, and the CPRR fungal population increased by 84.0%. The actinomycetes increased from 0.008×10^4 cfu g^{-1} (CK) to 7.99×10^4 cfu g^{-1} (CPRR). The bacterial and actinomycetes were significantly increased by the CPRR treatment. These results suggested that the CPRR treatment increased the soil microorganisms, in accordance with previous studies (Zayed and Abdel-Motaal, 2005; Ros *et al*., 2006; Gandolfi *et al*., 2010; Bernard *et al*., 2012).

The actions of these three types of microorganisms in the soil accelerated the decomposition of the pineapple residue and enhanced the transfer of organic matter and other nutrients to the soil, providing increased nutrition for the growth of the next-cropped pineapple plants. There was no significant difference, however, in the fungal abundance between CPRR and CK. Because a large amount of C and N sources are needed for fungal reproduction, the lack of organic matter and available N enhancement may be the reason why the fungi were not notably increased by the CPRR treatment in this study.

3.3. Activities of soil enzymes

Urease is responsible for the hydrolysis of urea fertilizer applied to the soil into NH_3 and CO_2 with the concomitant rise in the soil pH, and the activity of urease is often used to characterize the N content of the soil (Makoi and Ndakidemi, 2008). As presented in Table 3, the activity of urease was increased from 70.1 mg kg^{-1} h^{-1} to 89.2 mg kg^{-1} h^{-1} following the CPRR treatment; however, a significant difference was not observed. This result was similar to a previous study (Ros *et al*., 2006). Activity of soil urease is positively correlated to the contents of organic matter and available N. In this work, the content of available N was not markedly increased after CPRR treatment when compared to CK, which likely explains why the urease activity was not significantly increased by the CPRR treatment.

The catalase enzyme is known to decompose the hydrogen peroxide in organic matter into water and oxygen by transferring protons and electrons from substrates to acceptors. These processes are part of the respiration pathways of soil microorganisms and are closely related to the type of soil and soil air-water conditions. In this study, the activity of catalase of CPRR was 1.22 times higher than that of CK (Table 3), and the statistical analysis indicated that the catalase activity was significantly increased by the CPRR treatment. The increasing activity of soil catalase after CPRR treatment contributes to the decomposition of excess hydrogen peroxide in the soil and protects the pineapple plants against the accumulation of hydrogen peroxide in the soil.

Acid phosphatase is a type of enzyme that is capable of catalyzing the hydrolysis of the anhydrides of phosphoric acid. In soil ecosystems, acid phosphatase is believed to play critical roles in P cycles and is used to characterize the level of P in the soil (Makoi and Ndakidemi, 2008). The acid phosphatase activity in CPRR was increased by 96.3% compared with CK (Table 3), an observation that was consistent with previous studies (Ros *et al*., 2006; Saha *et al*., 2008). In this study, this increases in the acid phosphatase activity in CPRR and CK was in agreement with the increasing of content of available P, which further suggested that the CPRR treatment increased the availability of soil P, contributing to the growth of the pineapple plants and fruits.

Invertase is responsible for the hydrolysis of saccharides, stimulating C cycles, substance transition, and energy exchange in soil. The activity of invertase is related to the fertility of soil and is used to define the curing condition and accumulating density of organic matter. In this study, the invertase activity in CPRR was increased by 1.42 times when compared with CK (Table 3). This observation was similar to a previous report and indicated that the CPRR treatment augmented the activity of soil invertase, which benefits the curing and transfer of C and N in soil (Zhang *et al*., 2011).

Table 3. Effects of CPRR on soil enzyme activities

Treatment	Urease / mg kg^{-1} h^{-1}	Catalase / mL g^{-1} h^{-1}	Acid phosphatase / µg g^{-1} h^{-1}	Invertase / mL kg^{-1} h^{-1}
CPRR	89.2±7.1	2.85±0.9*	299.7±15.2*	46.4±24.1*
CK	70.1±3.1	1.28±0.1	152.7±14.5	19.2±0.6

Note: Values with * within a column are significantly different by the t-test ($p = 0.05$)

3.4. Plant growth performance

Table 4 provides the growth performance parameters of the next-cropped pineapple plants. The results showed that the pineapple plant growth was promoted by the CPRR treatment: the plant height, leaf length, leaf width and root length in the CPRR treatment were increased by 32.9%, 35.8%, 53.8% and 53.9%, respectively, when compared with CK. Furthermore, the statistical analysis indicated that the above parameters were notably increased by the CPRR treatment (p<0.05). The numbers of leaves and roots were increased by 23.9% and 44.8%, respectively, after the CPRR treatment, with the leaf number being particularly increased when compared with CK (p<0.05).

The fresh weight of the aboveground and belowground parts of CPRR were increased by 91.2% and 23.4%, respectively, when compared with CK, and the statistical analysis showed that the results were significant (p<0.05).

The above results revealed an enhancement in the growth of the pineapple plants in the CPRR treatment, and similar findings were reported in previous studies (Courtney and Mullen, 2008; Caballero *et al*., 2009; Traversa *et al*., 2010). Furthermore, previous studies stated that certain physiological parameters, such as nutrient uptake, root vigor, chlorophyll content, and soluble sugar and protein contents were improved through the application of compost (Ribeiro *et al*., 2007; Caballero *et al*., 2009).

Table 4. Effects of CPRR on the growth of next-cropped pineapple plants

Treatment	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Root length (cm)	Number of leaves	Number of roots	Fresh weight of aboveground parts (g)	Fresh weight of belowground parts (g)
CPRR	95.3±1.2*	91.0±1.2*	6.0±0.2*	25.7±0.9*	36.3±0.9*	54.0±4.7	1083.3±83.3*	41.1±2.9*
CK	71.7±0.9	67.0±2.3	3.9±0.1	16.7±1.2	29.3±0.3	37.3±9.1	566.7±33.3	33.3±2.7

Note: Values with * within a column are significantly different by the t-test (p = 0.05)

3.5. Physiological parameters

The chlorophyll content reflects the plant photosynthetic assimilation ability and photosynthetic rate. In this study, the contents of chlorophyll a and chlorophyll b in CPRR were increased by 30.7% and 30.4%, respectively, when compared with CK (Table 5), with the statistical analyses showing that the results were significant (p<0.05). These results parallel previous studies on rice, okra and gerbera (Tejada and Gonzalez, 2006; Siddiqui *et al*., 2008; Caballero *et al*., 2009).

The contents of soluble sugar and protein are related to the growth potential and stress-resistance ability of plants. As presented in Table 5, the soluble sugar content in CPRR was increased by 39.6% and that for soluble protein by 29.5%. Significant differences were observed for both the soluble sugar and protein when compared with CK (p<0.05), which was consistent with the previous results of Ribeiro *et al.* (2007) and Caballero *et al*. (2009).

Additionally, Abdel-Sabour and E1-Seoud (1996) and Tejada and Gonzalez (2006) stated that applying compost enhanced the root uptake activity of such nutrients as N, P, K, Ca and Mg. The root vigor reflects the growth performance of plants and the nutrient absorptive capacity of the roots.

In the present study, the root vigor of the CPRR plants was significantly increased by 48.3% (Table 5), in accordance with the results of Huang *et al*. (2009).

Table 5. Effects of CPRR on certain physiological parameters of pineapple plants

Treatment	Chlorophyll a (mg g^{-1})	Chlorophyll b (mg g^{-1})	Soluble sugar (mg g^{-1})	Soluble protein (mg g^{-1})	Root vigor (mg g^{-1} h^{-1})
CPRR	10.39±0.73*	1.03±0.07*	10.05±0.07*	2.72±0.09*	1.75±0.02*
CK	7.95±0.62	0.79±0.06	7.20±0.21	2.10±0.10	1.18±0.03

Note: Values with * within a column are significantly different by the t-test (p = 0.05)

3.6. Fruit growth and yield

The data for the size of the pineapple fruits are presented in Figures 1 and 2. The transverse and longitudinal diameters of fruits from the CPRR treatment were increased by 41.1% and 38.8%, respectively, when compared with CK. The CPRR weight per fruit was increased by 51.3%, and the yield per plot was increased by 47.9%. Statistical analyses showed that the transverse and longitudinal diameters and fruit weight and yield per plot were significantly increased after CPRR treatment. These findings are in agreement with prior reports (Abdelhamid *et al*., 2004; Courtney and Mullen, 2008; Siddiqui *et al*., 2008).

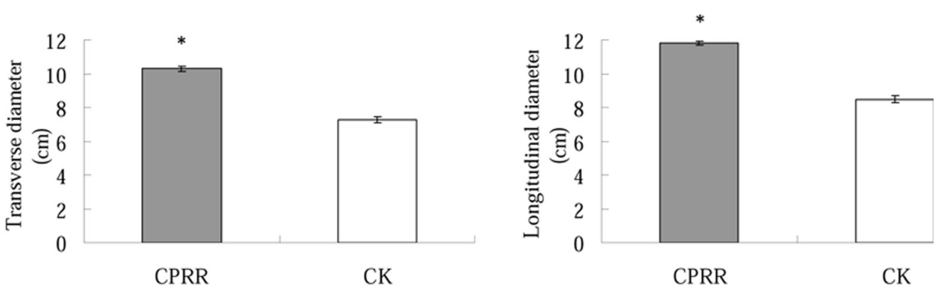

Figure 1. Size of pineapple fruits as affected by CPRR treatment

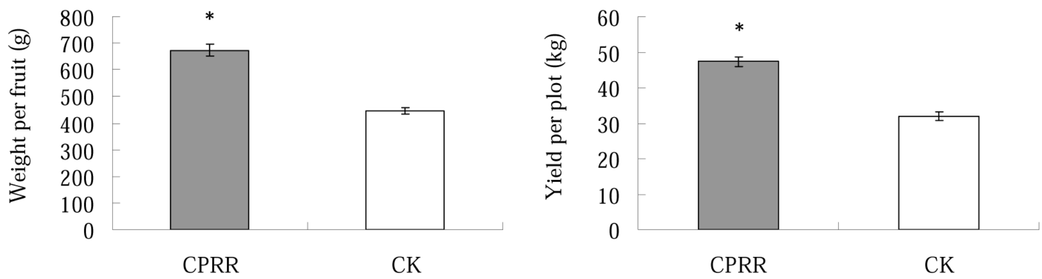

Figure 2. Weight per fruit and yield per plot as affected by CPRR treatment

Obviously, CPRR promoted the growth of next-cropped pineapple plants, as well as increased the size and yields of next-cropped fruits. However, this promotion was due to the enhancement of fertility of soil where the pineapple plants grown as affected by CPRR. As presented in this work, CPRR provided better soil environmental conditions for the next-cropped pineapple plants by decreasing the bulk density, increasing the fertility, the abundance of micro-organisms and activity of enzymes of the soil where the next-cropped pineapple grown. Just due to the better conditions, CPRR provided more positive nutritional factors for the next-cropped pineapple plants and stimulated the growth of next-cropped pineapple plants as well as increased the physiological characteristics of leaves and roots. So the growth of next-cropped CPRR fruits was promoted and yields were increased.

4. Conclusions

Composted pineapple residue return (CPRR) decreased the bulk density of the soil and increased the organic matter, available N, available P, and available K contents. CPRR increased the abundance of bacteria, fungi, and actinomycetes and the activities of urease, catalase, acid phosphatase, and invertase in the soil. CPRR stimulated the growth of the next-cropped pineapple plants. The chlorophyll, soluble sugar, and soluble protein contents of the leaves and root vigor were all enhanced by this practice. CPRR also promoted the growth and heightened the yield of pineapple fruits.

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