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Original Article

Using Aquaculture Waste Sludge and Agricultural By-products to Produce Organic Fertilizer

Dang Trung Thanh*, Nguyen Minh Ty, Nguyen Huynh Anh Tuyet

Thu Dau Mot University, 6 Tran Van On, Phu Hoa, Thu Dau Mot City, Binh Duong, Vietnam

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Abstract: The study was conducted to turn aquaculture sludge and agricultural by-products into organic fertilizer as part of the circular production. The main raw materials included sludge from catfish ponds after harvest and organic materials from agricultural by-products (25% from growing cordyceps, 25% from growing oyster mushrooms, 25% from peanut shells, and 25% from coconut fiber). The aquaculture sludge (AS) and agricultural by products (ABP) are mixed at five different ratios: 10% AS + 90% ABP; 30% AS + 70% ABP; 50% AS + 50% ABP; 70% AS + 30% ABP, and 90% AS + 10% ABP. The results showed that the experiment with the ratio of 30% AS + 70% ABP optimized the decomposition of organic compounds and produced organic fertilizer with higher nutrient content than the other four mixing ratios. Comparing the quality of organic fertilizer produced with the organic fertilizer quality standards of the Ministry of Agriculture and Rural Development, 15/18 biochemical indicators have met the regulations. The results of the study can provide a guideline for the local people to optimize organic fertilizer production utilizing aquaculture sludge and agricultural byproducts, save input costs for agricultural production, and contribute to reducing waste to the natural environment.

Keywords: Agricultural by-product, aquaculture sludge, experiment, organic fertilizer, production.

1. Introduction

Sediment from intensive aquaculture ponds or organic food waste contains very high levels of organic compounds (OC) and key nutrients such as nitrogen (N), phosphorus (P) and other macro and micronutrients [1].

Aquaculture sludge (AS) are enriched with OC and nutrients, they can be a source of continuously available fertilizer, which can be used to improve the soil environment for crop production [2]. In agricultural production, the amount of agricultural by-product (ABP) such as mushroom growing waste, straw, livestock

* Corresponding author.
E-mail address: hanhdt@tdmu.edu.vn

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waste, corn stalks, and bean plants is very large and may impact on the environment. Therefore, reusing them will contribute to reducing waste, protecting environmental pollution and conserving resources [3].

Research on utilizing pond sludge to make organic fertilizer and studying its effectiveness in corn cultivation shows that when combining organic fertilizer with inorganic fertilizer at the amount of 10 and 20 ton/ha, it will reduce the amount of inorganic fertilizer by 50-100% [4]. When using fish pond sludge to grow crops, it is possible to save a significant amount of fertilizer from 9-100% of inorganic fertilizer depending on the type of crop, which can improve productivity and product quality [5].

Solutions to recycle and reuse organic materials from domestic waste and agricultural by product for composting have recently been mentioned as one of the solutions to approach the circular economy [6, 7]. Organic materials when mixed with sediment at the bottom of aquaculture ponds for composting play a role in balancing the carbon ratio, reducing the moisture content of the mixture and enhancing the activity of microorganisms.

Binh Duong is the leading province in industrial development and urbanization in the country. Rapid industrialization and urbanization have caused a sharp decrease in agricultural land and a corresponding decrease in the proportion of agriculture in the economic structure. However, agriculture still plays a very important role, providing a part of fresh, green food for the huge demand of the population and large immigrant workers, maintaining green areas, reducing heat intensity, absorbing CO_2 and providing O_2 for the air environment.

Tan Uyen City is located in the South of Binh Duong Province, adjacent to the Dong Nai River, so the area has many advantages for aquaculture and cultivation. Developing aquaculture has created jobs, increased income for farmers and contributed to the local economic development in Thai Hoa ward, Tan Uyen City. The main types of aquatic products raised in Thai Hoa ward are: carp, snakehead, eel, frog and especially snakehead (*Channa striata*) with an area of over 40 ha [8].

High aquaculture density combined with the use of industrial feed sources has increased the amount of sludge settling at the bottom of the pond, polluting water sources and causing epidemics. Especially after harvesting, most households pump and discharge sludge directly into rivers and natural canals, polluting the natural environment. According to the results of some studies, the sludge from aquaculture ponds is rich in OC, N, P, potassium and other micronutrients. If this amount of sludge is recycled as fertilizer for use in agriculture, it can bring higher benefits. Based on the above requirements, in order to reuse by-products after agricultural production and aquaculture, contribute to environmental protection, and provide organic fertilizer for urban agricultural production, this study was conducted.

2. Research Materials and Methods

2.1. Research Materials and Locations

Figure 1. Harvesting of aquatic products and dredging of AS (a) and ABP for composting (b).

Materials: Aquaculture sludge was collected from the bottom of snakehead ponds after harvesting and dried for 7 days in the absence of direct sunlight. The total amount of sludge used in the study was 1,000 kg. Agricultural by-products, including: waste after growing cordyceps, waste after growing oyster mushrooms, peanut shells, coconut fiber. The total amount of ABP used in the study was 1,000 kg, including: 250 kg of waste after growing cordyceps: 250 kg of waste after growing oyster mushrooms: 250 kg of peanut shells: and 250 kg of coconut fiber (Figure 1). Trichoderma (Tricho) microbial product helps increase beneficial microorganisms and promote the decomposition of cenluloz in ABP.

Location and time of experiment: The experiments of organic fertilizer production was conducted at Mr. Nguyen Van Phi's snakehead farm in Thai Hoa ward. The research period was from June to August 2024.

2.2. Research Methods

2.1.1. Experimental Setup

Organic fertilizer production was arranged into 5 experiments with: The ratio of AS was changed from 10% to 90% and combined with ABP corresponding to the ratio from 90% to 10% (Figure 2). The experiments were repeated 3 times and divided into small plots in each experiment.

The mixture of mud and agricultural by-products was mixed evenly with Tricho preparation, piled up and covered with a tarpaulin to maintain the temperature at 60-65 °C and humidity at about 78% (the most familiar method for farmers to easily implement later). Every 10 days in the first month, the mixture was turned once to ensure uniformity [9] (Figure 3). The compost is considered to have met the requirements when the color of the compost in the pile changes from brown to dark green.

2.2.2. Analytical Method

Analysis of nutritional composition of AS, ABP and finished organic fertilizer was conducted at the Biology Laboratory of Thu Dau Mot University. The nutritional indicators analyzed and the analysis method are summarized as follows:

pH was measured by a pH meter, the ratio of distilled water was 1:5. OC was measured by a machine. Completely oxidize organic carbon with excess $K_2Cr_2O_7$ in H_2SO_4 at a stable temperature of 145-155 °C for 30 minutes (According to the instructions of the Ministry of Agriculture and Rural Development in 2004–10 TCN 366:2004). Titrate the excess $K_2Cr_2O_7$ with $FeSO_4$ solution. Total N (Nts) was mineralized with concentrated H_2SO_4 solution + H_2O_2 and determined by the Kjeldahl method. Total P (Pts) was mineralized with concentrated H_2SO_4 solution + H_2O_2 and measured on a spectrophotometer at a wavelength of 420 nm. Total potassium (Kts) was mineralized with concentrated H_2SO_4 + $HClO_4$ solution and measured on a flame photometer at 768 nm wavelength. Available N was extracted with 0.5 N H_2SO_4, determined by the Kjeldahl method. Available P was extracted with 2% citric acid at a ratio of 1 g sample: 100 mL citric acid solution and measured colorimetrically on a spectrophotometer at 420 nm wavelength. Available K was extracted with 0.05 N HCl solution, and the dissolved potassium in the sample solution was determined with a flame photometer at 768 nm wavelength (According to the instructions of the Ministry of Agriculture and Rural Development, 2004–10 TCN 360:2004).

For heavy metals: Total Cr was determined by atomic absorption spectroscopy (According to TCVN 11403:2016 on Fertilizers). Total Pb was determined by flame and electrothermal (non-flame) atomic absorption spectroscopy (According to TCVN 9290:2012). Total Cd was determined by flame and electrothermal (non-flame) atomic absorption spectroscopy (According to TCVN 9291:2018). Total Zn was determined by flame atomic absorption spectroscopy (According to TCVN 9289:2012). Total Fe, Cu and Mg were determined by flame atomic absorption spectroscopy (According to TCVN 9283:2012).

Microorganisms: E.coli density was determined by the method of detecting and quantifying presumptive Escherichia coli - the most probable number counting technique (According to TCVN 6846:2007 and fertilizer regulations QCVN: 2018/BNNPTNT).

Data and measurement indicators were compiled using Excel software and statistically processed using SPSS: ANOVA test, standard deviation, reliability.

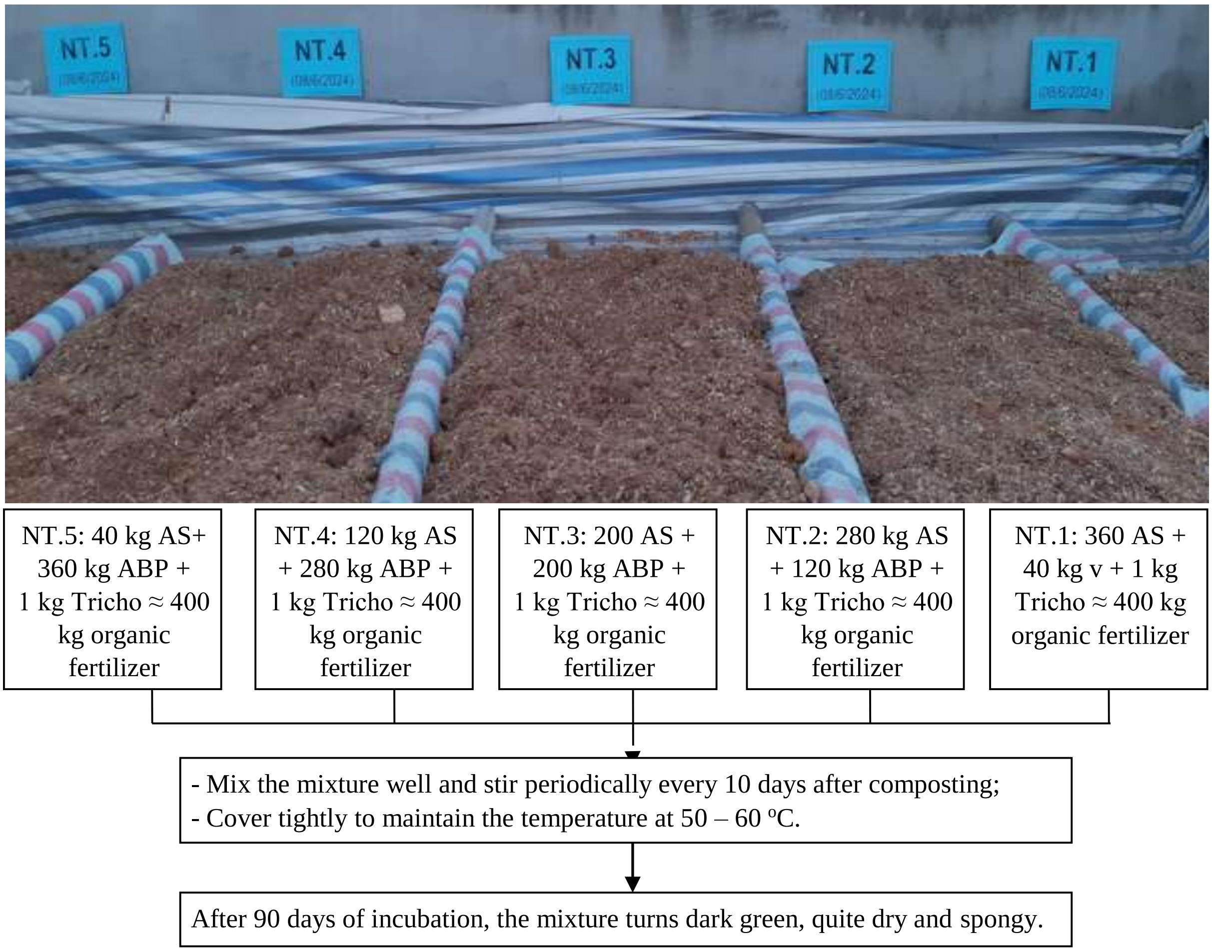

Figure 2. Experimental layout for organic fertilizer production.

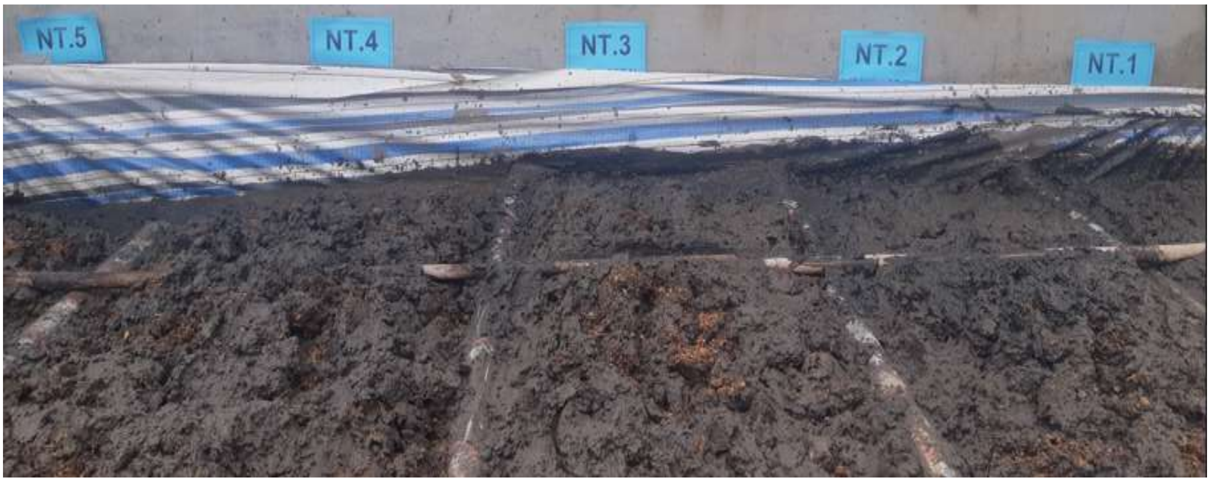

Figure 3. The compost mixture is stirred regularly every 10 days during the first month.

3. Research Results

3.1. Nutrient Composition of AS and ABP

The data in Table 1 show that the pH of AS and ABP is neutral. The organic carbon ratio in ABP is very high compared to AS, especially in peanut shells, which is nearly 4 times higher than AS. The Nts, Pts, Kts content of the waste after mushroom cultivation is very high, especially the waste after growing Cordyceps, showing that this is a source of by-products with very high nutritional content for the production of organic fertilizers used in agriculture. In particular, the values of Nts, Pts, Kts, available N, available P and available K of the waste after growing Cordyceps and the waste after growing Oyster mushrooms are higher than that of AS and other by-products at a statistically significant of $p<0.05$.

The values of the main nutritional components in the sludge from snakehead ponds in Thai Hoa ward are presented in Table 1, which is equivalent to the data published in some research results [9, 11]. Thus, the sludge from snakehead ponds in the research area has quite high main nutritional components such as: OC, N, P and K, suitable for use as organic fertilizer for cultivation.

Table 1. Nutrient composition of aquaculture sludge and agricultural by-products

Parameters	Aquaculture sludge	Waste after growing cordyceps	Waste after growing oyster mushrooms	Peanut shell	Cocomut fiber
pH	$6.6±0.1^c$	$7.1±0.2^a$	$6.9±0.1^b$	-	$5.6±0.1^d$
Organic carbon (C%)	$6.4±0.3^e$	$24.5±0.5^d$	$29.6±0.5^b$	$34.5±0.5^a$	$28.3±0.5^c$
Total N (%N)	$0.7±0.02^d$	$22.5±0.5^a$	$14.8±0.8^b$	$6.8±0.3^c$	$0.65±0.05^d$
Total P (%P_2O_5)	$0.57±0.06^c$	$0.88±0.03^a$	$0.78±0.03^b$	$0.12±0.01^e$	$0.38±0.03^d$
Total K (%K_2O)	$0.24±0.01^d$	$5.8±0.2^a$	$5.4±0.3^b$	4.4±0.1c	$0.48±0.03^d$
Available N (mg/kg)	$0.23±0.02^c$	$6.8±0.3^a$	$4.4±0.2^a$	-	$0.17±0.01^c$
Available P (mg/kg)	$0.13±0.01^c$	$0.32±0.03^a$	$0.28±0.03^b$	-	$0.11±0.01^c$
Available K (mg/kg)	$0.12±0.01^c$	$1.73±0.06^a$	$1.27±0.06^b$	-	$0.11±0.01^c$

Note: The letters a, b, c, d indicate statistically significant differences between values in the same row at $p<0.05$. (-) no data.

3.2. Quality of Organic Fertilizer

The data in Table 2 shows that in NT.4, corresponding to the mixing ratio of 30% AS and 70% ABP, the content of the main nutrients: Nts, Pts, Kts, available N, available P and available K was higher than the remaining treatments and had statistical significance of $p<0.05$.

Table 2. Nutritional composition of organic fertilizers according to experiments

No.	Parameters	NT.1	NT.2	NT.3	NT.4	NT.5
1	pH	$6.53±0.58^c$	$6.63±0.58^{bc}$	$6.72±0.76^b$	$6.83±0.58^a$	$6.85±0.50^a$
2	Organic carbon (%C)	$22.55±0.29^d$	$23.78±0.22^c$	$25.21±0.15^b$	$28.99±0.34^a$	$28.11±0.49^a$
3	TN (% N)	$1.21±0.12^d$	$1.41±0.06^c$	$1.51±0.05^c$	$2.01±0.18^a$	$1.78±0.03^b$
4	TP (% P_2O_5)	$0.47±0.05^b$	$0.47±0.03^b$	$0.50±0.02^b$	$0.58±0.04^a$	$0.48±0.07^b$
5	TK (% K_2O)	$0.31±0.04^c$	$0.37±0.05^{bc}$	$0.40±0.03^b$	$0.48±0.06^a$	$0.41±0.02^b$
6	Available N (mg/kg)	$0.62±0.01^c$	$0.63±0.01^{bc}$	$0.64±0.01^b$	$0.65±0.01^a$	$0.63±0.01^{bc}$
7	Available P (mg/kg)	$0.49±0.01^c$	$0.49±0.01^{bc}$	$0.49±0.01^{bc}$	$0.42±0.01^a$	$0.40±0.01^b$
8	Available K (mg/kg)	$0.55±0.02^b$	$0.55±0.01^b$	$0.55±0.01^b$	$0.60±0.03^a$	$0.56±0.02^b$

No.	Parameters	NT.1	NT.2	NT.3	NT.4	NT.5
9	Pb (mg/kg)	0.027±0.001[b]	0.028±0.001[b]	0.029±0.001[ab]	0.030±0.001[a]	0.029±0.001[a]
10	Cd (mg/kg)	0.013±0.005[a]	0.019±0.007[a]	0.018±0.001[a]	0.018±0.001[a]	0.017±0.002[a]
11	Zn (mg/kg)	50.33±0.06[a]	50.32±0.02[a]	50.35±0.01[a]	50.37±0.03[a]	50.32±0.01[a]
12	Fe (mg/kg)	953.0±30[b]	955.0±50[ab]	962±70[a]	959.0±20[ab]	959±20[ab]
13	Cr (mg/kg)	50.65±0.05[a]	50.72±0.07[a]	50.65±0.05[a]	50.66±0.06[a]	50.70±0.05[a]
14	Cu (mg/kg)	50.88±0.03[b]	50.92±0.03[ab]	50.94±0.05[ab]	50.95±0.05[ab]	50.97±0.05[a]
15	Mg (mg/kg)	320.07±0.05[c]	325.17±0.05[b]	330.17±0.06[a]	330.14±0.05[a]	330.1±0.1[a]
16	E.coli (CFU/ml)	0.29±0.003[bc]	0.31±0.006[a]	0.30±0.006[ab]	0.28±0.02[c]	0.30±0.005[bc]
17	Humidity (%)	41.57±0.49[a]	41.37±0.32[a]	41.78±0.67[a]	39.47±0.45[c]	39.17±0.57[c]
18	C/N	18.68±0.85[a]	16.89±0.52[ab]	16.71±0.38[abc]	14.54±0.94[c]	15.77±0.41[bc]

Note: The letters a, b, c, d represent statistically significant differences between values in the same row at $p<0.05$.

Table 3. Compare the quality of compost with the prescribed standards

No.	Parameters	Produced organic fertilizer (*)	Organic fertilizer standards (**)	Acceptable deviation (**)	Note
1	pH	6.83	≥ 5	≥ 95%	Meet
2	Organic carbon (%C)	28.99	≥ 15	≥ 93%	Meet
3	TN (% N)	2.01	≥ 2	≥ 90%	Meet
4	TP (% P_2O_5)	0.58	-	-	-
5	TK (% K_2O)	0.48	-	-	-
6	Available N (mg/kg)	0.65	-	-	-
7	Available P (mg/kg)	0.42	≥ 2	≥ 90%	Not meet
8	Available K (mg/kg)	0.60	≥ 2	≥ 90%	Not meet
9	Pb (mg/kg)	0.030	≤ 200	≤ 110%	Meet
10	Cd (mg/kg)	0.018	≤ 5	≤ 110%	Meet
11	Zn (mg/kg)	50.37	≥ 50	≥ 80%	Meet
12	Fe (mg/kg)	959.0	≥ 50	≥ 80%	Meet
13	Cr (mg/kg)	50.66	-	-	-
14	Cu (mg/kg)	50.95	≥ 50	≥ 80%	Meet
15	Mg (mg/kg)	330.14	≥ 20	≥ 93%	Meet
16	E.coli (CFU/ml)	0.28×10^3	$\leq 1.1 \times 10^3$	≤ 200%	Meet
17	Humidity (%)	39.47	≤ 30	≤ 105%	Not meet
18	C/N	14.54	≤ 12	≤ 105%	Not meet

Note: (-) Not specified.

Comparison of the quality of the best produced organic fertilizer in NT.4 (*) with the organic fertilizer standards (**) of the Ministry of Agriculture and Rural Development (Tables 19, 23 and 25 of Circular No. 09/2019/TT-BNNPTNT issued on August 27, 2019) is shown in Table 3.

Table 3 shows that there are 3 nutritional parameters including: available P, available K and C/N of the organic fertilizer produced that do not meet the organic fertilizer standards as prescribed. The solution can be solved by mixing nutrient-rich materials such as: catfish by-products, or NPK minerals into the input materials [2, 10]. The C/N ratio in the experiments was low (from 14.54-18.68), normally this ratio is around 25-30 [11]. However, the C/N ratio in this study is equivalent to the research results of [11-13].

The pH level of the organic fertilizer product is 6.38 compared to the input raw material sludge at 6.6. The reason may be that agricultural by-products, when decomposed under anaerobic conditions, have lowered the pH. For heavy metal indicators such as Pb, Cd, Zn, Fe, Cr, Cu, and Mg, the organic fertilizer product meets the standards as required. This demonstrates that the geological sediments and sludge from aquaculture used for composting the organic fertilizer do not exceed the regulated heavy metal concentration standards. Regarding the harmful microorganism indicator E. coli in the organic fertilizer product, it also meets the organic fertilizer quality standard, which is less than 1.1×10^3 CFU/ml. This indicates that composting under anaerobic conditions with input materials supplemented with Tricho and maintaining a closed environment at a temperature of 60 – 65 °C can effectively reduce E. coli density.

For humidity index not meeting the requirements, the solution is to reduce the humidity content of the sludge or dry the organic fertilizer product at low temperature or dry in an environment away from sunlight [10, 11].

4. Conclusion

The AS and ABP have high nutritional content and can be reused to produce organic fertilizer. At the mixing ratio of 30% AS and 70% ABP (NT.4), the fertilizer has the highest nutritional quality because most of nutritional indicators of organic fertilizer are higher than the remaining mixing ratios (data in the Table 2). The study is meaningful in providing a scientific basis for circular agricultural production, improving efficiency in agricultural production.

The organic fertilizer product obtained at NT.4, when compared with the 18 standards of organic fertilizers set by the Ministry of Agriculture and Rural Development, shows that most indicators meet the required standards, except for three nutritional indicators available P, available K and C/N of the organic fertilizer produced. The proposed remedy is to supplement with additional nutrient-rich inputs. Additionally, for the moisture content that did not meet the standard, the suggested measure is to dry the waste sludge in the shade before composting or to dry the organic fertilizer product.

Further research should find ways to reduce moisture content and look for additional organic materials to further enhance the nutrient content of compost.

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