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The Effect of Drying Temperature on Nitrogen Loss and Pathogen Removal in Laying Hen Manure

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Abstract: Exhaust air from the poultry houses or ambient hot air are normally utilized to dry the laying hen manure extensively in the summer in China. The drying process can not only reduce the moisture of lay hen manure but can also have a degerming effect. However, the ammonia emission is considered as one of the major issues of laying hen manure drying and air pollution scouse. Then, it is not clear that whether the ammonia emission increased using the hot ambient air to dry laying hen manure in summer and whether increasing the temperature can inactivate more bacteria during low temperature drying process. Therefore, the main works of this study were to investigate the evolution of ammonium nitrogen (NH_4-N) content, organic nitrogen (Org-N) content, and total bacteria count vs. time during the low-temperature drying process of laying hen manure at different drying temperatures. The results showed that increasing drying temperature can reduce the energy consumption of the manure drying system, but can increase the loss of NH_4-N. The Org-N content among the three drying temperatures within same drying time was not significantly different ($p > 0.05$), which suggested that increasing the temperature did not accelerate the degradation of Org-N during low-temperature drying process. Low-temperature drying had weak destruction of bacteria in laying hen manure and the end dried manure still had a great number of bacteria.

Keywords: laying hen manure; low-temperature drying; nitrogen loss; pathogen removal

1. Introduction

Improper manure treatment can result in environmental and health issues such as ammonia emission and pathogen transmission [1]. Ammonia emission is a concerned problem for chicken farms, which is a major source of air pollution. Ammonia can cause irritations of the breathing system and eyes as well as having irreversible effects on lung function at very high concentrations [2]. Moreover, ammonia is a precursor of fine particulate matter and attributes to water eutrophication [3,4]. Another major concern for environment and health is the pathogen in laying hen manure, because pathogens can threaten the biosecurity of chicken farms and humans. Ammonia emission and pathogens can be alleviated by drying manure [5]. Currently, heat treatment is one of the only common methods to reduce or eliminate potential pathogens in laying hen manure [6,7].

The residual heat from the poultry house or ambient hot air has been widely used in China for manure drying [8]. This manure drying system was illustrated in previous work [9]. The energy consumption of this system is mainly from the fans which is used to blow waste air of poultry house or ambient hot air into the manure drying system. It is a more energy-saving method compared to the traditional way of using burning coal or electrical-heating drying. Dried poultry manure is further used as organic fertilizer, which is more environmentally friendly than chemical fertilizers. This method reuses the waste heat from the poultry house and turns manure into valuable fertilizer. Therefore, it is a sustainable development for environment and economic benefit for farmers.

Some studies have confirmed that ammonia emissions were dramatically lower in dried manure compared to that of the other techniques, such as composting [10–12]. The drying process still caused high concentrations near the openings of the dryer, especially after loading the fresh manure. It was necessary to understand the involved factors and optimize the low-temperature drying process to reduce ammonia loss. Winkel et al. got the relationship between ammonia concentration and water content of poultry manure during the field drying experiment in chicken farms [13]. Furthermore, it was not clear whether the ammonia emissions increased with the increasing of drying temperature. The interactions between the different factors were significant, and it was not easy to create the single factor conditions we needed in the field drying experiment. Therefore, the impact of different factors on the poultry manure drying process need to be investigated in a laboratory setting. There have been many lab experiments on poultry manure drying. Thermo dynamics and drying behavior were studied more rather than the nitrogen conversion in the drying process. Aboltinsl and Kicl reported that the drying time and water removal was significantly affected by the air velocity and drying temperature [14]. Ghaly and Macdonald reported that the water loss rate of poultry manure was influenced by the hot air temperature and the manure layer thickness [15].

Many studies have investigated the ammonia loss from manure during storage, composting, and land application. Estela et al. reported that the temperature of the composting had a great influence on the ammonia emission during the composting process [16]. Prat et al. concluded that increasing the temperature caused an increase in total nitrogen loss during the storage of laying hen manure, and the suitable storage temperature was below 20 °C [17]. Most of uric acid and undigested protein was decomposed by micro-organisms in the manure, and then they formed ammonia. This process could be accelerated by increasing temperature when the temperature was between 20 and 30 °C [12,18]. Ammonia and ammonium ion were the two forms of reduced nitrogen in laying hen manure accumulated some time. Ammonia was extremely soluble in water and volatilization occurred when free ammonia was present [19]. As temperature increased, more ammonia dissolved in water and converted to free NH_3 which can escape into the air with the evaporation of water inside the laying hen manure. However, there was a lack of knowledge about the ammonia loss from the low-temperature drying. Ghaly and Alhattab reported that the drying process had 44–55% total nitrogen loss at the drying temperature of 40–60 °C, and the higher the drying temperature, the greater the total nitrogen loss [20]. Unfortunately, there has been no report about a detailed nitrogen conversion during the low-temperature drying process.

In order to understand the ammonia loss during the low temperature drying process and to find the optimal drying regime to reduce nitrogen loss in manure, it was necessary to understand the change rule of NH_4-N content and Org-N content. Meanwhile, most of the dried poultry manure was directly returned to land as organic fertilizer. Therefore, the microbial content during low temperature drying needed to be clarified to determine the biological safety of poultry manure.

The aims of this research were (1) to explore the effects of drying temperatures on change trend of NH_4-N content and Org-N content during low temperature drying, and (2) to quantify the counts of total bacteria and E. Coli in laying hen manure vs. time at different temperature of 15, 25, and 35 °C during drying process.

2. Materials and Methods

2.1. Laying Hen Manure Samples

Manure was collected from the caged laying hen (Jing Fen I layer) in an experimental barn (Shang Zhuang experimental station of China Agricultural university, Beijing) and stored (details seen in previous work [9]). Analytical of water content, total nitrogen concentration (TKN) and ammonium nitrogen (NH_4-N) adopted the official methods of analysis of AOAC International [21]. The moisture of the manure samples was determined using air drying in an oven. The pH was measured with a pH meter (MIK-PH6.0, Hangzhou Meicon Scientific Inc, Hangzhou, China). Total N concentration of manure samples was determined using the Kjeldahl method. The NH_4-N were measured with a continuous flow method. The organic nitrogen content was calculated with the amount of TKN, NH_4-N using the equation: Org-N = TKN − NH_4-N [22]. Table 1 showed the manure properties analyzed at 53–55 weeks of bird age, which did not significantly change with the age of the birds ($p > 0.05$). Therefore, manure collected at different days did not affect the results.

Table 1. Properties of raw manure samples at bird age 53, 54, and 55 weeks.

Manure Properties	**Bird Age, Week**		
	53	**54**	**55**
TKN, $g \cdot kg^{-1}$	55.19 ± 1.79	57.37 ± 1.80	56.53 ± 1.95
Org-N, $g \cdot kg^{-1}$	37.21 ± 2.01	38.05 ± 2.02	38.48 ± 2.20
NH_4-N, $g \cdot kg^{-1}$	17.98 ± 1.36	19.32 ± 1.44	18.05 ± 1.21
Moisture, %	74.8 ± 1.7	77.0 ± 3.4	76.4 ± 1.2
pH	8.2 ± 0.2	8.1 ± 0.3	8.2 ± 0.2

Note: TKN refers to total nitrogen concentration.

2.2. Experimental Drying Apparatus

The drying experiments were carried out in an experimental cross-flow drying apparatus (Figure 1). It basically consisted of two centrifugal fans (G1323A3, Hengshui Yongdong Scientific Inc., Hengshui, China), an electric heater (BXCP101, Shenzhen FHS Scientific Inc., Shenzhen, China), a humidifier (HTJ-2027B, Jiangmen Honetian Technology Co., Ltd., Jiangmen, China), and a humidity & temperature sensor and proportional controller (JWSK-5ACWD, Beijing Kunlunhai Technology Co., Ltd., Beijing, China).

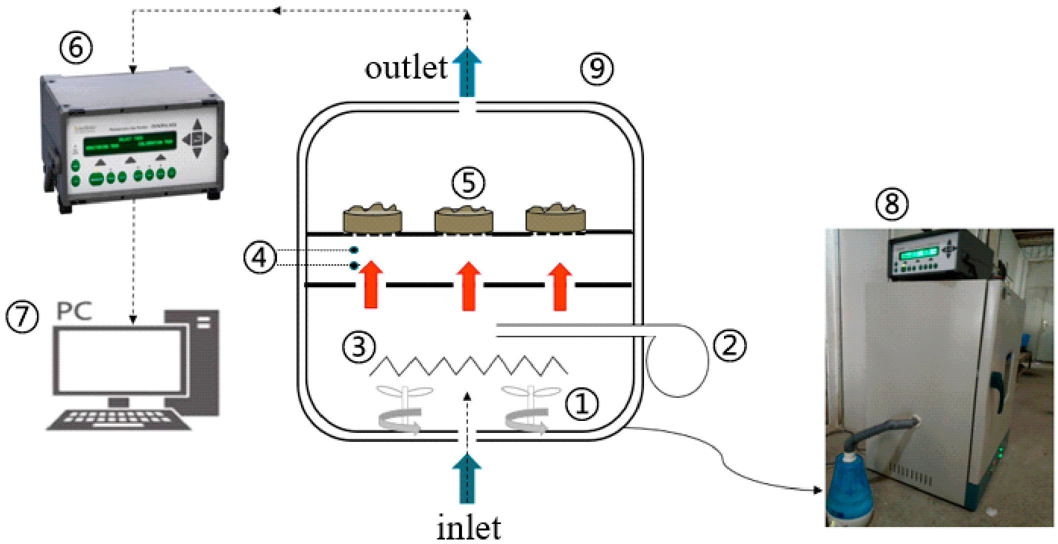


Figure 1. Experimental dryer unit: ① fan for force convection; ② humidifier; ③ electric heater; ④ Humidity & Temperature Sensor and proportional controller; ⑤ sample lying on perforated trays; ⑥ Innova 1412i; ⑦ computer for data recording and processing; ⑧ experiment site; ⑨ experimental dryer.

The hot air temperature for drying operations were set up to be 15 °C, 25 °C, and 35 °C with the relative humidity at 30%–35%, respectively. The layer thickness of manure samples was 100 mm and the underneath air velocity was constantly at 1.2 m/s. The drying experiments was carried out for three times and the working principle of drying apparatus was detailed in previous work [9].

2.3. Experimental Analyses

During the drying process, manure sampling was performed at a 4 h interval and raw manure was also sampled. For each tray, approximately 15 g of manure was taken out each time. The sample was then stored and transported on ice to the College of Resources and Environmental Sciences, China Agricultural University for analysis. The detail method for the analysis of moisture ratio, total N content, NH_4-N and NO_3-N of manure samples referred to the previous works by William [21]. The moisture ratio, NH_4-N content and Org-N content in drying process at different temperature of 15, 25, and 35 °C were calculated and recorded every four hours. NH_4-N and Org-N content were represented as g in kg of dried manure. Moisture ratio from here on was reported on a wet weight basis.

Total bacteria and E. Coli count of each laying hen manure samples were performed according to plate counting of bacteria method. The plate experiments were completed on the day of sampling and the number of colonies were recorded. In data analysis, microbial counts were converted to log CFU/g in dry weight.

This experiment only recorded the electricity consumption of the fan in drying apparatus, and the electricity consumption of fan was recorded by electric meter (LUEABB, Zhejing Langben Electric Inc., Wenzhou, China). Energy consumption of fan refers to fan's energy consumption of per unit mass of dried laying hen manure.

2.4. Statistical Analysis

The moisture ratio, NH_4-N content, and Org-N content were presented as the mean ± standard deviation (SD) of triplicate determinations. Analysis of variance was performed by one-way ANOVA procedures. Differences between the mean values of the treatments were determined by the least significant difference (LSD) test and the significance was defined at $p < 0.05$. The trend of moisture ratio, NH_4-N content, and Org-N content vs. time at different temperature were analyzed using the origin 8.5 software.

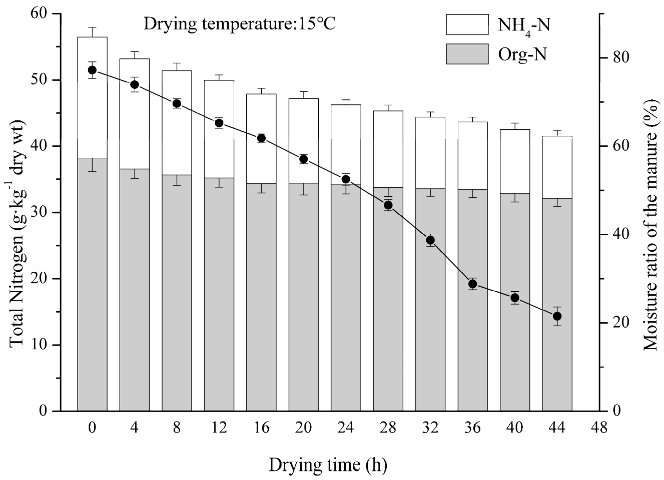
3. Results and Discussion

3.1. Manure Nitrogen Loss

The majority of N excreted in poultry manure was in the form of uric acid, which can be rapidly converted to urea and NH_4-N if temperature, pH, and water content were suitable for microbial reproduction. Loss of NH_4-N from manure began to occur immediately after excretion and was influenced by conditions within the production house. Previous work indicated that ammonia was mainly produced from decomposition and hydrolysis of uric acid, which was caused by an aerobic and microbially mediated process [12]. Therefore, the nitrogen content in laying hen manure was related to the moisture content.

There was no significant difference in moisture ratio, NH_4-N content, and Org-N content in raw laying hen manure ($p < 0.05$). The measured NO_3-N concentration (data was not shown) within all samples were negligible, which indicated that no nitrification occurred during the low temperature drying process of poultry manure [23].

Figure 2 shows the moisture ratio, NH_4-N content, and Org-N content of laying hen manure vs. time at different temperatures of 15, 25, and 35 °C. The moisture ratio of the manure samples decreased with time. As we can see from Figure 2a–c, the drying rate was greatly affected by the drying temperature: the higher the drying temperature, the shorter the drying time. The time needed to reduce the moisture ratio of laying hen manure samples from the initial to about 20.0% was 44, 28, and 20 h with the drying temperatures of 15 °C, 25 °C, and 35 °C, respectively. The moisture ratio of laying hen manure dried in the same drying time with different temperatures were significantly different ($p > 0.05$). Therefore, higher drying temperature significantly accelerated the drying rate. At the same drying time, the moisture content in laying hen manure was significantly different ($p > 0.05$) at different drying temperatures.



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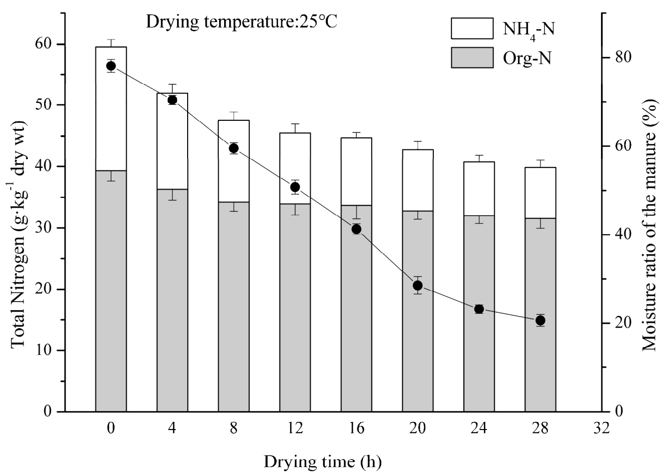

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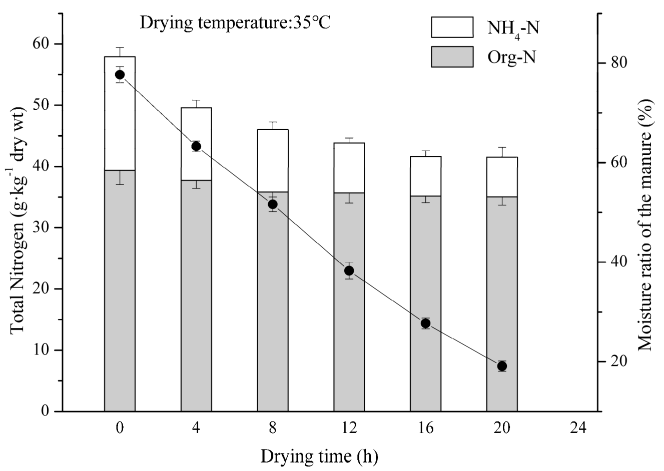

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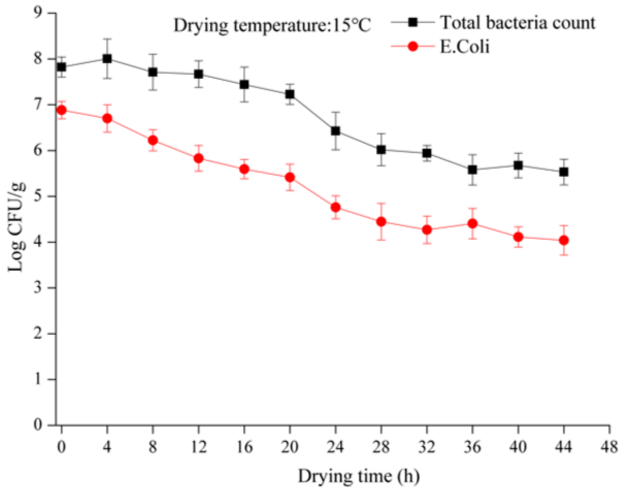
Figure 2. (**a**) The moisture ratio, NH_4-N content, and Org-N content of laying hen manure vs. drying time at drying temperature of 15 °C, (**b**) The moisture ratio, NH_4-N content, and Org-N content of laying hen manure vs. drying time at drying temperature of 25 °C, (**c**) The moisture ratio, NH_4-N content, and Org-N content of laying hen manure vs. drying time at drying temperature of 35 °C.

According to Figure 2a–c, the initial NH_4-N was relatively high. Related researches show that 55–65% of moisture ratio was favorable for manure microbial degradation and NH_3 volatilization, and most of the ammonia nitrogen evaporated at this stage [17]. This was consistent with the results that the highest nitrogen lost in the initial drying period. After 8 h of drying, the NH_4-N content of manure dried at 15 °C and 25 °C was not significantly different ($p > 0.05$), but the NH_4-N content at 35 °C was significantly less than that of the manure dried at the two lower temperatures. As the drying process continued, the NH_4-N content of manure dried within same time at different temperatures were significantly different ($p < 0.05$) until the end of drying. The main reasons for the above phenomenon may be found within the following aspects: NH_4-N was formed in the manure layer by micro-organisms from the decomposition of mostly uric acid and undigested proteins. NH_4-N was highly soluble in water [24]. Therefore, the raw manure (accumulated 48 h in the poultry house) retained suitable moisture to hold the NH_4-N, which was produced through the ammonification process. Temperature had the positive influence on the dissociation constant [25], and the higher the temperature, the greater the heat transfer driving force. It resulted in the increase of evaporate rate of water, which explained that the higher the temperature, the faster the NH_4-N loss and the greater the NH_4-N loss.

The Org-N concentration had a little decrease during the drying process, indicating that slight degradation or composting of laying hen manure occurred in this process. The Org-N content of manure dried at three temperatures within same time were not significantly different ($p > 0.05$), which suggested that increasing temperature did not accelerate the degradation of Org-N during low-temperature drying process. Hadas et al. also reported that the temperature had little effect on the rate of mineralization when the temperature was between 14 °C and 35 °C [26]. The reason why the lower temperature drying process lead to lower organic nitrogen content may be the longer drying time. There was more Org-N loss in the initial stage (the moisture content was reduced from the original to 55–65%) of drying process. With the decrease of moisture ratio, the decrease rate of Org-N became slow and the change of Org-N was very small, especially in the late period of drying. The main reason was that certain moisture was required for both dissolution of solid urea forms and subsequent urea hydrolysis [18].

3.2. Pathogen Removal

The drying process can not only reduce the moisture of lay hen manure, but also has a degerming effect. The decay patterns of the microbial analyze results, plotted on a log10 scale, was shown in Figure 3. During the drying process, the corresponding mean log10 reduction values of E. coli were 2.28, 2.51, and 2.84 at 15 °C, 25 °C, and 35 °C, respectively. The corresponding log10 reduction values of total bacteria were 2.29, 2.54, and 2.28 at 15 °C, 25 °C, and 35 °C, respectively. There was no difference ($p > 0.05$) among the E. coli or total bacteria values of the manure dried at 15 °C, 25 °C, and 35 °C. However, it needed a shorter time for the bacteria decreasing under a higher drying temperature. It was likely due to the decreased microbial activity with the decrease of moisture content. This result also showed that low-temperature drying had a weak destruction of bacteria in laying hen manure. When the drying process was over, the moisture of dried manure was below 20% and E. Coli content was found to be below 2×10^6 CFU/g dry wt, which was the limit value of the U.S. Environmental Protection Agency (EPA) Class B pathogen requirement [27]. This value was no longer harmful to public health and environment. However, the E. Coli content in the end dried manure exceeded EPA Class A pathogen requirement (E. Coli: <1000 MPN/g dry wt). Therefore, increased drying temperature or other follow-up measures need to be taken to inactivate the bacteria. Ghaly and Alhattab reported that the poultry manure drying process had a good effect on the elimination of E. Coli, yeast, and mold when the drying temperature was 40–60 °C [20]. They also concluded that the higher the drying temperature, the more inactivation of total bacteria in the dried poultry manure. Kim et al. investigated the thermal inactivation of broiler litter using 70–80 °C drying temperature. He concluded that 70–80 °C drying temperature can inactivate salmonella, and the higher the temperature, the faster salmonella was inactivated [7].



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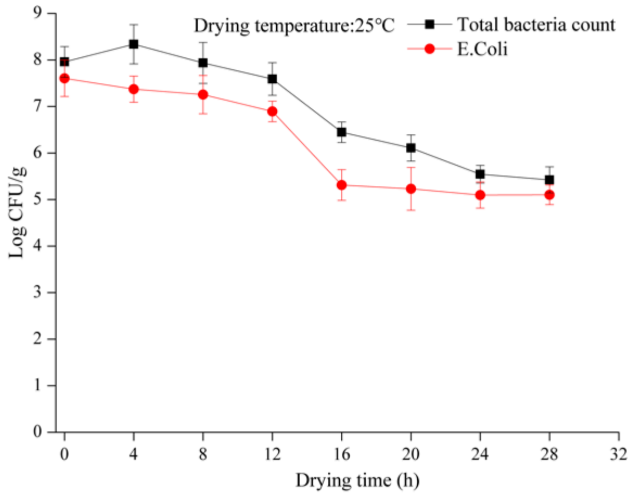

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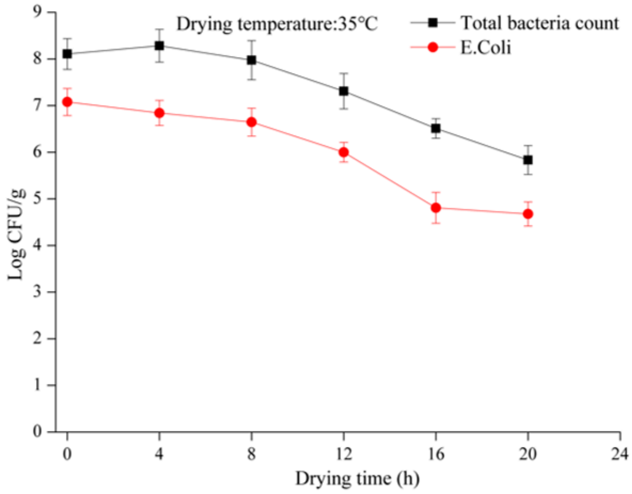

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Figure 3. (**a**) Counts of total bacteria and E. Coli in laying hen manure vs. time at drying temperature of 15 °C, (**b**) Counts of total bacteria and E. Coli in laying hen manure vs. time at drying temperature of 25 °C, (**c**) Counts of total bacteria and E. Coli in laying hen manure vs. time at drying temperature of 35 °C.

Turner indicated that the inactivation was not merely temperature dependent [28]. In the initial stage of drying (0–4 h), the moisture content of laying hen manure was about 60%, which was conducive to the activity of aerobic microorganisms and microbial decompositions [29]. Therefore, there was a slight increase in the total bacteria counts. The total bacteria counts increased most in the initial stage of drying when the drying temperature was 25 °C, as seen in Figure 3. This was probably due to the fact that 25 °C was more suitable for the growth of aerobic micro-organisms. However, Koerkamp concluded that 35 °C was more suitable for the growth of aerobic micro-organisms compared to 25 °C [12]. Generally, temperature range between 25–35 °C was suitable for the growth of aerobic micro-organisms. In the late period of the drying process, the inactivation process was mainly affected by water content of laying hen manure. Figure 3 shows that the total bacteria content decreased with the decrease of moisture content.

The E. Coli count did not increase during the initial drying period, which decreased with the decrease of moisture content throughout the drying process. Therefore, the increase in total bacteria was not caused by the growth of E. Coli, which did not multiply during the initial drying period. The suitable temperature for E. Coli was 37 °C, and it was higher than the temperature of the low-temperature drying process, which was only between 15–35 °C. Another reason was that the moisture content of the lay hen manure was reduced below 60% in a short time, which was not conducive to the reproduction of E. Coli [30]. E. Coli decreased more in late period of drying process when the moisture content was lower compared to that of the initial stage. Wilkinson observed more effective reductions of E. coli counts at lower moisture content of poultry litter at 35 or 45 °C [6]. Overall, the low-temperature drying process did not result in the reproduction of E. Coli. However, low-temperature drying had a weak destruction of bacteria in laying hen manure and the end dried manure still had a great number of bacteria. Therefore, increasing drying temperature or other follow-up measures were suggested to be taken to inactivate the bacteria.

3.3. Energy Consumption

Currently, the drying industry needs to consume substantial traditional energy, and energy-saving drying technologies are necessary [31,32]. The heating source of this manure drying system was the residual heat from the house ventilation (in winter) or ambient hot air (in summer). The main source of energy consumption in this drying system was the fan, which was used to blow the waste air from the closed chicken house or the ambient air into the manure drying system. Compared to the other drying technologies, this method can save more energy. Therefore, only the running fan was calculated for the energy evaluation in this experiment, while the heating equipment was not considered. The energy consumption of fan in different drying temperatures was recorded and shown in Figure 4. It was found that the energy consumption of the fan decreased with the increase of the drying temperature. The potential reasons for this phenomenon was that the higher the drying temperature was, the shorter the drying time would be, and the smaller the energy consumption of the fan would be. Therefore, the temperature of the waste air from the poultry house was limited in the field drying. The temperature of the hot air entering the manure drying system need to be increased as much as possible. For example, the hot air after solar radiation in summer can be used.

It was seen from the above studies that if the drying temperature increased, not only the drying rate can be accelerated and the inactivation time can be shortened, but also the energy consumption of the fan can be reduced. However, the increasing temperature also caused the loss of ammonium nitrogen. Therefore, the drying parameters need to be further optimized and a more suitable drying temperature needs to be determined in further studies for lower energy consumption and less ammonia loss.

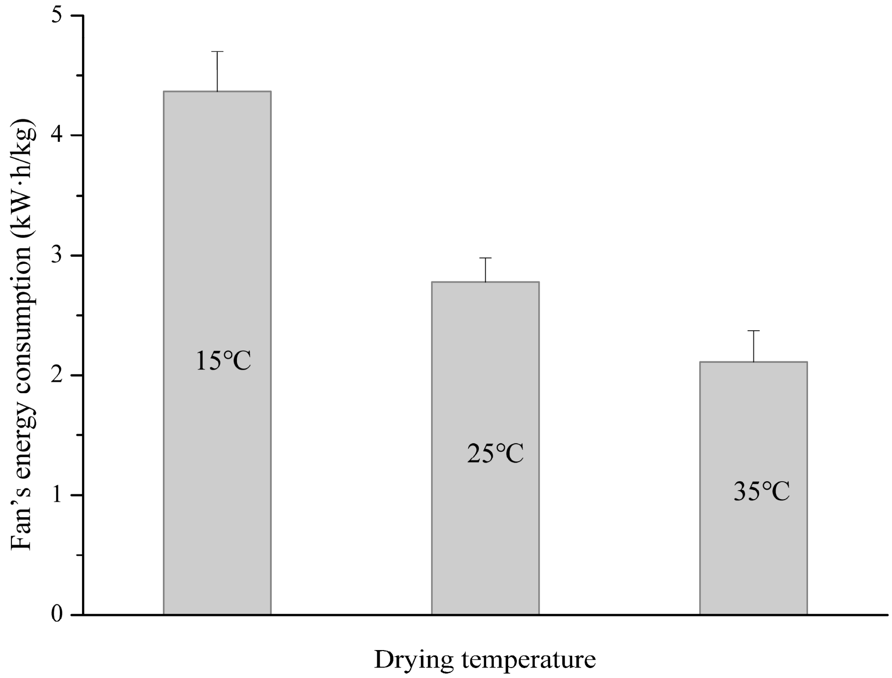

Figure 4. Energy consumption of fan in different temperatures drying process. Note: Energy consumption of fan refers to fan's energy consumption of per unit mass of dried manure.

4. Conclusions

This study illustrated the influence of drying temperature at 15, 25, and 35 °C on the moisture ratio, NH_4-N and Org-N content in laying hen manure. Furthermore, the bacteria and E. Coli count of manure and energy consumption of the system fan were analyzed. The following conclusions were summarized:

(1) The higher the temperature, the faster the NH_4-N loss, and the greater the NH_4-N loss. The higher the temperature, the greater heat transfer driving force, resulting in the increase of water removed rate and further leading to more volatilization of NH_4-N at the early period of drying.

(2) Differences in the Org-N content of manure dried at the three temperatures within same time were not significantly ($p > 0.05$), which suggested that increasing temperature did not accelerate the degradation of Org-N during low-temperature drying process.

(3) Low-temperature drying had a weak destruction of bacteria in laying hen manure and the end dried manure still had a great number of bacteria. Therefore, increasing drying temperature or further treatment were suggested to inactivate the bacteria.

(4) Increasing drying temperature can reduce the duration and the energy consumption of the manure drying.

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Conflicts of Interest: The authors declare no conflict of interest.

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