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# Applications of Cleaner Production Techniques in a Commercial Laying Hen House

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**HIGHLIGHTS**

- Cleaner production techniques are an important issue in ensuring sustainability in animal barns.
- Composting is the most efficient method among waste management practices.
- The adjustment of the feed ration reduces the $NH_3$ level in the laying hen enterprise by 12.37%.
- By using LED bulbs for lighting, an energy saving of 27.87% is achieved.

**Abstract**

The fact that environmental pollution is increasing daily and the emergence of negativities in the lives of living things has led to an increase in environmental awareness. Studying how to reduce soil, water, and air pollution is important. As a result of this situation, the concept of cleaner production has emerged. In this study, calculations and designs were carried out to cleaner production techniques for waste management, natural resource use, and control of pollutants from an hen house with a capacity of 12000 animals. Within the scope of the study, an analysis was conducted on the economic and environmental contributions that would be achieved in enteprise if the fertilizer obtained from the enterprise were used as compost or biogas. Additionally, calculations were performed including rainwater harvesting, feed ration adjustments, LED and fluorescent lamp comparisons, and windbreaks. As a result of the study, the most beneficial method for fertilizer management in the enterprise is composting with an annual income of 6000000 TL. The initial investment costs the enterprise will incur for compost production can be recouped in as little as 2 years. With the installation of rainwater harvesting in the enterprise, an annual water saving of 266.96 $m^3$ is achieved, and a 12.37% reduction in indoor ammonia emissions is experienced as a result of necessary adjustments to the feed ration. As a result of the calculations, it has been determined that the application of clean production techniques in laying hen houses can lead to improvements in animal health and welfare, reduce environmental problems caused by animal production and resource usage.

**Keywords:** Waste Management; Environment; Animal Welfare; Sustainable Production; Cleaner Production Techniques

## 1. Introduction

As the population continues to grow over the years, the resulting excessive and distorted urbanization, the increased use of vehicles, and the advancements in technology in the industry have led to a rise in

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environmental pollution problems (Kozak 1992). However, the agriculture and livestock sectors can also cause high levels of environmental pollution. Various pollutants originating from animal shelters may vary depending on the type of animals in the facilities and the production methods used. However, they pose a high risk to the air, soil, and water resources. For example, in laying hen enterprises, the primary pollutants are manure from dead animals and primarily ammonia as a pollutant gas. Therefore, environmental damage can be minimized by taking various measures in the enterprises and adjusting the production systems used.

Regular cleaning of manures, which are the primary cause of pollutant gases in enterprises, and ensuring that ventilation is carried out in appropriate amounts are some of the measures that can be taken to somewhat control the indoor air quality within the enterprise (Choiniere and Munroe 1997). Organic manure cannot be used fresh because it contains a high amount of ammonia and nitrate; therefore, it must be aged for a while. The periods when organic manures are most harmful to the environment are due to improper storage or incorrect storage during the drying periods (Follett et al. 1981). For reason, it should be stored under appropriate conditions, and its moisture content should be reduced to minimize the harmful effects of chicken manure on the external environment and surroundings. Composting is an important method used to minimize harmful effects and achieve economic gains. During the composting process in the hen house, it is necessary to pay attention to the moisture content of the manure, the C/N ratio, and the regulating agent to be used (Iqbal et al. 2010; Chen et al. 2017; Shan et al. 2021; Özbek and Uçaroğlu 2022). In addition to manure, a primary pollutant in hen houses, dead animals pose significant problems for the operation and the environment. In enterprises, methods such as burial and incineration are often used to get rid of these dead animals. However, the incineration or burial of dead animals causes environmental pollution and results in negative economic and environmental consequences for the enterprises (Kılıç and Karaman 2014).

Measures to reduce the effects of factors causing pollution in henhouses impose high economic costs on enterprises while failing to prevent environmental pollution entirely. For this reason, cleaner production techniques have started to be utilized in production and other applications in enterprises. Cleaner production techniques can be defined as strategies to prevent the formation of pollutants that cause environmental pollution at the source. Examples of these strategies include using manure produced in hen house as compost or biogas, properly adjusting ventilation according to the heat and humidity balance, regulating the feed ration, choosing the right lamps for lighting, rainwater harvesting and windbreaks. In hen house, using cleaner production techniques reduces resource usage and environmental pollution, and provides economic benefits such as reducing existing costs and increasing enterprise efficiency (Demirer, 2001).

Biogas applications, which are one of the clean production techniques applied in livestock enterprises, provide the utilization of manure in enterprises and are also a source of energy. Biogas application has many contributions such as energy saving in livestock enterprises, removal of harmful gases and microorganisms from manure, and prevention of environmental pollution (Demirulus ve Aydın, 1996; Eleroğlu ve ark. 2012).

The use of fluorescent or LED lamps in hen house indoor lighting has implications for animal welfare and productivity, energy consumption and cost. With the preference of led lamps in the poultry house, economic savings are achieved in direct proportion to energy savings. In addition to this situation, since led lamps have the ability to adjust the amount of current, the brightness level can be adjusted in the hen house to provide the best lighting for the chickens. Therefore, increases in the development of chickens and egg productivity can be seen (Rezazad ve İngin, 2019).

Windbreaks are an example of cleaner production techniques that can be applied in the external environment of hen house. Windbreaks are protective barriers made by placing trees around the perimeters of hen houses to shield the operation and animals from the effects of the wind. Windbreaks have many benefits, such as reducing wind speed, minimizing the impact of wind on animals, decreasing the effect of wind on the structural elements of the enterprise, and preventing snow accumulation in the same area during winter months, thereby reducing the effects of snowmelt (Yılmaz 2015).

Cleaner production has been on the agenda in developed countries for many years. In this context, Cleaner Production Programs have been implemented in 47 countries since 1994, and National Cleaner Production Centers (UTÜM) have been established (Anonymous 2020). In Turkey, the concept of cleaner production was first brought to the agenda in 1999 by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) and the Türkiye Technology Development Foundation (TTGV). However, no new steps were taken in this regard until 2008. Türkiye's only nationwide Eco-efficiency (Clean Production) program was launched in 2008 and completed in 2011 (Öztürk 2017).

This study aims to determine the necessary conditions and carry out the designs for the cleaner production of a laying hen house with a capacity of 12000 animals located in the Bursa region, utilizing cleaner production techniques in the areas of waste management, natural resource use, pollutant gas control, and occupational health and safety.

## 2. Materials and Methods

### *2.1. Study Area*

The study was conducted in a layer hen house with a wire cage system with a capacity of 12000 animals located in the Bursa region. The building is oriented in the North-South direction and Brown Nick breed chickens are raised in the hen house. General size information about the hen house is provided in Table 1.

**Table 1.** General dimension information of the hen house

| House Width (m) | House Length (m) | Wall height (m) | Ridge height (m) | Roof slope (°) | Window | | | Door | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Length (m) | Width (m) | Height (m) | Length (m) | Width (m) |
| 12.10 | 39.00 | 3.60 | 5.60 | 18.00 | 2.10 | 0.7 | 1.70 | 3.10 | 1.40 |

### *2.2. Designs Related to Waste Management*

#### *2.2.1. Production and Storage of Organic Manure*

In this current study, since there will be losses during the collection and transportation of the manure produced in the barn, it has been assumed that 70% of the total manure amount will be collectible, and calculations have been made accordingly. The size of the storage required for the manure obtained from the hen house where the study will be conducted, and the amounts of manure to be collected and used have been determined using equations 1, 2, and 3.

$$\text{Manure amount (kg)} = NA\ x\ DMA\ x\ D \quad (1)$$

$$\text{Tank Volume (m}^3\text{)} = \frac{NA\ x\ DMA\ x\ D}{P} \quad (2)$$

$$\text{Amount of Manure to be Used (kg)} = \frac{H}{Y} \quad (3)$$

Where;

NA: Number of animals in the enterprises

DMA: The amount of manure to be collected from the hen (kg/day)

P: The specific weight of chicken manure

D: Duration (Day)

H=The N, P, K value to be applied to a hectare of land

Y = The N, P, K value found in chicken manure

In agricultural production, the amount of organic manure to be applied per hectare of land is a maximum of 170 kg N annually. A chicken produces an average of 128 grams of fresh manure daily. The nutrient element contents of organic animal manure from different animals are provided in Table 2 (Gatzweiler 2003; ASAE 2005; Taban et al. 2013; Abdeshahian et al. 2016; Katip 2020).

**Table 2.** Basic nutrient element contents of different animal manures

| | Nutrient Dry Matter (%) | | |
|---|---|---|---|
| Manures | N | P | K |
| Cow Manure | 2 | 1 | 2 |
| Horse Manure | 1.7 | 0.3 | 1.5 |
| Sheep Manure | 4 | 0.6 | 2.9 |
| Chicken Manure | 3.9 | 2.1 | 1.8 |

*2.2.2. Compost Production*

The process of recycling the manure formed in the hen house to be used as a nutrient source in agricultural production is called composting. To determine the moisture content and C/N ratios of the compost mixture, equations 4, 5, and 6 were utilized (Öztürk 2017).

$$\text{Moisture Content (\%)} = \frac{(a\ x\ na)+(b\ x\ nb)+(c\ x\ nc)+\cdots}{a+b+c+\cdots} \quad (4)$$

$$\text{C/N ratio} = \frac{a+b+c+\cdots C\ weight}{a+b+c+\cdots N\ weight} \quad (5)$$

$$x = \frac{\text{nb}-\text{N}}{\text{N}-\text{na}} \quad (6)$$

Where;

x: kg of substance A/kg of substance B

N: desired moisture content in the mixture

a, b, c: respectively, the total weights of items a, b, c

na, nb, nc, the moisture contents of substances a, b, c, respectively

%Na, Nb, Nc, respectively the nitrogen percentage of substances a, b, c (dry weight)

%Ca, Cb, Cc, respectively the carbon percentage of substances a, b, c (dry weight)

In composting, a regulator is used as a component along with manure. The study plans to use rice husk as a regulating agent due to its good solubility, odor adsorption, and reasonable price. For the composting process, the ideal values for the moisture content of the mixture to be created are between 40-60%, and the C: N ratio is between 25-30. The total C and N amounts and moisture contents of the manure and rice husk to be used in compost production calculations are given in Table 3 (Öztürk 2017; Saeed et al. 2021; Ekinci et al. 2021).

**Table 3.** Properties of manure and regulatory substances

| Parameters | %C | %N | Moisture Content (%) |
|---|---|---|---|
| Chicken Manure | 39.89 | 1.62 | 71.84 |
| Rice Husk | 38 | 0.28 | 10 |

The sequential pile method has been used for the composting process. The machines required for mixing compost materials are determined based on the size, shape, and distance between the rows of piles (Öztürk, 2017). It is planned to carry out the composting operation on a concrete surface. Drainage channels will be constructed where the composting process will take place to drain any leaks that may occur during composting. To complete the maturation process of the compost, it is planned to be dried in the compost facility over 45 days (Bilgili et al. 2011).

*2.2.3. Biogas Production*

In recent years, due to the increasing energy demand, countries have placed greater importance on renewable energy sources to meet their energy needs. Biogas is a gas mixture that results from the fermentation of organic waste in an oxygen-free environment. Biogas production can be achieved through organic manures in hen houses. The biogas potential per ton from different types of animals is provided in Table 4 (Ilgar 2012; Şenol 2017).

**Table 4.** Biogas production potential from fresh manure of different animal species

| Animal Species | Amount of Fresh Manure (tons) | Biogas potential ($m^3$) |
|---|---|---|
| Cow | 1 | 33 |
| Sheep | 1 | 58 |
| Chicken | 1 | 78 |

The study plans to produce the biogas from chicken manure for electricity production. The equivalents necessary for converting biogas into electricity and other fuel types are provided in Table 5 (United Nations 1980; Gümüşçü and Uyanık 2010).

**Table 5.** Conversion equivalents of biogas to different fuel types

| Fuel Types | Biogas Quantity ($m^3$) | Values | Units |
|---|---|---|---|
| Electricity | 1 | 4.70 | $m^3$ |
| Kerosene | 1 | 0.62 | L |
| Coal | 1 | 1.46 | kg |
| Wood | 1 | 3.47 | kg |
| Natural Gas | 1 | 1.18 | $m^3$ |

*2.3. Designs Related to Natural Resource Usage*

*2.3.1. Heat and Moisture Balance*

In cases where appropriate environmental conditions are not provided in the hen house, a decline in productivity and animal deaths are likely due to the deterioration of the chickens' health and stress. Therefore, the heat and humidity balance must be adjusted to meet the ideal conditions. To ensure the heat and humidity balance in the hen houses, the necessary calculations were carried out using equations 7, 8, 9, 10, and 11 (Albright, 1990; Demir and Öztürk 1991; Uğurlu 1999).

$$\text{Minimum air quantity (m3 h}^{-1}\text{)} = \frac{Wa}{gi - gd} \quad (7)$$

$$\text{The amount of heat lost through ventilation (Kcal hour}^{-1}\text{)} = 0{,}29\ x\ Q(ti - td) \quad (8)$$

$$\text{The amount of heat lost from the roof (Kcal hour}^{-1}\text{)} = U\ x\ A(ti - td) \quad (9)$$

$$\text{The total amount of heat emitted by the chickens into the environment} = (qh)\ x\ n \quad (10)$$

$$\text{Wall Heat Transfer Coefficient (Kcal m}^{-2}\text{)} = \frac{1}{\frac{1}{fi} + \frac{d1}{k1} + \frac{d2}{k2} + \frac{1}{fd}} \quad (11)$$

Where;

Wa: Total amount of water vapor generated in the poultry house (g/hour)

Q: Minimum air quantity (m3 $h^{-1}$)

U: Total heat transfer coefficient of the roof (Kcal/$m^2$h°C)

A: Surface area of the structural element ($m^2$)

ti: Enterprises indoor temperature (°C)

td: Enterprises outdoor temperature (°C)

gi: Indoor absolute humidity value (gr $m^{-3}$)

gd: Outdoor absolute humidity value (gr $m^{-3}$)

qh: Heat given off by the animal per kilogram to the environment (W)

n: Total number of animals in the enterprise (number)

fi: Thermal conductivity of the inner wall surface (KJ/$m^2$h°C)

fd: Thermal conductivity of the wall's outer surface (KJ/$m^2$h°C)

d: The thicknesses of the different materials that make up the wall (m)

k: Thermal conductivities of the different materials forming the wall (KJ/$m^2$h°C)

*2.3.2. Electricity Usage*

Hen houses are enterprises that operate throughout the day, use numerous electrical appliances, and are illuminated for a large part of the day. Lighting is the main reason for the highest electricity usage in the hen houses. One of the applications that can be implemented to achieve energy savings in the laying hen house where the study is conducted is the changes to be made in the lighting systems. For this reason, a comparison of LED and fluorescent lamps was conducted to determine the most suitable lighting system for the hen house. Calculations were carried out assuming the facility was illuminated for 16 hours daily.

*2.3.3. Water Usage*

Water consumption in hen houses is at a high level. The use of large amounts of water has environmental and economic impacts. Therefore, within the scope of cleaner production techniques, the storage and reuse of rainwater reduce environmental negative impacts and provide economic savings. The amount of water obtained from rainwater harvesting in the hen house has been determined using Equation 12 (TEMA 2025).

$$\text{Amount of rainwater to be collected (L)} = A \; x \; f \; x \; kc \; x \; kf \qquad (12)$$

Where;

A=Rainwater collection area ($m^2$)

f= Average rainfall amount (mm)

kc= Roof coefficient (The coefficient specified as 0.8 in DIN1989 by German standards)

kf = Filter activity coefficient (the coefficient specified in DIN1989 is 0.9)

The roof lengths of the enterprise were determined, and the roof area was calculated. The long-term average rainfall amount for the Bursa region was obtained from the General Directorate of State Meteorology Affairs website. The obtained data were used to calculate rainwater harvesting using the roof coefficient and filter efficiency coefficient (MGM 2025).

The amount of water obtained from the roof of the hen house is intended to meet the water needs for the animals' drinking and care. The daily water requirement for a laying hen is 0.45 L (Chapagain and Hoekstra 2003; Esen and Özdemir 2004). In this context, the amount of water that can be obtained through rainwater harvesting and the potential of this water to meet the needs have been determined.

### *2.4. Applications Related to Reducing Pollutant Emissions*

#### *2.4.1. Determination of Feed Ration*

In hen houses, different crude protein feeds consumed by animals significantly impact pollutant gas emissions. High crude protein feed increases the nutrient elements in the animals' manure and the amount of gas released into the environment. Therefore, within the framework of clean production techniques, changes in the amounts of nutrient elements such as nitrogen, phosphorus, copper, and zinc in feed rations to prevent pollution at the source are some of the measures that can be taken to prevent this pollution. The daily feed consumption of a laying hen is between 120-130 grams. This amount can vary depending on the breed of the chicken, the feeding system, the quality of the feed, and similar parameters (Anonymous, 2018). The amounts of pollutants released by feeds with different crude protein levels belonging to the barn where the study was conducted were determined using equations 13, 14, and 15 (Klopfenstein et al. 2002; Kutlu 2008).

$$\text{Daily protein intake (gr)} = \frac{FC}{AP} \tag{13}$$

$$\text{The amount of nitrogen in the manure} = \frac{DPC}{6.25} \tag{14}$$

$$\text{Amount of Ammonia Released} = \frac{AN}{1.21} \tag{15}$$

Where;

FC=Daily feed consumption (gr)

AP=Crude protein amount

DPC=Daily protein intake (gr)

AN = The amount of nitrogen in the manure

#### *2.4.2. Windbreaks*

When creating windbreaks, it is essential to know the climate conditions, the soil structure, and the necessary depth for the types of trees to be planted. After the planting process is carried out, irrigation is necessary when irrigation is insufficient. The distances between trees and rows can vary depending on the type of plants used during the formation of windbreaks. The distances between trees and rows according to the plant species are given in Table 6 (Anonymous 2016).

**Table 6**. Tree-to-tree and row-to-row distances by plant species

| Plant species | Distance between Trees (m) | Between rows Distance (m) |
|---|---|---|
| Shrubs or deciduous species with narrow crown | 1-2 | 3.5-6 |
| Small evergreen trees | 2-3.5 | 3.5-6 |
| Large evergreen trees | 2.5-4 | 3.5-6 |
| Small deciduous trees | 2.5-3.5 | 3.5-6 |
| Large deciduous trees | 2.5-5.5 | 3.5-6 |
| Single-row evergreen and two-row high | 2-2.5 | 3.5-6 |

## 3. Results and Discussion

### *3.1. Proposed Cleaner Production Designs in Waste Management*

#### *3.1.1. Obtaining Organic Manure for Plant Production*

Within the scope of the study, the amount of manure that can be collected annually from a hen house with a capacity of 12000 laying hens and the storage volume required for this manure to be used in plant production were calculated. Additionally, the area of land where the organic manure obtained from the henhouse can be used after drying was calculated. The values obtained from the calculations are presented in Table 7.

**Table 7.** Calculations related to the production of organic manure obtained from the henhouse

| Annual Manure Production in the Hen House (tons) | Annual Collectible Manure Amount (tons) | Tank Volume ($m^3$) | Amount of Manure to be Applied to the land (kg/ha) | Available Land Area (ha) |
|---|---|---|---|---|
| 560.64 | 392.44 | 33.75 | 4473.68 | 125.2 |

A storage facility with a capacity of 33.75 $m^3$ is needed to store the manure obtained monthly from the hen house. In order to store the amount of manure to be collected over 6 months from the facility, it is planned to use a total of 6 storage units, each with dimensions of 4.5x5x1.5 m and a volume of 33.75 m3. The design of the manure storage facility belonging to the enterprise is shown in Figure 1.

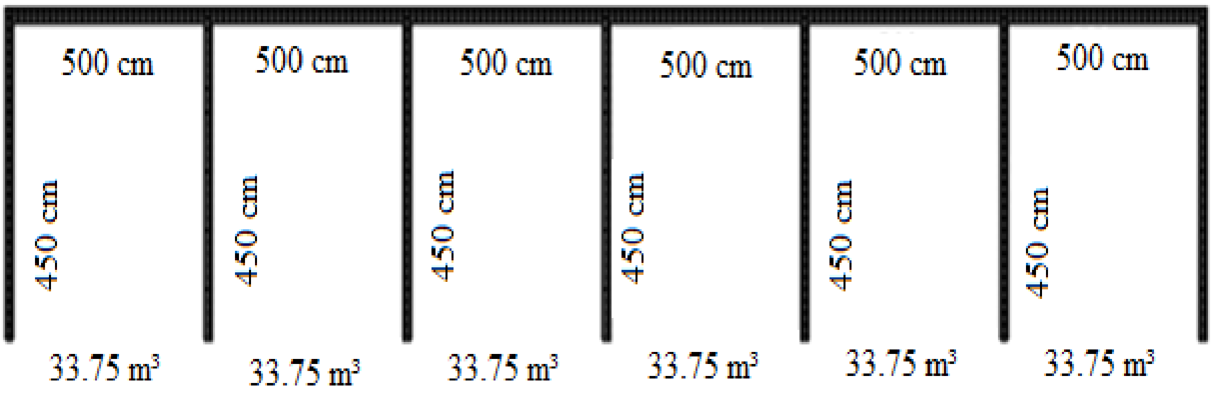



**Figure 1.** Manure storage design

*3.1.2. Compost Production Facility*

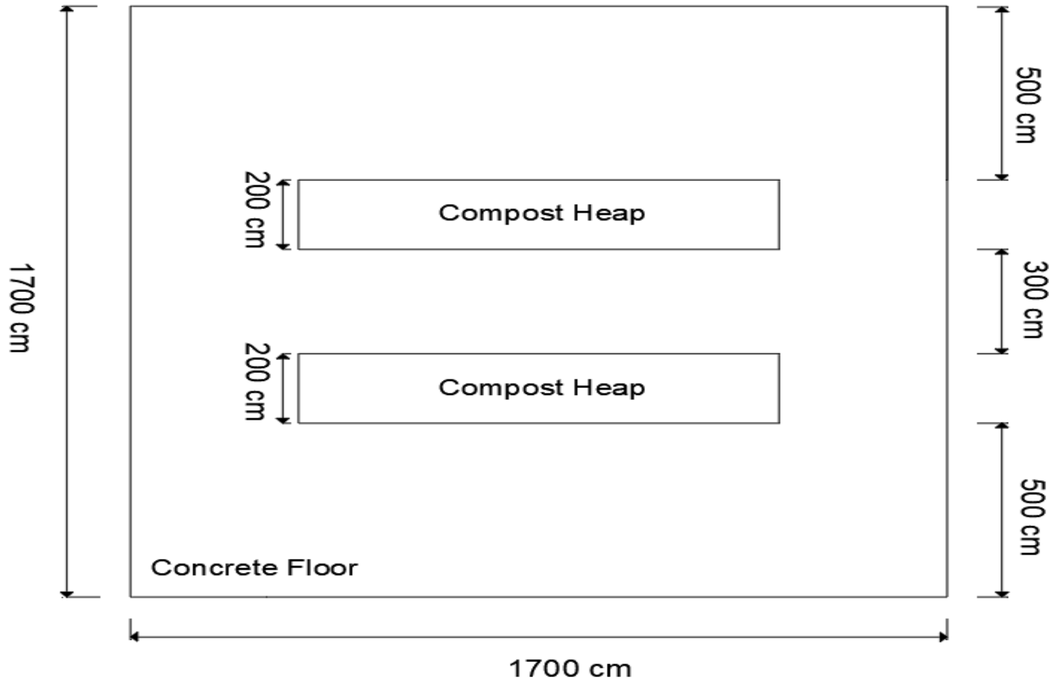
As a result of the calculations conducted for compost production, it has been determined that with a 60% moisture content and a 29 C/N ratio in the mixture, 0.24 kg of rice husk is needed for 1 kg of moist manure within the ideal range. The daily manure amount obtained from the enterprise and the rice husk needed for the mixture have been calculated. It has been determined that 1075 kg of manure will be collected daily from the facility, and 258 kg of rice husk will be needed daily to achieve the ideal moisture content and C/N ratio range in the compost mixture. It has been determined that 480 tons of compost will be produced annually due to compost production from the facility. The amount of compost to be obtained during the maturation process and other calculations are provided in Table 8.

**Table 8.** Compost production calculations

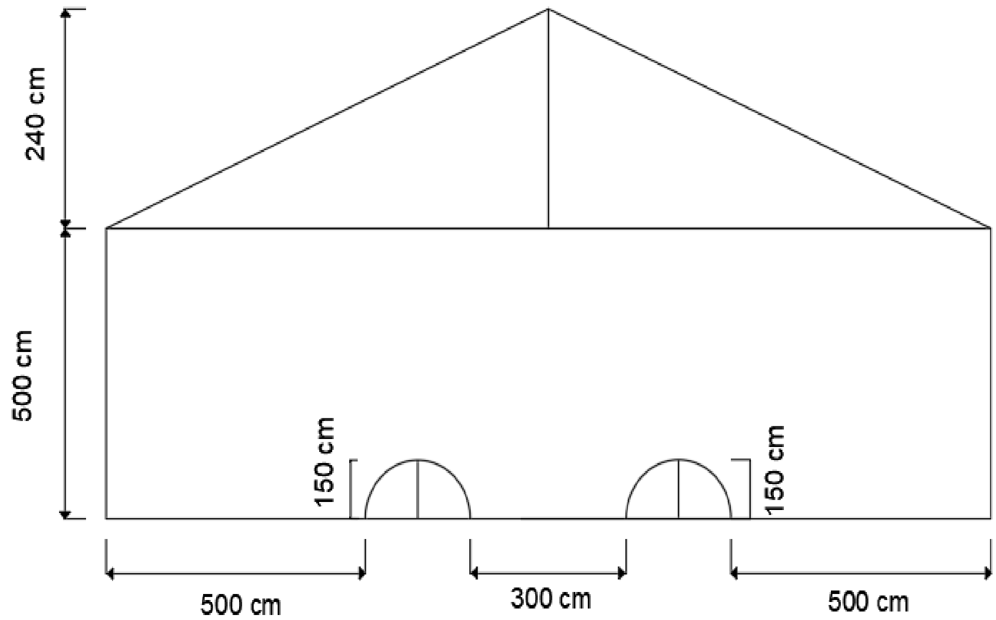
| Daily Manure Production in the Hen House (kg/day) | Daily Collectible Manure Amount (kg/day) | Required rice husk amount (kg/day) | Total Mixture Amount (kg/day) | The amount of compost that will accumulate during the maturation period (tons) | Annual accumulated compost amount (tons) |
|---|---|---|---|---|---|
| 1536 | 1075 | 258 | 1333 | 60 | 480 |

Özbek and Uçaroğlu (2022) aimed to compare the yields of the mixtures formed by separately composting cattle, horse, and chicken manure with sunflower stalks and to determine the best animal manure. The study created a mixture of 80% animal manure and 20% sunflower stalk within three different composts. As a result of the study, the highest yield was achieved with compost made from cattle manure, while the lowest yield was achieved with horse manure. They have concluded that composting animal manures with different regulatory substances and mixing ratios will yield higher efficiency mixtures and that the composts can be used in agriculture.

A design has been created considering the maturation period of the compost mixture to be obtained from the facility. Within the design scope, 60 m3 of the mixture will be stored in two piles, each 1.5 m high, 2 m wide, and 10 m long. The implemented design is shown in Figure 2.




(a)




(b)

**Figure 2.** Compost Facility Design. (a) Compost facility 2D drawing; (b) Compost facility cross-section

The installation of the compost facility involves an initial investment cost of 4900328 TL. In addition, there is an annual maintenance and material cost of 2571732 TL. The initial investment cost and annual cost amounts required to establish the facility are provided in Table 9 (Bilgili et al. 2011; Anonymous 2025a).

**Table 9.** Initial investment and annual costs of the compost facility

| First Investment | Price (TL) | Annual Expenses | Price (TL year$^{-1}$) |
|---|---|---|---|
| Porch | 216350 | Personel expense | 1302356 |
| Machines | 2693558 | The maintance and repair of the facility | 9952 |
| Floor | 1125020 | Repair and maintenance costs of the machines | 80915 |
| Construction and similar expense | 216350 | Energy expense | 141709 |
| Labor and Engineering Services | 649050 | Regulator material | 1036800 |
| Total | 4900328 | Total | 2571732 |

As a result of selling the amount of compost obtained from the enterprise, an annual economic gain of 6000000 TL is achieved (Anonymous 2025b). The compost facility's initial investment and annual expenses can be amortized by the end of the second year. After the second year, the amount of profit obtained each year increases, and at the end of 15 years, an economic gain of over 40 million TL is achieved for the enterprise. The income and expense situation of the compost facility over the years is provided in Table 10.

**Table 10.** Long-term income and expense status of the compost facility

| Year | Income (TL) | Expense (TL) | Profit (TL) |
|---|---|---|---|
| 0 | x | 4900328 | x |
| 1. year | 6000000 | 2571732 | x |
| 2-6 years (5 years) | 30000000 | 12858661 | 15669279 |
| 7-14 years (8 years) | 48000000 | 20573858 | 27426142 |
| Total | 84000000 | 40904579 | 43095421 |

*3.1.3. Biogas Production Facility*

The potential biogas production amount was determined using the organic manure produced from the hen house. The manure to be collected annually from the hen house is 392.44 tons (Table 7). As a result of the calculations, an annual production of 30610 m$^3$ of biogas will be achieved. The amount of biogas to be obtained from the chicken manure in the facility is given in Table 11.

**Table 11.** The amount of biogas produced from chicken manure in the hen house

| Number of Animals | Annual Collectible Manure Amount (tons) | Amount of Biogas Produced (m$^3$ year$^{-1}$) | Energy Value (MJ/year) |
|---|---|---|---|
| 12000 | 392.44 | 30610 | 494208 |

As a result of converting biogas from chicken manure into electricity, an annual production of 143867 kWh can be achieved. An economic gain of 412898 TL is achieved annually with the electricity produced. The amount of electricity to be produced as a result of biogas production and the economic analysis are provided in Table 12.

**Table 12.** The amount of electricity to be produced from the henhouse and its economic analysis

| Monthly electricity production amount (kWh) | Daily electricity production amount (kWh) | Monthly Earnings (TL) | Daily Earnings (TL) |
|---|---|---|---|
| 11988 | 399 | 33936.82 | 1131.22 |

The biogas facility to be established has an initial investment cost of 926263 TL. In addition, the facility incurs annual maintenance and operating costs amounting to 257140 TL. Considering the biogas plant's initial investment and annual costs, it can amortize itself over 6 years. After the process of amortizing the investment costs of the facility is completed, an annual economic gain of 155758 TL will be achieved. The initial investment cost and annual cost amounts required for establishing the facility are provided in Table 13 (Yaldız and Sözer 2005).

**Table 13.** Biogas facility investment costs

| Investment | Price (TL) | Unit |
|---|---|---|
| Producer costs | 548164 | 1302356 |
| Generator costs | 194059 | 9952 |
| Devices costs | 184040 | 80915 |
| Operating costs | 257140 | 141709 |

There are similar studies on biogas production in animal enterprises such as Gümüşçü and Uyanık (2010) determined the potential for obtaining biogas from manure produced in cattle shelters in the Southeastern region of Turkey. When determining the biogas potential, they based their calculations on the fact that a minimum of 25 kg and a maximum of 35 kg of manure can be obtained daily from cattle enterprises. As a result of the calculations, they determined that an enterprise with 1500 cattle would produce a minimum of 2093850 kWh and a maximum of 3664238.4 kWh of electricity annually. They concluded that an average economic gain of 576000 TL would be achieved through electricity production from the operation.

Similarly, Taşova (2017) determined the biogas potential to be produced from the manure obtained from poultry in Tokat province between 2010 and 2014 in their study. In result, they determined that a total of 30263 tons of manure would be collected across the province over 5 years, and 2360478 $m^3$ of biogas could be produced. They concluded that 11094,247 kWh of electricity can be produced from the amount of biogas obtained in the province.

*3.2. Proposed Cleaner Production Designs for Natural Resource Use in Hen Houses*

*3.2.1. Water Conservation*

One of the methods that can be used to save water in a laying hen house is rainwater harvesting. With the implementation of the rainwater harvesting method in the facility, an average of 266.96 $m^3$ of water is harvested annually. To meet the needs of the animals in the barn, an annual water requirement of 1971 $m^3$ is needed. Therefore, it has been determined that by using rainwater harvesting methods, the amount of water collected can meet 13.5% of the annual water requirement.

Calculations were made to determine the water tank size in the system, considering December, the month with the highest rainfall. In this context, a water tank with a volume of 40 $m^3$ is planned to be used. The design of the rainwater system is provided in Figure 3.

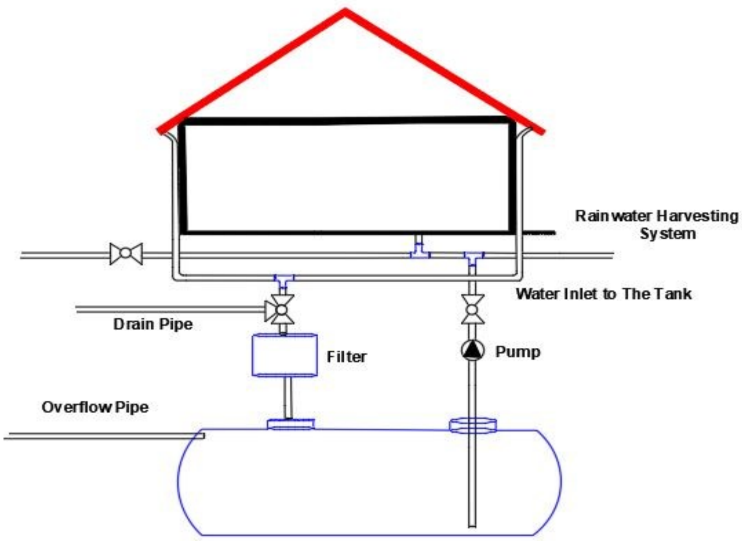



**Figure 3.** Rainwater harvesting system design

With the annual collection of 266.96 $m^3$ of water from the henhouse, an annual savings of 8011 TL on the water bill is achieved. A capital investment of 144220 TL is required to install the system in the henhouse.

Therefore, with the profit from the water fee, the system can amortize itself over an 18-year year. The list of materials and prices required for the system's installation is provided in Table 14 (Anonymous 2025 d,e,f).

**Table 14.** Material and price list for rainwater harvesting system installation

| Materials | Price (TL) |
|---|---|
| 40-ton galvanized modular water tank | 120000 |
| Polyethylene (HDPE) Vortex Rainwater Filter (YFVR-0200) | 18260 |
| Clean Water Submersible Pump | 5960 |

*3.2.2. Energy Conservation*

Chickens are quickly affected by climatic conditions, so it is important to maintain the indoor environmental conditions in the hen houses at the best level for the chickens. Heat and humidity balance calculations were conducted for the hen house where the study was conducted. As the first step in the calculations, the surface areas of structural elements such as the total window area, door area, wall surface, and roof surface that could cause heat loss from the hen house have been determined. After determining the building elements' surface areas, the heat losses experienced in the operation were calculated in the second stage. As a result of the calculations, there is an excess heat of 51144.75 Kcal hour$^{-1}$ in the indoor environment of the hen house because the amount of heat emitted by the chickens is greater than the amount of heat lost. Therefore, it has been determined that mechanical ventilation should also be utilized to increase the amount of ventilation to provide the ideal airflow to expel excess heat and humidity from the structure and create ideal conditions for the chickens. The calculations carried out to determine the heat and humidity balance for the hen house are presented in Table 15.

**Table 15.** Calculations of the heat and humidity balance inside the hen house

| Parameters | Amount of Heat | Unit |
|---|---|---|
| Amount of Heat in the Environment | | |
| The total amount of heat emitted by the chickens into the environment | 140188.8 | Kcal hour$^{-1}$ |
| Heat Losses | | |
| The amount of heat that will be lost through natural ventilation | 67532.01 | Kcal hour$^{-1}$ |
| Heat loss through the wall | 12645.67 | Kcal hour$^{-1}$ |
| Heat loss through the window | 3454.5 | Kcal hour$^{-1}$ |
| Heat loss through doors | 930.3 | Kcal hour$^{-1}$ |
| The amount of heat loss allowed from the roof | 4481.57 | Kcal hour$^{-1}$ |

Lighting in hen houses is an important source of energy consumption. A comparison of fluorescent and LED lamps used to light the henhouse was conducted. As a result of the comparison, it was determined that LED lamps provide an annual savings of 1927.68 KW due to their similar light intensity compared to fluorescent lamps despite their low power consumption. An annual savings of 27.87% is achieved in the electricity consumption required for the facility's lighting. In addition, LED lamps' greater durability than fluorescent lamps and their lower environmental pollution also significantly influence their preference (Ataç 2013; Demir et al. 2020). The technical comparison of LED and fluorescent lamps in the hen house is provided in Table 16.

**Table 16.** Technical comparison of LED and fluorescent lamps

| Parameters | Fluorescent | LED |
|---|---|---|
| Bulb Lifespan (Hours) | 13000 | 30000 |
| Light Intensity (Lumen) | 2500 | 2200 |
| Bulb Power (W) | 36 | 22 |
| Number of Armature | 33 | 39 |
| Number of Lamp | 33 | 39 |
| Total Consumption (KW Year$^{-1}$) | 6937.92 | 5010.24 |
| Energy Savings Rate | %27.87 | |

Dursun (2014) conducted a study to determine the effects of using fluorescent and LED lamps for lighting in laying hen houses on the productivity of laying hens. It has been determined that using LED or fluorescent lamps in laying hen farms has an insignificant effect on animal productivity. However, LED lamps are more economical due to their long lifespan and energy-saving properties. As a result of the study, it was predicted that the use of LED lamps in the hen house would increase due to their positive aspects compared to fluorescent lamps.

Genç et al. (2017) aimed to determine the effect of fluorescent and LED lamps on growth performance in a broiler chicken house with a capacity of 216 animals. In the study, they divided the animals into three different groups. While illuminating the animals in the first group with different LED lights, they illuminated the animals in the second group with a cool white LED lamp and the animals in the third group with only a fluorescent lamp. As a result of the study, it was found that there was no difference in the growth performance of animals illuminated with LED and fluorescent lights, but due to the advantages of LED lamps, they could be used in broiler farms.

The enterprise achieves an annual economic gain of 5494 TL using LED instead of fluorescent lamps. Due to the higher prices of LED lamps, the initial investment cost is 10611 TL higher than that of fluorescent lamps. However, with the use of LED lamps, the difference in the initial investment cost can be amortized in approximately 1.9 years through the annual savings achieved. In addition, the fact that LED lamps have a lifespan twice as long as fluorescent lamps results in additional savings on lamp replacement costs. The costs of LED and fluorescent lamps are provided in Table 17 (Anonymous f,g,h).

**Table 17.** Cost comparison of LED and fluorescent lamps

| Investment | Fluorescent | | | LED | | |
|---|---|---|---|---|---|---|
| | Number | Unit Price (TL) | Price (TL) | Number | Unit Price (TL) | Price (TL) |
| Armature | 33 | 410.4 | 13543 | 39 | 410.4 | 16005 |
| Lamp | 33 | 155 | 5115 | 39 | 263.2 | 10264 |
| Automation Cost | 16500 | | | 19500 | | |
| Total (TL) | 35158 | | | 45769 | | |

The lengths of the LED lamps planned to be used in the facility are 150 cm. While installing the lamps in the facility, 39 will be used, with nine between each row and three at the entrance. The layout design of the lamps within the facility is provided in Figure 4.

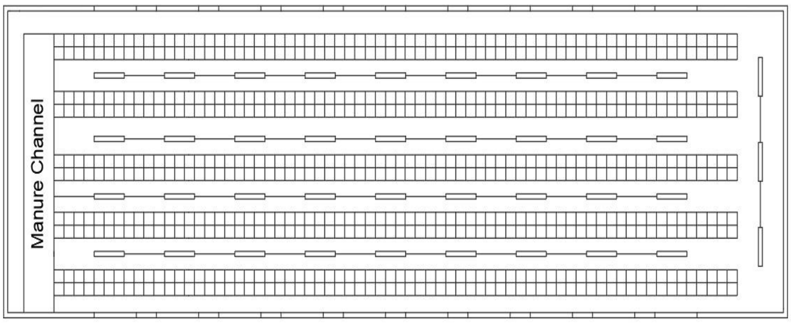



**Figure 4.** Design of the layout of LED lamps in the enterprise

*3.3. Cleaner Production Design for Reducing Emissions from Hen Houses*

*3.3.1. Reorganizing the Feed Ration*

The feeding process in hen houses significantly impacts animal productivity and environmental pollution. Most enterprises use ready-made feeds, making it possible to reach multiple different crude protein feed rations. Calculations were carried out to compare the amount of $NH_3$ emissions that could arise from using two different feed rations with 14% and 16% crude protein in the laying hen house where the study was conducted. As a result of the comparisons, we have concluded that using a feed ration with 14% crude protein in the enterprise will lead to a 12.37% reduction in $NH_3$ emissions compared to a feed ration with 16% crude protein. The comparison results of two different feed rations are presented in Table 18.

**Table 18.** Comparison data of two different feed rations

| Parameters | Feed Ration | |
|---|---|---|
| | 14% protein feed ration | 16% protein feed ration |
| The daily amount of $NH_3$ emitted by a chicken (gr) | 3.4 | 3.88 |
| Daily $NH_3$ emission from the hen house (gr) | 40800 | 46560 |
| Daily $NH_3$ Savings Amount (gr) | 5760 | |
| Daily $NH_3$ Savings Amount (%) | 12.37 | |

*3.3.2. Design of Windbreaks*

Windbreaks within the cluster where the work is being carried out have been planned to reduce the impact of the wind. It has been decided to use shrubs or narrow-crowned deciduous tree species for these types of trees. Windbreaks have been designed in an L shape along the long and short sides of the facility, considering the prevailing wind direction. The trees will be planted with a one-meter spacing between them and a 3.5-meter spacing between rows (Table 6). The trees will be planted in two rows. One hundred thirteen trees will be planted, with 60 in the first row and 53 in the second. The design of the windbreaks planned for the hen house is shown in Figure 6.

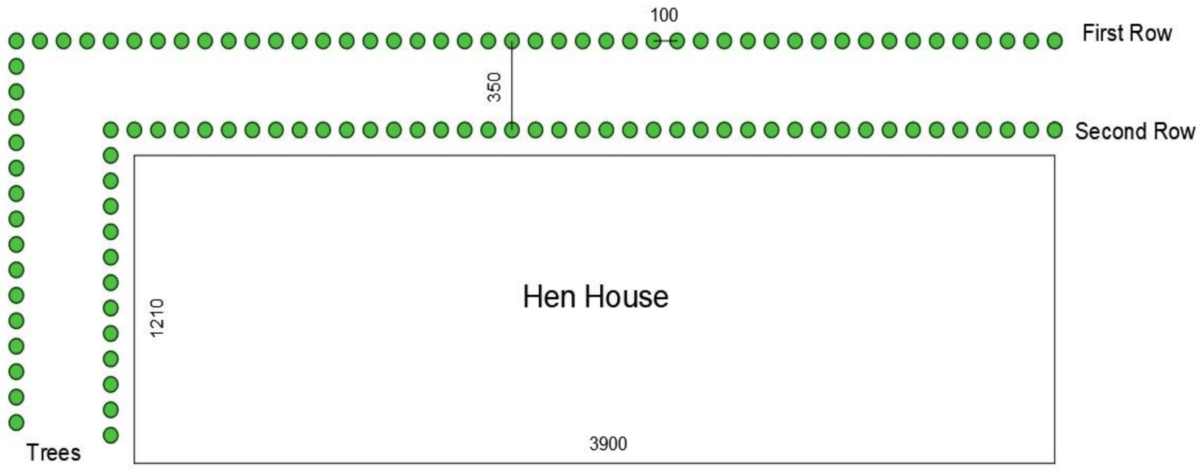



**Figure 6.** Windbreak Design

*3.4. Cleaner Production Recommendations for Worker Health and Safety in Hen House*

Due to the exposure of workers in the livestock sector to high noise, polluting gases and dust, manure, feed, viruses, and adverse thermal comfort conditions, some negative effects arise. Due to exposure to such negative factors, respiratory diseases, skin diseases, hearing loss, and many other ailments are observed in employees. In order to prevent such adverse situations, various measures need to be taken by considering cleaner production techniques. These are as follows (Choiniere and Munroe 1997; Schiffman et al. 2006; Altan et al. 2009; Kılıç and Arıcı 2013; TS EN 12464-1 2013; Anonymous 2015b; Olgun 2016; Türkoğlu et al. 2018; Kılıç 2021; Yaylı and Kılıç 2021);

- Employees must regularly use masks and similar personal protective equipment, and the managers in the workplace must ensure that employees are consistently using protective equipment.
- In hen houses, it is necessary to comply with the required exposure standards for pollutants such as $NH_3$ (short-term exposure limit 50 ppm, long-term exposure limit 20 ppm), $H_2S$ (limit value 70 ppb), $CO_2$ (short-term upper limit value 30000 ppm), and similar gases.
- Periodic health checks should be conducted for employees.
- It is necessary to provide climatic conditions such as 10 °C – 25 °C and relative humidity of 65% - 80% in the hen houses.

- To prevent the impact on employees' psychology and workplace accidents, an appropriate distribution of light intensity in workplace lighting should be ensured (a band at least 0.5 m wide surrounding the area within the field of view of the work area).
- Employees must be vaccinated to prevent disease transmission from animals to humans.

As a result of the regular use of equipment, skin diseases, hearing loss, and respiratory diseases can be prevented to a certain extent. Employees' good physical and psychological health will also positively contribute to the efficiency of the enterprises. Implementing clean production practices in poultry farms aims to reduce environmental pollution to the lowest level while enhancing employee health and safety.

## 4. Conclusions

As a result of study, with the income generated from compost production, the initial investment costs of the compost facility to be established for the enterprise are amortized over two years. As a result of generating electricity from the biogas obtained from the facility, it has been determined that the initial investment cost and annual expenses will be amortized over 6 years, and an annual profit of 155758 TL will be achieved in the subsequent period. In this context, it has been determined that using the manure obtained from the hen house in compost production is more advantageous in terms of the economic profitability of the enterprise.

It has been determined that establishing a rainwater harvesting system at the facility will result in an annual water saving of 266.96 $m^3$ and meet 13.5% of the facility's annual water needs. It has been determined that the facility's ventilation should be increased to eliminate excess heat in the enterprise. Another important issue in the hen houses is lighting. Proper lighting is a vital issue for animal welfare and economic conditions. In this context, the amount of energy savings and economic profitability that would occur if LED lamps were used instead of fluorescent lamps in the facility has been determined. In the case of using LED lamps instead of fluorescent lamps, an annual energy saving of 27.87% and an economic gain of 5494 TL can be achieved. It has been determined that the difference in the initial investment cost resulting from using LED lamps will be amortized over 1.9 years. It was concluded that using a feed ration with 14% crude protein in the enterprise would lead to a 12.37% reduction in $NH_3$ emissions compared to a feed ration with 16% crude protein.

With the implementation of clean production techniques in various activities in the hen houses, a decrease in the rate of enterprise-related environmental pollution is observed while also resulting in additional economic gains. In addition to this situation, by using cleaner production techniques, the working conditions in enterprises can be improved, and the effects that cause diseases can be reduced, thereby preventing many ailments such as respiratory diseases, skin diseases, hearing loss, and similar issues that can be seen in employees. As a result of the study, it was concluded that the increased use of cleaner production techniques in hen houses could significantly reduce the negative impacts caused by the livestock sector due to the numerous benefits of these techniques.

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