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Optimization of spatial utilization efficiency of captive Hu sheep based on multi-objective programming model

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Abstract: Hu sheep is an excellent breed of sheep for lambskins. Usually, to obtain greater economic benefits, the breeding of Hu sheep has certain standard sheep pens. According to gender and growth stage, Hu sheep were raised in groups. Different stages, genders and sizes of sheep have different requirements for space, so the number of sheep in each pen is determined by the factors mentioned above. This paper mainly studies the problem of space utilization in the process of Hu sheep breeding. In this paper, the multi-objective programming model, Monte Carlo model and dynamic programming are established and solved, and the specific production plan is given, so as to better solve the problem of space utilization and improve the operating efficiency. This paper first analyzed the data. According to According to the 20-day natural mating period, 149-day pregnancy period, 40-day lactation period, and 20-day postpartum period, it can be determined that the complete production cycle of a ewe is 229 days. Then determine the constraints and the objective function, establish the linear programming model to determine the reasonable number of breeding rams and ewes, and then calculate the total demand for sheep cotes and the maximum annual number of sheep to be slaughtered.

1. Introduction

Many scholars at home and abroad have done a lot of research on the captive breeding of Hu sheep. Taking the Hu sheep breeding industry in Wubao County, Shaanxi Province as the research object, Song Yu et al [1] proposed a new breeding mode for the breeding of Hu sheep, and analyzed the benefits under the mode, which achieved better results. Liu Shaoming [2] studied the breeding technology of Hu sheep and analyzed various aspects such as the site selection of the sheep factory, sheep house requirements, feeding grass, breeder management, ewe management, and reproduction technology of Hu sheep. The goal of building digital, mechanized, modernized, standardized, and intelligent breeding was proposed. Li Peng et al [3] elaborated on the development opportunities and development effectiveness of the Huzhou Hu sheep and analyzed the problems in its development, putting forward development strategies and recommendations to promote the high-quality development of the Huzhou Hu sheep industry. Xu Hongying [4] discussed the problems in the breeding of Hu sheep and the scientific breeding technology, laying a solid foundation for the sustainable development of the Hu sheep breeding industry. Wei Changliao [5] proposed that large-

scale Hu sheep breeding has become an important choice in the adjustment of animal husbandry structure. Scientific and reasonable breeding management methods are gradually developing towards intensification, scaling, and standardization. At the same time, in large-scale breeding, disease prevention and treatment should be made well to fundamentally promote the development of the large-scale Hu sheep breeding industry.

Based on the above research, this paper focuses on the optimization of space utilization in the captive breeding of Hu sheep in a Hu sheep farm. When raising Hu sheep in captivity, managers need to rationally allocate the sheep according to the gender, size, growth stage, and other factors to improve the economic benefits under the premise of ensuring the safety and health of the Hu sheep. In actual operation, although there are many other factors to be considered, space utilization is a relatively independent and important issue that affects the operational efficiency of the farm.

The data in this article is sourced from the China Undergraduate Mathematical Contest in Modeling official website. The study in this paper determines the reasonable number of breeding rams and ewes on the farm, determines the production cycle of a single ewe, then calculates the annualized demand and output of sheep pens. According to the output of sheep pens, a specific production plan is formulated, and the range of annualized sheep pens is estimated, which can be turned out on an annualized basis, regardless of all the uncertainties, such as disease, climate, and the culling of breeding sheep. In the process of research, it is necessary to develop a specific production plan to achieve the annualized number of sheep that can reach the maximum value. First of all, it is necessary to determine the timing of breeding according to the growth stage of the Hu sheep, and then calculate the number of the breeder rams and basic ewes in different periods according to the growth rate of the Hu sheep. Then, depending on the growth stage of the Hu sheep, the use of sheep pens is determined. Finally, the timing and number of the breeder rams and basic ewes, as well as the use of sheep pens, can be calculated to achieve the maximum number of sheep in the annualized slaughter.

2. Analysis of mathematical problems in captive breeding of Hu sheep

Hu sheep breeding generally needs to go through two main links, reproduction and fattening. Hu sheep reproduction mainly adopts natural mating between rams and basic ewes. In principle, a basic ewe can be bred according to the law of 3 births in 2 years. The basic ewe needs to breastfeed the lambs for a period of time after giving birth, and then the lambs need to be bred independently for 7 months. Without considering the mating ability of rams, breeding rams and ewes are usually kept in a ratio of 1:50. To improve economic efficiency, it is necessary to control the lactation period and postpartum period of Hu sheep to realize continuous production and improve the economic efficiency of the farm.

The standard pen specifications for a Hu sheep farm we studied are as follows: no more than 14 basic ewes per pen during the postpartum period; no more than 4 breeding rams per pen during the non-mating period; 1 breeding ram and no more than 14 basic ewes per pen during the natural mating period; no more than 8 ewes per pen during the pregnancy period; during the lactation period after delivery, no more than 6 ewes and their lambs per pen; no more than 14 lambs per pen during the fattening period. In principle, sheep at different stages should not be penned together. To ensure the benefits, the farm managers need to optimize the space utilization by developing a production plan, that is, to determine when to start mating the number of basic ewes that can be mated, control sheep breeding, and thus adjust the demand for sheep pens. To ensure that there are enough sheep pens, while minimizing the number of unused pens.

The natural mating period is 20 days, without taking into account uncertainties and replacement of breeding sheep. The ewes can be pregnant for 149 days, with 2 lambs per litter, 40 days of lactation,

210 days of lamb fattening, and 20 days of postpartum period. The Hu sheep farm has 112 standard pens and is capable of continuous production. The farm wishes to produce no less than 1500 sheep per year.

Estimating the shortfall in the number of standard pens available, we can determine that the working cycle of ewes is 229 days. We consider that n basic ewes are allowed to enter the mating period and immediately enter the next working cycle after the resting period. It is uniquely determined how many pens this n ewes and the lambs they produce will use at each period during this cycle. If there is only 1 batch of repeated back and forth, the number of pens used is bound to fluctuate greatly. Increasing the number of batches can make the use of pens more evenly. We estimate the ideal state that after alternating between batches, the number of integrated pens used becomes an approximate constant function of time. Then the average number of pens occupied by the batch can be found out, and the annualized number of pens is positively correlated with the number of ewes. Threrfore, the number of pens per ewe can be derived under different decisions. The range of the number of sheep in 112 pens can be obtained by letting n be from a fixed range, and the number of pens needed in addition to the number of sheep to reach the annualized number of 1500 sheep can also be estimated. In this paper, the visual analysis using Monte Carlo simulation can be obtained as shown in Fig 1.

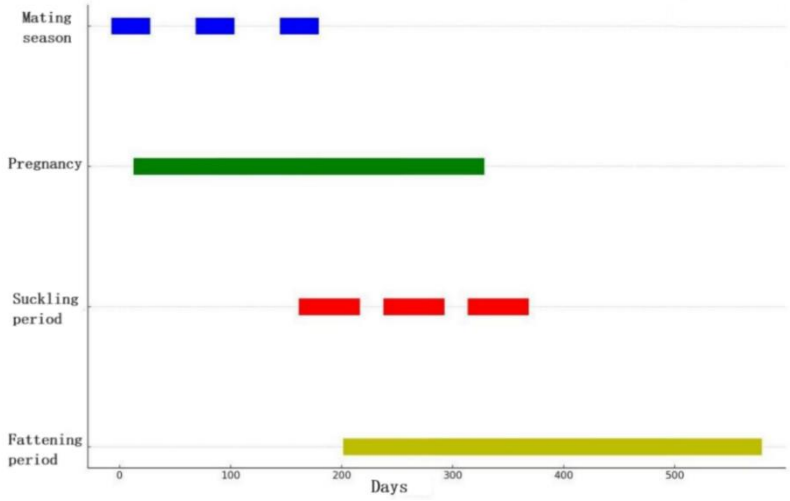

Figure 1: Use of sheep pens at different growth stages

3. Establishment and Solution of Mathematical Model of Hu sleep breeding

3.1 The establishment of the Mathematical model

One ram working for 20 days corresponds to 14 ewes working for 229 days. If the mating ability of the ram is utilized as much as possible during the steady state period, the ratio of rams to ewes should be set at 1:160, which is much lower than 1:50. Therefore, rams are bound to be out of work for a long period, whereas lambs are produced by ewes, so the number of lambs in the pen is dependent on the number of ewes. Overall, rams are fewer in number and occupy a much smaller number of pens than ewes, so the number of pens occupied by rams is not taken into account in the estimation, only the number of pens needed for ewes and lambs is considered.

For ease of calculation, we mated a fixed number of ewes at fixed intervals of days, and ewes entering the mating period at the same time are called ewes in the same batch, so the decision we need to make is to determine the duration of the intervals and the number of ewes in each batch[6], and we have put the durations of various states of rams, ewes, and lambs and the requirements for the number of pens as shown in Table 1.

Table 1: Different states of the various species of sheep

	State of affairs	Duration (days)	Standard sheep pen requirement
Ram (male sheep)	Mating period	≥20	1 RAM with no more than 14 foundation ewes
	Non-mating period	≥0	No more than 4 rams
Ewe	Mating period	20	1 RAM with no more than 14 foundation ewes
	Duration of pregnancy	149	No more than 8 pregnant ewes
	Lactation period	40	No more than 6 lactating ewes with their lambs
	Rest period	20	No more than 14 foundation ewes
Lambs	fattening period	210	No more than 14 covered sheep

In order not to overlap the mating periods, we consider the interval days greater than the mating period of 20 days, it may be appropriate to take 20 days as an example. The status of ewes of each batch in such a production model for each period is shown in Table 2.

Table 2: Time of different states of ewes in each batch

State of affairs									
Consig-nment	Mating period	Duration pregnancy	Lactation period	Rest period	Mating period	Duration pregnancy	Lactation period	Rest period	…
1	1-20	21-169	170-209	210-229	230-249	250-398	399-438	439-458	…
2	21-40	41-189	190-229	230-249	250-269	270-418	419-458	459-478	…
3	41-60	61-209	210-249	250-269	270-289	290-438	439-478	479-498	…
4	61-80	81-229	230-269	270-289	290-309	310-458	459-498	499-518	…
…	…	…	…	…	…	…	…	…	…
Number of days									

3.2 The resolution of the Mathematical model

In the course of the study, the batch was noted as k and the number of days between adjacent batches was $g \geq 20$. When the number of ewes x in each batch was determined, the production plan was obtained. According to the time sequence, the four states of ewes were recorded: the mating period, the pregnancy period, the lactation period, and the rest period were noted as P_1=20, P_2=149, P_3=40, P_4=20, respectively[7].

The maximum number of lambs that can be accommodated in one standard lamb pen in each state is n_1=14,n_2=8,n_3=6,n_4=14, and the fattening period of lambs P_5=210, with a maximum of n_5=14 fattening lambs per pen. To maximize production efficiency, when a full cycle is completed in 229 days, it immediately move on to the next cycle[8]. Then each batch has 4 critical nodes, and the critical nodes of each batch are interleaved to form different phases. At each phase, the sheep of each batch will be in different periods, with different demands on the standard pens. The lambs will need to occupy the pens for a long period after lactation. After entering the stabilization period, the various states of ewes in each batch are interleaved to form the 229-day cycle, but the states of each batch in that one cycle differ by only one translation, which is essentially equivalent. Therefore, only the case

of a single cycle needs to be considered in the estimation[9].

First, calculate the total number of days of pens required when the number of ewes in each batch x is calculated for a full working cycle of 229 days.

$$A = \frac{20p_1}{n_1} + \frac{149p_2}{n_2} + \frac{40p_3}{n_3} + \frac{20p_4}{n_4} + \frac{210p_5}{n_5} \tag{1}$$

Next, calculate the annualized number of ewes to be slaughtered B when the number of ewes per batch x is calculated based on 3 litters in 2 years for a full work cycle of 229 days.

$$B = 2x \times \frac{3}{2} = 3x \tag{2}$$

Finally, calculate the number of sheep pen gap as D according to the annual number of 1500 sheep.

$$D = \frac{1500A}{229B} = 112 \tag{3}$$

Taking $x \in [30,60]$, It can be calculated that the annualized number of sheep ranges from [1160,1320], and the range of sheep pen gap is [15,30].

The solution results of a Hu sheep captive breeding model are verified, and the calculation results can well meet the demand. The model established in this paper has good applicability and can be popularized to achieve good economic benefits.

4. Conclusions

Taking a Hu sheep farm as the research object, the range of annualized number of sheep slaughtered was calculated by establishing a linear programming mathematical model.

The validated linear regression model is a simple and easy-to-implement model. It uses ordinary least squares to fit the data, and the calculation process is relatively intuitive. The form of linear regression model is intuitive, which can clearly reflect the linear relationship between independent variables and dependent variables. This makes the model highly interpretive and helps in understanding the relationship between the variables. The calculation is efficient and results can be obtained quickly.

Through the study in this paper, the range of annualized number of sheep under a specific number of standard sheep pens was simulated. The results of the study are of good practicality and provide good guidance to the breeding methods of Hu sheep farms, under which mode, superior economic benefits can be achieved.

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