Research Article

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Optimization of sustainable corn–cattle integration in Gorontalo Province using goal programming

https://doi.org/10.1515/opag-2022-0405
received July 9, 2024; accepted December 4, 2024

Abstract: Farmers cannot achieve the optimum profits using an integrated system in corn and cattle farming because they are not utilizing their resources in the best way possible. Therefore, finding better ways to use farm waste as animal food and cow manure as corn plant fertilizer is of utter importance. Goal programming enables a combination of production because it can complete several goals simultaneously. To the best of our knowledge, this type of analysis has not been used in previous livestock crop integration studies. Our study aims to (1) determine the optimal production combination in corn–cattle integration and (2) analyze the optimal allocation of resource use in corn–cattle integration. A total of 66 corn–cattle farmers were interviewed for this study. Data were analyzed through a goal programming model using Linear Interactive and Discrete Optimizer. The results indicate that (1) the optimal production combination with profit targets, production costs, and production risks in corn–cattle integration is met, but the achievement value obtained is still below the target, where the best optimal production combination is 14,693 kg of corn, 18 cows, 3,061 kg of corn waste, and 6,087 kg of compost. (2) In the corn–cattle integration system, the best way to use resources is to increase the supply of medicine, land, and labor by one unit. This is true even if those resources are scarce. The sensitivity interval for the optimal use of production resources in the corn–cattle integration system with the target of profit, cost, and production risk can be increased by 1% from the amount of resources used to infinity and can be reduced by 4–16% of the amount of resources used. To be more food secure, independent, wealthy, and able to support ecosystem sustainability in rural areas, farmers should set up an integrated corn–cattle system with the right mix of output and resource allocation.

Keywords: optimization, integration, corn, beef, sustainable

1 Introduction

Using fertilizer is currently an important problem in Indonesia's agricultural sector. The reason is that the amount of fertilizer is not proportionate to the existing demand; thus, farmers' fertilizer needs in Indonesia are 13 million tons annually, but Indonesia can only produce 3.5 million tons annually, and the remaining 6.3 million tons are imported. As explained in the literature [1], if not handled well, the problem of fertilizer scarcity will become serious because it will affect the food crisis, making the food prices soar in Indonesia.

Fertilizer is an important factor in assisting plant growth and providing a sufficient amount of fertilizer will help achieve the maximum quantity and quality of plants [2]. In addition, not enough fertilizer will result in a suboptimal harvest and crop failure [3].

One solution to overcoming fertilizer scarcity is to implement a crop–livestock integration (CLI) system, namely integrated farming through a low external input approach between agricultural crop commodities and livestock [4]. The plant–livestock integration system will produce waste that must be managed, because apart from reducing environmental pollution [5], it will also provide added value from the waste [6].

One type of CLI is corn–cattle. Corn straw, which has been considered waste, turns out to have a nutritional value close to the nutritional value of elephant grass and is quite popular with cattle [7]. Apart from that, other waste such as cobs and fruit peels can be processed into forage for cows. Cattle waste in the form of solid and liquid

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manure can be processed into compost and liquid fertilizer, which can reduce the use of inorganic fertilizer while increasing farmer income by 29.5% than without the use of organic fertilizer [8,9].

Corn is the main commodity developed in Gorontalo Province. In 2015, corn production was 643,512 tons. Meanwhile, beef production was 2,913,750 kg in 2022 [10]. This proves that Gorontalo Province has the potential to implement a corn–cattle integration system. This area has a high potential for utilizing feed from agricultural waste, namely 2471.77 tons compared to the feed requirement of 439,884, and it has an Agricultural Waste Carrying Capacity Index (IDDLP) of 5.62, indicating it is in the very safe category for animal feed [11].

In reality, only a few farmers are working on an integrated corn–cattle system in Gorontalo. Although most of them also raise cattle in addition to cultivating corn, the management is traditional. There is no synergy between corn plants and cattle, where livestock manure has not been used as fertilizer, and corn plant waste has not been used as animal feed; in fact, it has only been burned. Apart from that, the implemented system of integrating corn with cattle is not in accordance with the established implementation principles, that is, corn plant waste is used as forage, but cow dung waste has not been utilized as liquid fertilizer or compost. These two processes are only run individually, which causes high production costs and the amount of production produced by both is not optimal [12]. According to Irham et al. [13], the high cost of corn farming is caused by the purchase of expensive inorganic fertilizers, and sometimes farmers expect fertilizer assistance from the government. In addition, the increase in body weight of cows is not optimal because farmers have difficulty obtaining feed for livestock. The suboptimal production of corn and beef is also caused by pest attacks and a prolonged El Nino climate. Therefore, corn and cattle farming experiences high production risks [14], which will cause a decrease in production and have an effect on price fluctuation.

The CLI system is a way of implementing the concept of integrated agriculture by seeking resources that come from the agricultural system itself, and using very minimal production resources from outside the agricultural system [15,16]. The main goal of integrated agriculture is to build a productive and profitable farming system [17]. Optimizing the use of agricultural waste as animal feed and the use of cow manure as fertilizer for corn plants is important to develop, considering that the use of resources in the plant–livestock integration system is not yet optimal [18]. Apart from that, one of the advantages of implementing a CLI system is reducing business risks [19].

Optimization problems can be solved using various analytical tools, such as linear programming, or regression using Cobb–Douglass production function analysis [2,20]. To use resources with a dual-purpose program, goal programming is employed [21]. Goal programming is a modification or special variation of linear programming, so all assumptions, notation, mathematical model formulation, model formulation procedures, and solutions are not different. The only difference lies in the presence of a pair of divisional variables (both negative and positive), which will appear in the goal function and the goal or target constraint functions [22]. The goal programming model is able to solve linear programming cases that have more than one goal to be achieved [23]. For this reason, it is important to use this approach to analyze the optimal product combination and optimal allocation of resources in the corn–cattle integration system.

Several previous studies on livestock crop integration have been carried out, such as the study by Stark et al. [24] examined the implementation of CLI, which utilizes the synergy between livestock crop systems, resilience, efficiency, and productivity; Widiastuti et al. [25] examined the impact zero-waste model for corn–cattle integration efforts. Conducted peatlands management for sustainable use for the integration of maize and cattle in a circular agriculture system. Imran et al. [26] compared corn farming income with integrated and non-integrated systems. In addition, Imran [27] investigated the production and income risks of system integration, and Grinnell et al. [15] examined the integration of palm oil and cow oil as a strategy to improve resource use efficiency in plantations and beef self-sufficiency.

Several goal programming studies have also been conducted in the past: Liu [28] conducted a study on goal orientation, social capital, and entrepreneurial intentions; Widiastuti et al. [29] examined a stability analysis of maritime inventory route re-planning, and researchers [30–32] examined the application in the health sector; and Lu and Tsai [33] in the computer sector. Adamo et al. [34] only explained optimizing the layout of the intercropping system using a constraint programming analysis. Previous research indicates that there has been no research in sustainable agriculture, especially CLI systems that use a goal programming approach. Therefore, this study introduces novelty, namely, production optimization in the corn–cattle integration system aiming to maximize income and minimize costs and production risks, which is analyzed using the goal programming model.

Goal programming is used to obtain a production combination, as it effectively solves cases involving multiple goals simultaneously. Previous system integration studies usually used linear programming with one goal, namely revenue maximization or cost minimization. The weakness of the linear programming model is that it is unable to solve cases that require certain targets to be achieved simultaneously. Meanwhile, goal programming is an extension of linear programming, where goal programming is able to solve cases that have more than one goal simultaneously. This research uses goal programming because it has three objectives, namely maximizing income, minimizing costs, and minimizing risk.

In reality, sometimes livestock production is usually higher than corn production, or the other way around, corn production is usually higher than livestock output. Therefore, it is important to find the best way to grow corn and raise beef cattle together. The objectives of the study are to (1) determine the optimal production combination in the integration of corn–cattle and (2) analyze the allocation of optimal resource use in the integration of corn–cattle in Gorontalo Province.

2 Research method

The research was carried out in Gorontalo Province, which focused on Bone Bolango Regency (Tilongkabila District) and Gorontalo Regency (Tolangohula District). The location determination was carried out purposively, considering that a corn–cow integration system had been carried out. The plant–livestock integration system activity carried out is a program by the Directorate General of Livestock and Animal Health from 2014 to 2016. The research was carried out for 3 months, from January to March 2023. The population in this study was 193 farmers who implemented the corn–cattle integration system program (Gorontalo Provincial Agriculture Office, 2023). Before determining the number of samples, information on the number of farmers who implemented the plant–livestock integration system program in each district was collected. Sampling was carried out using a simple random method, which was adjusted to the conditions at the research site. The number of corn–cattle farmer respondents was 66. The number of respondents was determined using the Slovin method [35]:

$$n = \frac{N}{1 + Ne^2},$$

where n is the number of samples, N is the number of population, and e is the error tolerance 10%.

Data were collected using interviews based on questionnaires, with data being classified based on modeling needs with production maximization, cost minimization, and production risk minimization scenarios. Data analysis with the goal programming model was used to examine the use of resources for seed production, fertilizers, labor medicines, and land. The data processed manually were tabulated according to activities and entered into a linear program. From these activities, an equation was obtained for the function of the purpose and the inequality of the function of the constraint. Furthermore, based on the equations and inequalities, a new equation and inconsistency for goal programming was prepared [36]. The equations and inequalities formed were processed using a computer with the help of the Linear Interactive and Discrete Optimizer program. In this program, primal analysis, dual analysis, and sensitivity analysis were carried out.

Consent: The respondents involved in this study have given their consent to be interviewed, which will be used as part of the data collection process to support the objectives of the research. The respondent consent form was created and provided to the respondents with the aim of establishing cooperation between the researcher and the respondents to facilitate the research process. Thus, the researcher has obtained permission from the respondents.

2.1 Primary analysis

Primal analysis was an analysis of the number of best production combinations (Xi) that can produce the maximum goal (Z) with limited available resources (bi). A comparison was made between the analysis results and the conditions in the field to determine whether the production was optimal.

2.2 Secondary analysis

Dual analysis was a value that shows the change in the objective function (Z) if the resource changes by one unit. Through this analysis, it can be known whether the resources used by farmers are scarce or vice versa. If the dual value was greater than zero (> 0), and the slack or surplus value was equal to zero (= 0), the resource was a scarce resource. Scarce resources, or what is referred to as active constraints, are constraints that limit the value of the objective function. Meanwhile, excess resources or inactive constraints are obstacles that are not used up in the production process and will not affect the function of the goal if there is a change of one unit [37].

2.3 Sensitivity analysis

Sensitivity analysis was employed to find the effects of parameter changes in the model on the value of decisionmaker variables. This analysis was used because of the uncertainty of the parameters where changes include those in the objective coefficient, input–output coefficient, model right-hand value, the new constraint function, and additional decision-making variables [38].

Production planning can create scenarios that describe the decision-making mechanism. The scenario was intended to determine optimal production conditions by utilizing available resources to meet income targets, production costs, and production risks. Next, a comparison was made between the actual conditions of farmer production and the optimal calculation results.

Before being analyzed using the analysis above, the objective, activity, and constraint functions were first created, as follows.

2.4 Target function

In this research, the objectives to be achieved were determined, namely income targets, production costs, and production risks. In this scenario, there was no prioritization of the goals to be achieved. Based on these targets, a target function was created by minimizing deviations from existing goals.

2.5 Activities

The activities included in the model are production activities carried out by integrated farmers. Production activities carried out by corn-beef cattle integration farmers are as follows:

a. Corn farming activities,
b. Cattle farming business activities,
c. Corn waste production activities, and
d. Compost production activities.

2.6 Constraints

2.6.1 Target constraints

Target constraints in optimizing production in a corn–cattle integration system include integration income, production costs, and production risks.

2.6.1.1 Profit target

Income was a target that must be achieved to optimize production and resource allocation, which was achieved through the minimum negative deviation from the predetermined target. To achieve this goal, the objective function only minimizes the deviation variable, which will accommodate the deviation below the target (DB).

2.6.1.2 Production cost targets

Corn–cattle integration business activities require production costs to achieve cost minimization. Therefore, the objective function must minimize deviation variables above the target and deviation variables below the target (DA and DB).

2.6.1.3 Production risk targets

Corn–cattle integration business activities have production risks that can result in not achieving maximum income. Therefore, to achieve the target of minimizing production risk, the objective function must minimize deviation variables above the target and deviation variables below the target (DA and DB, respectively).

2.6.2 Functional constraints

Factors that were functional obstacles to the corn–cattle integration business were production facilities (*saprodi*), land and labor, and relationship constraints.

2.6.2.1 Production facility constraints

Production facilities used by farmers in the corn–cattle integration were seed, fertilizers, medicines, vitamins, feeder cattle, and animal feed.

2.6.2.2 Land constraints

The land used was land for corn and cattle farming. The land that was calculated was the land area as a limit in the production of corn and cattle.

2.6.2.3 Labor constraints

Labor considered a limitation in production was direct labor. The availability of direct labor was calculated based on the number of working hours in a certain period. Under conditions where the production quantity minimized deviations from the predetermined targets, we will determine whether the existing labor input was sufficient to achieve that production level.

2.7 Model formulation

$$\text{Minimization } Z = \sum(\mathrm{DA}_{ik} + \mathrm{DB}_{ik}), \tag{1}$$

$$Z = \mathrm{DB}_{1k} + \mathrm{DA}_{2k} + \mathrm{DA}_{3k} + \mathrm{DA}_{4k} + \mathrm{DA}_{5k} + \mathrm{DA}_{6k} + \mathrm{DA}_{7k}, \tag{2}$$

where DB_{ik} represents the deviational variable that captures deviations below the profit target in the period of $-k$, DA_{2k} represents the deviational variable that captures deviations above the target production of corn in the agricultural period of $-k$, DA_{3k} represents the deviational variable that captures deviations above the target production goal for cattle farming during the period of $-k$, DA_{4k} represents the deviational variable that captures deviations above the target production goal for corn waste during the specified period of $-k$, DA_{5k} represents the deviational variable that captures deviations above the target production of livestock waste during the specified period of $-k$, DA_{6k} represents the deviational variable that captures deviations below the integration cost target in the period of $-k$, and DA_{7k} represents the deviational variable that captures deviations below the integrated production risk target during the period of $-k$.

2.8 Constraints target

2.8.1 Target benefits

$$\sum_{i=1}^{4} \pi_i X_{ij} + DB_k - DA_k = \pi_j; \text{ for every } j = 1, 2, 3 \ \& \quad k = 1, 2, 3, \tag{3}$$

where π_j represents the integration benefits, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, and π_i represents the business benefits of $-i$.

2.8.2 Cost production targets

$$\sum_{i=1}^{4} c_i X_{ij} + DB_l - DA_l = C_j; \quad \text{for every } j = 1, 2, 3 \ \& \quad l = 4, 5, 6, \tag{4}$$

where C_j represents the integrated production cost, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, and c_i represents the production costs of $-i$.

2.8.3 Production risk targets

$$\sum_{i=1}^{4} r_i X_{ij} + DB_m - DA_m = R_j; \quad \text{for every } j = 1, \ 2, \ 3 \ \& \quad m = 7, \ 8, \ 9, \tag{5}$$

where R_j represents the target production risk integration, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, r_i represents the production risks of $-i$.

2.9 Functional constraints

2.9.1 Production facility constraints

$$\sum_{j=1}^{3} i_i X_{ij} \le I_j; \quad \text{for every } i = 1, \ 2, \ 3, \tag{6}$$

where I_j represents the production equipment requirements, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, and i_i represents the coefficient input for production of $-i$.

2.9.2 Labor constraints

$$\sum_{i=1}^{4} t_i X_{ij} \le T_j; \quad \text{for every } j = 1, \ 2, \ 3, \tag{7}$$

where T_j represents the labor needs, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, and t_i represents the labor force coefficient of $-i$.

2.9.3 Land area constraints

$$\sum_{i=1}^{2} l_i X_{ij} \le L_j; \quad \text{for every } j = 1, \ 2, \ 3, \tag{8}$$

where L_j represents the land requirements, X_{ij} represents the production quantity, DB_k represents the lower deviational, DA_k represents the upper deviational, and I_i represents the Land coefficient of $-i$.

3 Results

3.1 Respondents' demographic characteristics

Age, education, family dependents, and farming experience play a crucial role for farmers in developing their agricultural business, in terms of both production and productivity.

In terms of age, the respondents were in their productive age range, which is 15–64 years. On average, corn–cattle farmers are 44 years old. Generally, the formal education level of the respondent farmers is completion of elementary school, with only five individuals having completed high school. The average corn farming experience among the respondents is 13 years, while the average cattle farming experience is 9 years. This indicates that the respondent farmers have not been engaged in the corn–cattle integration system for a long time. The number of dependents within the productive age group is a source of labor assistance for the farmers, with an average of three family dependents for each respondent. Land area greatly affects farmers' decisions and policies on land use to produce the desired agricultural production. In general, corn land is privately owned, with the largest land holding being 2 ha and the smallest 0.25 ha; the average land area owned by farmers is 1.2 ha.

3.2 Goal programming analysis

3.2.1 Targets and target coefficients

The targets to be achieved in the corn–cattle business integration system in Gorontalo Province are profit, production cost, and production risk targets. The targets targeted by the corn–cattle business integration system in Gorontalo Province are illustrated in Figure 1.

As shown in Figure 1, the profit target is expected to increase for the next period, while the cost target and production risk are expected to decrease. Determining the amount of target value, profit targets, costs, and production risks refers to the ideal standards of profit, cost, and production risk based on previous research.

The differential variables that accommodate the deviation are as follows:

1. Profit target is added to the lower deviation variable (DB) to accommodate deviations below the target. Meanwhile, it is not added to accommodate deviations above the target because excess profits are not limited.
2. To achieve the target, production costs are expected not to deviate far above the target; thus, it is necessary to provide a variable differential that accommodates deviations above the target (DA).
3. The production risk target is added to the upper differential variable (DA) to accommodate deviations above the target.

3.2.1.1 Constraints and input–output coefficients

The obstacles faced by the corn–cattle business integration system consist of target and functional obstacles. A differential variable is added to accommodate the deviations that occur in the target constraint. Functional constraints are technical constraints based on the prevalence of the production process in the corn–cattle integration system.

3.2.1.1.1 Target constraints

The coefficient of profit target constraints is the profit of corn farming, beef cattle business, corn waste, and compost for one season. Meanwhile, the value of the right segment is the target profit to be achieved during each period.

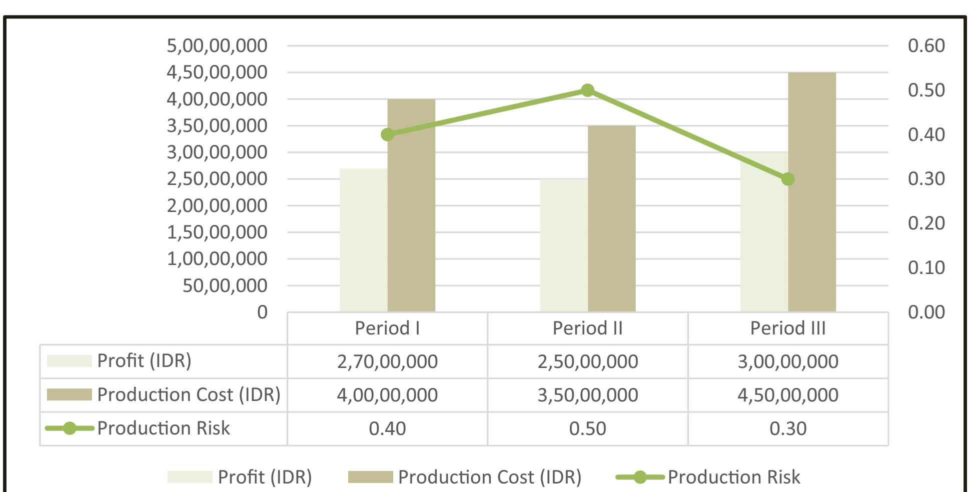

Figure 1: Targets for the Corn–Cattle business integration system in Gorontalo Province, 2024. Source: Primary Data Analysis, 2024.

The upper differential variable and the lower derivative variable are added to the equation.

The cost target constraint coefficient is the cost of corn farming, cattle business, corn waste, and compost for one season. Meanwhile, the value of the right section is the target cost that needs to be minimized in each period. The upper differential and lower derivative variables are added to the equation. The coefficient of constraints on production risk targets is the value of the coefficient of variance from the production of corn, cattle, corn waste, and compost during one season. Meanwhile, the value of the right segment is the target of production risk that wants to be minimized in each period. The upper differential variable and the lower derivative variable are added to the equation.

3.2.1.1.2 Functional Constraints

Constraints on production facilities. The coefficients in the equation of production facilities are the use of seeds (kg), fertilizers (kg), and medicines (L) for corn farming and the use of feeder cattle (tails), feed (kg), and vitamins and medicines (L) for beef cattle business, while corn waste and compost do not have production facilities.

Labor constraints. The labor used in the corn–cattle integration system is family labor and non-family labor, from planting and maintenance to harvesting. The coefficient of labor constraints is the sum of the Male Equivalent Working Days (HKSP) required to produce corn, cattle, corn waste, and compost for a period.

Land area constraints. The area of land planted with corn and forage (HMT) used in the beef cattle business in the corn–cattle integration system in Ha (Hare) units for one period.

From the activities and obstacles faced by the corn–cattle integration system, a model of the objective function, target constraint function, and functional constraint mathematically can be formulated.

3.2.2 Relationship between corn, cow, corn waste, and compost commodities

The corn–cattle integration system's main products are corn and cattle, while corn waste and compost are by-products. Corn waste is a by-product of corn farming used by farmers as additional feed for cattle. Compost is a by-product of the cattle farming business used by integrated farmers as fertilizer for corn farming. The relationship between the commodities is as follows: if corn production increases, corn waste will automatically increase, and increased cattle production will be followed by an increase in the amount of compost. If corn waste increases, an increase in the body weight of cattle is expected, and if compost production increases, an increase in corn production is expected.

3.2.2.1 Optimal results

Production planning in the corn–cattle integration system is limited by various obstacles, both target and functional constraints. From the results of processing with the goal programming model, the optimal production planning is given in Table 1, which shows the optimization results with actual conditions to find out how much the performance of the corn–cattle integration business in production is.

3.3 Production profit, cost, and risk targets

3.3.1 Optimal activity level

This scenario has the goal of all goals, namely profit targets, cost targets, and production risk targets. The actual condition of the corn–cattle integration business system produces corn, beef cattle, corn waste, and compost, where the optimal solution is shown in Table 1.

Table 1 shows that to achieve production optimization, in the first period, the optimal production combination is the production of 4,898 kg of corn, 6 heads of cattle, 1,020 kg of corn waste, and 2,029 kg of compost. In the second period, the optimal production combination is 4,198 kg of corn, 5 heads of cattle, 875 kg of corn waste,

Table 1: Optimal solution scenario on the corn–cattle integration system in Gorontalo Province, 2024

Periods	Commodity	Actual	Scenario	%
I	Corn (kg)	4,891	4,898	0.14
	Cattle (head)	3	6	100.00
	Corn waste (kg)	1,020	1,020	0.00
	Compost (kg)	1,160	2,029	74.91
II	Corn (kg)	4,722	4,198	−11.10
	Cattle (head)	3	5	66.67
	Corn waste (kg)	1,017	875	−13.96
	Compost (kg)	1,150	1,739	51.22
III	Corn (kg)	5,174	5,597	8.18
	Cattle (head)	3	7	133.33
	Corn waste (kg)	1,025	1,166	13.76
	Compost (kg)	2,019	2,319	14.86

Source: Primary Data Analysis, 2024.

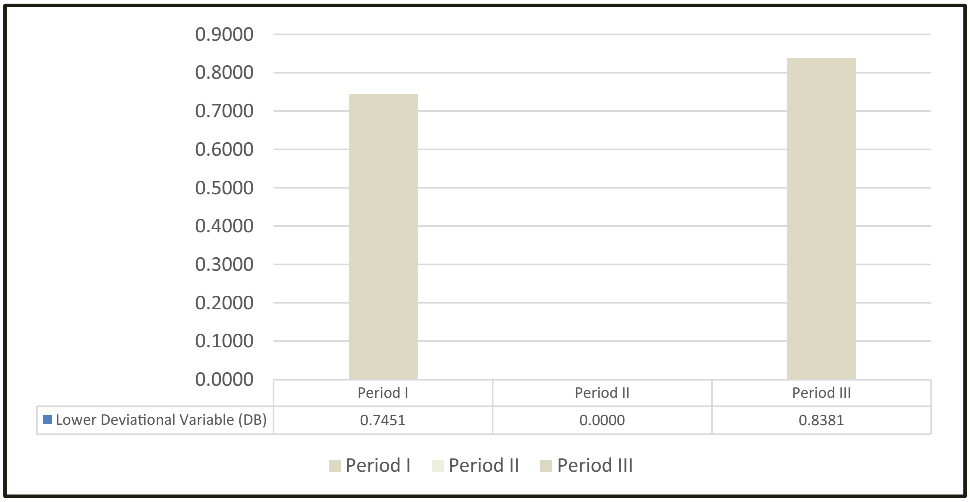

Figure 2: Values of deviational variables below the target of corn–cattle integration profits in Gorontalo Province, 2024. Source: Primary Data Analysis, 2024.

and 1,739 kg of compost. In the third period, the optimal production combination is 5,597 kg of corn, 7 heads of cattle, 1,166 kg of corn waste, and 2,319 kg of compost.

In Table 1, the first period shows that all production levels are below their optimal conditions. In the second period, most of the production levels are above the optimal conditions. The actual production of corn and corn waste exceeded the production level under optimal conditions, namely 4,722 and 1,017 kg, respectively, to 4,198 and 875 kg in optimal conditions, or it decreased to 11.1 and 13.96%, respectively. Meanwhile, in the third period, it can be seen that all production levels are still below their optimal condition.

In this scenario, farmers' profit level, costs, and risks fluctuate each period and are still below optimal conditions. When comparing the profit level in actual with optimal conditions, it can be seen that the profits achieved have increased in each period. The profit, cost, and risk targets of production in Periods I, II, and III are achieved or not shown by the value of the lower derivative variable (DB) of the profit target and the value of the upper derivative variable (DA) of the production cost and risk target (Figures 2 and 3).

Figure 2 shows the value of the lower differential variable (DB) in Period II with the profit target equal to zero. This means that the target of integration benefits in the

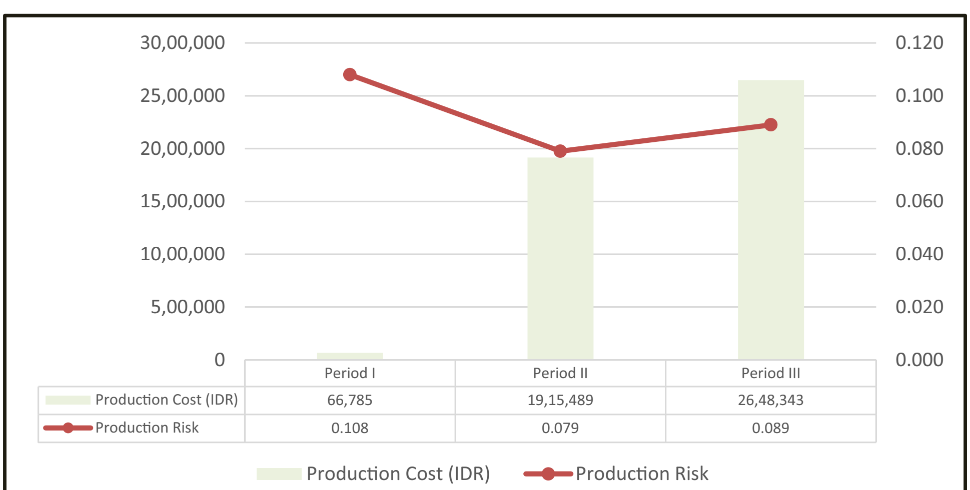

Figure 3: Values of deviational variables on cost targets and production risks of corn–cattle integration system in Gorontalo Province, 2024. Source: Primary Data Analysis, 2024.

second period has been achieved. In Periods I and III, the value of the differential variable (DB) below the profit target is greater than zero, although the value is not too large. This means that the target of integration benefits in Periods I and III was not achieved, with negative deviations in Period I of Rp 0.7451 and Period III of Rp 0.8381.

Figure 3 shows that the value of the variable (DA) on the production cost target was greater than zero in all periods. This means that the target of good production costs in the first period was not achieved with a positive deviation of Rp 66,785. Likewise, in the second period, the production cost target was not achieved with a positive deviation of Rp 1,915,489. Meanwhile, in the third period, the value of the upper differential variable (DA) was greater than zero so that the production cost target was not achieved with a positive deviation of Rp 2,648,343. This table also shows that the value of the differential variable (DA) of the production risk target is greater than zero in all periods, although the value is not too large. This means that the production risk targets for all periods were not achieved. The positive deviation was 0.108 in Period I, 0.079 in Period II, and 0.089 in Period III.

3.4 Resource usage rate

The difference between actual production and optimal production will affect the number of production facilities used, labor, and land area. The extent of use of production facilities is presented in Table 2.

In each period, farmers tried to provide sufficient production facilities to be used in farming activities and as supplies in the next period. This aims to ensure the smooth production process in the corn–cattle integration system.

Table 2 points that the availability of production facilities by farmers is excessive unless these drugs or resources are not an obstacle in the production process. This can be seen from its slack value, which is greater than zero. A slack value greater than zero indicates the amount of resources not used in the production process (residual resources). Meanwhile, in medicines, a slack value equal to zero indicates that the resource has been fully used (no remainder). These resources are said to be scarce resources or active constraints. Every scarce resource has a dual value greater than zero, meaning that every change in one resource unit will cause a change in the destination value by the same dual value. For example, the dual value of drugs of 27,565 means that every additional liter of medicines will increase the profit by Rp 27,565.

The slack and dual values of labor use and land area are presented in Table 3.

Table 3 shows that labor and land in the corn–cattle integration system are excess resources or still have leftovers because the slack value is greater than zero. This happened in all periods, which means that the availability of labor and land in the corn–cattle integration system by farmers is excessive, or these resources are not an obstacle in the production process.

However, the labor force in Period I and land in Period II have a slack value equal to zero, indicating that the resource has been fully used (no leftovers). These resources are said to be scarce resources or active constraints. Every scarce resource has a dual value greater than zero, and this means that every change in one resource unit will cause a change in the destination value by the same dual value. For example, the dual labor value in the first period of 92,694 means that for every additional HKSP of labor, the profit will increase by IDR 92,694. Meanwhile, the value of dual land in Period II is 3,860,101, which means that for every additional hectare of land, the profit will increase by Rp 3,860,101.

3.5 Sensitivity analysis

The analysis carried out on the optimal solution to obtain additional useful information is known as the post-optimal

Table 2: Slack and dual use of production facilities in the corn–cattle integration system in Gorontalo Province, 2024

No.	Production	Slack	Dual
1.	Seeds (kg)	3	0.00
2.	Fertilizer (kg)	15	0.00
3.	Chemicals (L)	0.00	27565.0
4.	Cow	1	0.00
5.	Feed (kg)	10	0.00
6.	Vitamins and chemicals (L)	2.3	0.00

Source: Primary Data Analysis, 2024.

Table 3: Slack and dual use of labor and land in the corn–cattle integration system in Gorontalo Province, 2024

Period	Resources	Slack	Dual
I	Human resources	0.00	92694.00
	Farm	0.37	0.00
II	Human resources	0.33	0.00
	Farm	0.00	3860101.00
III	Human resources	0.34	0.00
	Farm	0.37	0.00

Source: Primary Data Analysis, 2024.

analysis (sensitivity analysis). Sensitivity analysis is an attempt to study the values of decision-making variables in a mathematical model if one, several, or all of the model parameters change. Sensitivity analysis is performed to examine how changes in data might change the solution of a linear program (e.g., how changes in production costs or demand might affect the production schedule). Sensitivity analysis is carried out to analyze the impact that occurs in the optimal solution on changes that occur in the model boundary coefficients and coefficients in the objective function [39].

The optimal conditions achieved can be changed if there is a change in the parameter values contained in the model used. A sensitivity analysis was carried out to determine the change to the optimal condition, and it produced a sensitivity interval.

The sensitivity interval consists of a minimum limit and a maximum limit. The minimum limit indicates the limit of the allowable increase in the right segment of the obstacle so that the optimal solution does not change, while the maximum limit shows the limit of the allowable decrease in the value of the right segment of the obstacle without changing the optimal completion result. Therefore, if there is a change in the value of the right segment that is still within the allowed hose, then the optimal result will not change, or the optimal condition will remain stable.

Sensitivity analysis on data processing shows that the means of production, labor, and land are excess resources. Reducing the amount of excess resources to the permissible limit will not change the benefits of the planning results to be achieved. This happens because the optimal production quantity and combination will not change. In contrast, the increase in the number of resources will be detrimental, because it incurs storage costs (Table 4).

Table 4 shows that the reduction of resources such as seeds is allowed up to the limit of 49.9 kg, fertilizers are reduced to the limit of 1114.5 kg, medicines are reduced to the limit of 18.1 L and increased to the limit of 22.8 L, feeder cattle can be lowered to the limit of nine heads, feed can be reduced to 10,763 kg, and vitamins and medicines can be reduced to the limit of 5.8 kg. Meanwhile, labor (I) is reduced to the limit of 170.92 HKSP and increased to the limit of 178.52, labor (II) can be lowered to the limit of 171.42 HKSP, and labor (III) can be reduced to the limit of 170.92 HKSP. Land area (I) is allowed to decrease to 1.54 ha, land (II) can be reduced to the limit of 1.67 ha and increased to the limit of 3.43 ha, and land (III) can be reduced to the limit of 1.71 ha. This aligns with the study by Irawan et al. [40], the sensitivity analysis indicating that a variation of 10–30% in product prices would affect the quantity of beef concentrate production, while it would have no effect on the production of dairy cow concentrate. Rendel et al. [41] present a model called AgInform®, which optimizes and allocates resources in a land-based integrated grazing farm. The study offers supporting evidence for this model. The model provides a useful framework for understanding the interconnections of resource economics, environmental variables, and farmer preferences. Producers can enhance animal health and environmental stewardship by utilizing AI decision support systems to optimize feed composition [42].

Optimizing production factors in the corn–cattle integration system can increase the efficiency of resource use so that corn yields and cattle productivity can increase without increasing production costs. This system can automatically increase farmers' income because it has two sources, namely corn production and cattle production, in one production cycle. This will also allow farmers to

Table 4: Resource sensitivity hose in the corn–cattle Integration System in Gorontalo Province, 2024

No.	Resources	Current RHS	Allowable increase		Allowable decrease	
1.	Seeds (kg)	52	Infinity		2.1	49.90
2.	Fertilizer (kg)	1,215	Infinity		100.5	1114.50
3.	Chemicals (L)	20	2.8	22.80	1.9	18.10
4.	Cattle	10	Infinity		1.11	9
5.	Feed (kg)	10,820	Infinity		57.0	10,763
6.	Vitamins and chemicals (L)	9	Infinity		3.2	5.80
7.	Human resource (Period I)	176.72	1.8	78.52	5.8	170.92
8.	Human resource (Period II)	176.72	Infinity		5.3	171.42
9.	Human resource (Period III)	176.72	Infinity		5.8	170.92
10.	Farm (Period I)	2.00	Infinity		0.46	1.54
11.	Farm (Period II)	2.00	1.43	3.43	0.33	1.67
12.	Farm (Period III)	2.00	Infinity		0.29	1.71

Source: Primary Data Analysis, 2024.

diversify their income, which can reduce the risk of total loss when one sector experiences problems. With feed and fertilizer sources originating from the corn waste cycle and cow dung, farmers and livestock breeders can reduce their dependence on external inputs. This will also reduce uncertainty in prices and supply of inputs, especially fertilizers, which are often scarce. The government can provide incentives or technical assistance to farmers and livestock breeders to adopt this integration system to increase food independence and security, as well as productivity in the agricultural sector. This aligns with the study by Widiastuti et al. [29]. The circular rural agricultural management model on integrating maize and cattle as a benchmark could increase farmers' income in the peatland areas by more than 208% from IDR 4,760,000 to IDR 14,600,000 per month. The management of peatlands through circular agriculture can improve quality products and add value to the utilization of waste such as animal feed products (silage), organic fertilizers, and biourine. This rural circular agriculture model is carried out by social engineering, initiation, and strengthening of rural agribusiness institutions that are environmentally friendly so that they can be sustainable.

4 Discussion

In all periods, the production level under conditions is not optimal, because in this scenario, there is no priority scale so that the corn–cattle integration system does not focus on one target, whether profit, production costs, or production risks. The conditions experienced by farmers running the integrated system, including their own health conditions and the unpredictable climatic conditions they face, contribute to the ups and downs in production. Apart from that, farmers' methods of raising cattle in Gorontalo are semi-intensive, where farmers only tie up their cattle in their yard and do not build stalls. When their cattle are sick, farmers only give them worm medicine and mix traditional potions to cure them. For corn commodities, farmers often expect subsidized fertilizer and assistance from the agricultural department, as well as medicines. The doses of fertilizers and medicines used by farmers are often not as recommended; they are expensive and scarce. This will cause production risks and production costs to increase, and profits to decrease.

Efforts to increase production by increasing the number of inputs such as seeds, fertilizer, medicines, feeder cattle, feed, vitamins, and medicines with the aim of increasing profits. However, the excessive use of these inputs should be carefully considered to avoid sharp increases in production costs and risks. It is best to prioritize the use of feed made from corn waste and compost. This aligns with the study by Salam et al. [43], a practical way to boost productivity in maize farming is suggested: farmers should be able to manage more land for maize farming; use more urea fertilizers, insecticides, and herbicides; and hire more people to work in maize farming. Growing more maize should result from all these changes.

Medicines are a scarce resource, so for activities to eradicate pests and diseases, alternatives to chemical drugs are needed, namely by controlling insects (plant pest organisms) and using natural enemies. To suppress pest attacks, the effort is to monitor them from an early age through regular observations from seeding to planting. In addition, the Integrated Pest Management Field School (Sekolah Lapangan Pengelolaan Hama Terpadu) provides technical guidance to corn farmers for one planting season, enabling them to conduct independent and routine observations, develop control measures, and understand the six correct methods for using pesticides and natural enemies. This aligns with the study by Tonle et al. [44]. Integrated Pest Management (IPM) technologies offer effective solutions to reduce the negative effects of crop pests, while considering human and environmental health.

Still, it can be seen that the optimal integration of corn–cattle can achieve the goal of increasing profits and reducing production costs and production risks. This aligns with the study by Bahri et al. [45] according to which the profits obtained from integrated farming are greater than from corn or cattle farming. If farming only focuses on corn, the profit is only Rp 5,121,875/month, and if it only focuses on raising 12 cattle for slaughter, the profit is Rp 11,236,500/month. Meanwhile, the integration profit reaches Rp 16,299,000/month. This is also supported by Imran et al. [26] who state that the profits from corn farming obtained by integrated farmers are higher than those of non-integrated corn farmers. This is because the amount of corn production the integrated farmer group received increased by 22% compared to the non-integrated farmer group. Due to the impact of fertilization, integrated farmers use organic fertilizers from cow manure for corn plants. This is supported by research studies [9,46,47], which state that an integrated crop–livestock system can increase the content of organic matter in the soil, which increases agricultural production. In addition, corn waste is used by cattle as feed.

Meanwhile, the use of inorganic fertilizer costs in the integration farmer group was lower (decreased by 30%) than the non-integration corn farmer group that did not use organic fertilizer from cows. The profit of corn farming and the R/C ratio of integrated farmers are higher than those of non-integrated farmers, which are Rp 11,468,605/ha and the R/C ratio is 2.81 [26]. By strategically integrating maize and cattle, producers can achieve more profitability, while simultaneously reducing production costs and mitigating hazards [48,49].

This integrated farming system is more profitable than if farmers only grew corn or raised beef cattle separately [50,51]. Implementing this integration is crucial as the agricultural sector and sustainable agricultural movements are increasingly considering ecological factors. Utilizing cow dung as organic fertilizer enhances soil health by improving its structure and increasing organic matter content [52].

This can reduce soil erosion and increase the soil's ability to retain water, which is critical for long-term sustainability. In addition, the utilization of organic fertilizers diminishes reliance on chemical fertilizers, which can have a negative impact on the environment. In addition to the numerous advantages, the process of enhancing sustainable agriculture by combining beef cattle and corn cultivation has several obstacles that necessitate the involvement and cooperation of all stakeholders [53]. The integration of beef cattle and corn requires more complex knowledge and skills than single farming or animal husbandry. Farmers must possess a comprehensive understanding of both crop and animal management, encompassing knowledge of organic fertilization techniques, feed management, and the proper handling of livestock excrement. Establishing sufficient farmer-breeder capacity is crucial to ensure that farmers can successfully and efficiently manage the integrated system. Therefore, overcoming these obstacles calls for thorough preparation, support from relevant institutions and technology, and policies from the government. In this way, farmers can overcome these obstacles and maximize the potential profits from the integration of beef cattle and corn.

In addition, using waste as a resource will reduce agricultural and livestock waste while minimizing the environmental effects of production. This will maintain ecosystem balance, especially in terms of reducing greenhouse gas emissions and increasing soil fertility through the use of organic fertilizer from cow dung. This research has the potential to encourage technological development and innovation in managing corn–cattle integration systems. Technologies such as waste management and feed efficiency can be optimized to produce a more efficient and sustainable system, which aligns with the study by Widiastuti et al. [25]. This rural circular agriculture model is carried out by social engineering, initiation, and strengthening of rural agribusiness institutions that are environmentally friendly so that they can be sustainable.

5 Conclusion

1. The combination of optimal production with the target of profit, production cost, and production risk in the corn–cattle integration is met, but the achievement value obtained is still below the target, where the best optimal production combination is, in the first period, 4,898 kg of corn, 6 heads of cattle, 1,020 kg of corn waste, and 2,029 kg of compost; for the second period, 4,198 kg of corn, 5 heads of cattle, 875 kg of corn waste, and 1,739 kg of compost; and for the third period, 5,597 kg of corn, 7 heads of cattle, 1,166 kg of corn waste, and 2,319 kg of compost.
2. The allocation of optimal use of production resources in the corn–cattle integration system, namely medicines, labor, and land, including scarce resources, with a scarcity value of 27,565 medicines, 92,694 workers, and 3,860,101 land. The sensitivity interval for the optimal use of production resources in the corn–cattle integration system with the target of profit, cost, and production risk can be increased by 1% from the amount of resources used to infinity and can be reduced by 4–16% of the amount of resources used. Farmers should implement an integrated corn–cattle system with the right combination of production and resource allocation to be more food resilient, independent, prosperous, and able to support ecosystem sustainability in rural areas. Research on optimizing production factors in corn–cattle integration systems has several important implications that can influence various economic, environmental, and social aspects, increasing production efficiency, reducing feed costs, being sustainable and environmentally friendly, increasing farmer income, food and feed independence, developing technology and innovation, and reducing dependence on chemical fertilizers.

Acknowledgments: The authors would like to thank the Faculty of Agriculture, Gorontalo State University, the Gorontalo Provincial Agricultural Service, and those who have assisted with fieldwork.

Funding information: This research was funded with resources from the Non-Tax State Revenue (PNBP) of the Faculty of Agriculture, Universitas Negeri Gorontalo through Penelitian Kolaboratif 2023.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and consented to its submission to the journal, reviewed all the results and approved the final version of the manuscript.

All the authors listed made significant contributions to the completion of the scientific article and its successful publication. S.I. and R.I. proposed research ideas, coordinated the research team, and corrected the results of the analysis, manuscript writing, and manuscript revision. M.Z.H. performed data analysis and checked the validity of the data and the results of data analysis.

Conflict of interest: Authors state no conflict of interest.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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