

# **Altitude and Agroecological Conditions in Production, Profitability, and Risks of Alfalfa (*Medicago Sativa*) Cultivation in the Highlands of Lima, Peru**

## **Altitude e Condições Agroecológicas na Produção, Rentabilidade e Riscos do Cultivo de Alfafa (*Medicago Sativa*) nas Terras Altas de Lima, Peru**

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### **Abstract**

Alfalfa (*Medicago sativa*) is a crucial legume as fodder for livestock, especially in high Andean regions. Despite its growing national importance, production remains limited by agroecological and climatic factors, mainly altitude. In this context, this study estimated the profitability and risks of alfalfa production in the district of San Andrés de Tupicocha, located in the highlands of Lima, Peru. To this end, surveys were conducted with producers during the year 2024, collecting information on yields, costs and risk perceptions. Profitability was analyzed using a stochastic Monte Carlo simulation of the Net Present Value (NPV), complemented by statistical tests comparing two zones with different altitudes and agroecological conditions. On average, the NPV/ha was S/ 159,555; with S/ 134,832 in the high zone (up to 4000 m.a.s.l) and S/ 188,286 in the low zone (up to 2500 m.a.s.l). The high zone showed a higher probability of economic losses, mainly due to frost and heavy rains. These findings suggest that, in order to improve productive efficiency and mitigate risks, it is necessary to implement strategies differentiated according to altitude and local agroecological characteristics. This differentiation will allow optimizing land use and available resources, favoring the sustainability of alfalfa production in the district.

**Keywords:** Alfalfa; profitability of permanent crop; risks in agriculture, stochastic simulation, agroecological conditions

**JEL Codes:** Q12, Q16, C63

## Resumo

A alfafa (*Medicago sativa*) é uma leguminosa crucial como forragem para o gado, especialmente nas regiões andinas altas. Apesar da sua crescente importância nacional, a produção continua limitada por fatores agroecológicos e climáticos, principalmente a altitude. Neste contexto, este estudo estimou a rentabilidade e os riscos da produção de alfafa no distrito de San Andrés de Tupicocha, localizado nas terras altas de Lima, Peru. Para tal, foram realizadas pesquisas com produtores durante o ano de 2024, recolhendo informações sobre rendimentos, custos e percepções de risco. A rentabilidade foi analisada utilizando uma simulação estocástica de Monte Carlo do Valor Presente Líquido (VPL), complementada por testes estatísticos comparando duas zonas com diferentes altitudes e condições agroecológicas. Em média, o VPL/ha foi de S/ 159.555; com S/ 134.832 na zona alta (até 4000 m.a.s.l) e S/ 188.286 na zona baixa (até 2500 m.a.s.l). A zona alta apresentou maior probabilidade de perdas económicas, principalmente devido à geada e às chuvas fortes. Esses resultados sugerem que, para melhorar a eficiência produtiva e mitigar os riscos, é necessário implementar estratégias diferenciadas de acordo com a altitude e as características agroecológicas locais. Essa diferenciação permitirá otimizar o uso da terra e dos recursos disponíveis, favorecendo a sustentabilidade da produção de alfafa no distrito.

*Palavras-chave:* Alfafa; rentabilidade das culturas permanentes; riscos na agricultura, simulação estocástica, condições agroecológicas.

*Classificação JEL:* Q12, Q16, C63

## 1. INTRODUCTION

Alfafa (*Medicago sativa*), known as the “King of Forages” (Feng et al., 2022), is one of the most widely cultivated and important legume species in Peru due to its use as feed for both large and small livestock (especially guinea pigs and rabbits). For this reason, the Peruvian Ministry of Agrarian Development and Irrigation [MIDAGRI] (2025) states that this crop is becoming a key component of the national agricultural sector.

According to the Peruvian Ministry of the Environment [MINAM] (2019), alfalfa cultivation is considered a cultivated pasture agroecosystem, where agricultural fields function as artificial systems composed of interacting inputs that generate outputs. The productivity and quality of the crop depend on the efficiency of these processes, which in turn determine the crop’s profitability and sustainability.

In 2024, national alfalfa production reached 7.766,425 metric tons, with the majority concentrated in the regions of Arequipa (34%) and Puno (25%) (MIDAGRI, 2025). According to the Peruvian Integrated System of Agricultural Statistics [SIEA] (2025), alfalfa accounts for 17.3% of the cultivated area in the Lima region. Specifically, in the district of San Andrés de Tupicocha, as of 2024, there are 99.60 hectares of alfalfa under cultivation, representing approximately 15% of the district’s total area.

On the demand side, the dynamism of the crop is reflected in the increase in the Gross Value of Agricultural Production (GVAP), which grew by 14.6% between January 2023 and May 2024 (MIDAGRI, 2024). The main production areas in Peru are concentrated in the Andean region, with Puno leading national production (46.7%), followed by Arequipa (22.65%) (MIDAGRI, 2024).

In Latin America, countries such as Argentina—in the Pampa Ondulada region—and Brazil—in the states of Paraná and Rio Grande do Sul—stand out for their alfalfa production, which ranges between 14 and 22 tons per hectare. In these countries, alfalfa is primarily used as forage for feeding large livestock, significantly contributing to the production and quality of beef and dairy products (Blain et al., 2023; Dos Santos et al., 2020). This positions alfalfa as a strategic resource for animal nutrition. Similarly, in the Peruvian context, alfalfa production is considered a strength for agrarian development (Bazán et al., 2017).

On the other hand, it is important to highlight that water availability is a key factor in alfalfa cultivation. However, in many production areas of Peru, it is grown under rainfed conditions, which limits its economic potential (MINAM, 2019). In Chile, Inostroza (2022) notes that alfalfa production is highly profitable even under rainfed conditions; nevertheless, he reports that the

productivity of rainfed alfalfa fields can be half that of irrigated ones. In this study, it is important to mention that 100% of the respondents reported having access to water sources from the district's reservoirs (Durand, 2011).

In the province of Huarochirí, alfalfa plays a crucial role in the local economy. In 2019, it was the second-highest income-generating agricultural product in the province, accounting for 18.53% of the Gross Value of Agricultural Production (GVAP). It also occupied the largest harvested area between 2015 and 2019, reaching 1,759 hectares in 2019, equivalent to 25.66% of the total harvested area in the province (INEI & MIDAGRI, 2023).

Specifically, in the district of San Andrés de Tupicocha, alfalfa accounts for 63% of the district's GVAP (SIEA, 2025). Despite its economic relevance, there is a lack of detailed economic studies on alfalfa cultivation in Peru, particularly in highland areas such as Huarochirí.

Given this context, the aim of this paper was to estimate the profitability and risks associated with alfalfa production in the district of San Andrés de Tupicocha, Huarochirí, Lima, Peru, considering two different agroecological zones based on the altitude at which this economic activity is carried out.

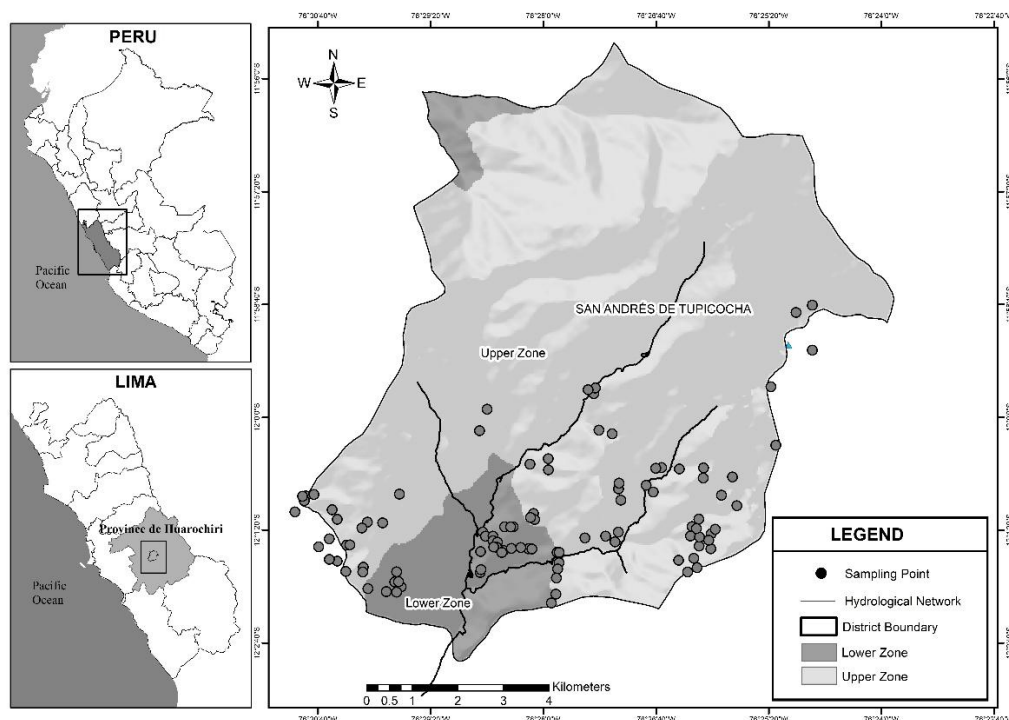
## 2. MATERIALS AND METHODS

### 2.1 Area of study

*San Andrés de Tupicocha* is a district located in the province of Huarochirí, in the department of Lima, Peru. It has an average elevation of 3,606 meters above sea level and is situated at 12° 00' 07" south latitude and 76° 28' 29" west longitude. The district covers an area of 83.35 km<sup>2</sup> and has access to various ecological zones, which allows for a diversity of agricultural products (Gómez de la Torre Barrúa & Ibañez Blancas, 2023; Cantaro-Segura et al., 2021).

It is worth noting that communal dam systems were constructed in this district in the early 2000s (Durand, 2011), which significantly improved access to water resources, particularly for agricultural use. This advancement enabled year-round farming and triggered a boom in alfalfa cultivation beginning in 2010. Based on fieldwork conducted in the district, two distinct production zones for alfalfa can be identified: a high-altitude zone (up to 4,000 meters above sea level) and a low-altitude zone (up to 2,500 meters above sea level).

Figure 1: Location map of the district of San Andrés de Tupicocha, Lima, Peru



## 2.2 Research design

This study adopted a sequential methodological approach aimed at estimating both the profitability and economic risk associated with alfalfa cultivation in the district of *San Andrés de Tupicocha*, located in the highlands of Lima, Peru. This design made it possible to account for the agroecological diversity of the territory—particularly the differences between zones at varying altitudes—and how these influence farmers' economic outcomes.

The procedure was structured into four stages. First, the Net Present Value (NPV) of profitability was estimated for each farmer based on detailed field data, including initial investment, per-harvest costs, production horizon, and selling prices. This information was standardized per hectare. The estimation provided a baseline of the crop's economic performance under observed conditions.

In the second stage, the variability of key economic variables was incorporated through the application of Stochastic Monte Carlo Simulation (SMC) using @Risk software. This technique allowed for the simulation of multiple possible scenarios in which prices and investment fluctuated according to probability distributions fitted to empirical data. As a result, a probabilistic range of NPV values was constructed for each farmer, capturing the inherent uncertainty of agricultural production.

In the third stage, a profitability comparison was made between the high-altitude and low-altitude zones of the district using a two-sample t-test. This statistical test was used to determine whether the observed differences in average NPVs between the two zones were statistically significant—thus justifying a differentiated economic analysis.

Finally, in the fourth stage, the Monte Carlo simulations were repeated separately for each production zone. This disaggregation not only allowed for the estimation of expected NPV values by altitude but also made it possible to analyze the dispersion and variation ranges associated with each productive area.

## 2.3 Indicators of economic profitability of permanent crops

Cost-benefit analysis is a theoretically robust and widely applied tool for evaluating the economic viability of investment decisions (Das et al., 2024; Roberts et al., 2023). Within this framework, the discounted cash flow method is used to calculate the NPV of cash flows generated by an investment. This is particularly relevant when there is a time lag before all benefits are realized (Kabir et al., 2025).

According to Kabir et al. (2025), Maaß and H. Kehlenbeck (2024), and Jin et al. (2023), the NPV is estimated using the following expression:

$$NPV = \sum_{t=1}^N \frac{B_t - C_t}{(1 + r)^t} \dots (1)$$

Where:  $B_t$ : benefits at time  $t$ ;  $C_t$ : costs at time  $t$ ;  $r$ : discount rate;  $N$ : number of periods

In addition, the Internal Rate of Return (IRR) is used to evaluate an investment decision by comparing it with the best available alternatives at a given bank interest rate. An IRR higher than other available rates of return (e.g., the bank rate), or an IRR that makes the NPV equal to zero, indicates that the investment is economically viable (Sokolov, 2024; Ben-Horin, 2017).

It is worth noting that NPV and IRR are widely used decision-support criteria that help identify the most economically viable investment options among alternatives (Chizmar et al., 2020). However, IRR does not capture the risks or uncertainty inherent in most agricultural investment projects (Vilani et al., 2024). Therefore, in this study, the economic evaluation of alfalfa cultivation investment decisions will be carried out using the NPV as the primary decision criterion.

## 2.4 Stochastic Monte Carlo simulation (SMC)

SMC is a quantitative technique that allows modeling economic phenomena under conditions of uncertainty by generating multiple possible scenarios for the variables that influence a project's performance (Maggauer & Fina, 2025; McNulty et al., 2021; Rahaman & Abdul, 2025). This technique uses probability distributions to represent the expected behavior of key variables such as prices, yields, or costs, enabling the estimation not only of average values but also of variation ranges and the probability of occurrence of different economic outcomes (Pawlak, 2024; Celestin et al., 2025).

According to Traverso et al. (2021), its application enhances the accuracy of risk profiling by explicitly incorporating uncertainty into economic evaluations. In agricultural activities, this technique has been used to capture the inherent variability of production systems exposed to climatic risks, price fluctuations, and changes in productivity (Amorim et al., 2024; Liu et al., 2017). Through SMC, these sources of uncertainty can be modeled in a structured way, allowing for the anticipation of economically adverse scenarios and more informed decision-making regarding resource allocation and production planning (Oktoviany et al., 2021; Mahmudiono et al., 2022; Javadi et al., 2024).

When applied to permanent crops, SMC makes it possible to account for cumulative risks associated with long production horizons. These include soil degradation, interannual variability in productivity, and the persistent effects of climate on crop yields (Cesca et al., 2024). In such contexts, the technique enables not only the estimation of the expected NPV but also the analysis of outcome dispersion, the identification of the probability of economically unfavorable scenarios, and the evaluation of the stability of net cash flows throughout the production cycle (Kunwar et al., 2025; Trejo-Pech et al., 2024).

This ability to estimate both economic returns and exposure to risk provides a more precise analysis of long-cycle crops such as alfalfa, whose economic performance depends on variable agroecological conditions and technical decisions that influence outcomes over the entire productive horizon.

Thus, the average result from the Monte Carlo Simulation for each variable was obtained using the following equation:

$$a_m = \frac{1}{n} \sum_{i=1}^n x_i \dots (2)$$

where  $a_m$  is the mean result of the Monte Carlo Simulation (MCS) for the variable,  $x$  represents the individual outcome of each simulated iteration, and  $n$  is the total number of simulations. The value  $a_m$  acts as the normalization factor, indicating that the sum of all simulated results is divided by the number of iterations. The expression  $1/n$  is used to estimate the expected value or average outcome across the simulations. It represents the central tendency of a variable or the average result of multiple simulated outcomes. By dividing the sum of simulated outcomes by the total number of simulations (or by the normalization factor), the model yields an estimation of the expected value of the system or process being analyzed.

### 3. RESULTS AND DISCUSSION

#### 3.1 Descriptive results

**Table 1. Main descriptive statistics of alfalfa production dynamics**

Indicator	Mean	Std. Dev.	Min	Max	Mode
Farmer's gender (0 = male, 1 = female)	0.16*	0.37	0	1	0
Farmer's age (years)	48.2	13.64	23	79	54
Education level (0 = no education, 1 = incomplete primary, 2 = completed primary, ..., 12 = completed PhD)	3.73	1.008	2	8	4
Years of experience as a farmer	22.9	12.36	3	60	30
Years of experience in alfalfa production	11.22	6.51	2	30	10
Total cultivated area (ha)	1.73	0.67	0.5	4	2
Area dedicated to alfalfa (ha)	0.33	0.28	0.063	1	0.25
Exclusive alfalfa production for sale (0 = yes, 1 = no)	0.22**	0.41	0	1	0
Source of information for agricultural decision-making (0 = MIDAGRI/other institutions, 1 = internet and social media, 2 = seed store, 3 = fellow farmers, 4 = other sources)	3.02	0.55	0	4	3
Alfalfa production throughout the year (0 = no, 1 = yes)	0.43** *	0.5	0	1	0
Main reason for year-round production (0 = contractual agreement with buyer, 1 = feed for livestock and/or small animals, 2 = other reason)	0.17** **	0.59	0	2	0
Alfalfa sale (0 = local market, 1 = intermediary, 2 = both)	1	0	1	1	1

\* The percentage of male farmers is 83.7%

\*\* The percentage of farmers who produce alfalfa exclusively for sale is 78.8%

\*\*\* The percentage of farmers who produce alfalfa year-round is 56.3%

\*\*\*\* The percentage of farmers who report having a contractual agreement with a buyer is 86.3%

As shown in Table 1, most alfalfa producers in *San Andrés de Tupicocha* are male, with an average (and modal) age close to 50 years. Regarding educational attainment, 33% of respondents reported having completed secondary education, and some farmers indicated having completed higher education, including university degrees.

The producers in the district reported an average of 23 years of farming experience, with a maximum of 60 years and a mode of 30 years. Specifically for alfalfa cultivation, the average experience was approximately 10 years, which also matches the modal value. This pattern reflects the boom in alfalfa production in the district following the implementation of water harvesting and irrigation infrastructure projects (Durand, 2011), given that alfalfa is a crop with significant water requirements (Crookston et al., 2025).

In terms of the categorization of the farming system, both overall and specifically for alfalfa cultivation, producers are best classified as smallholders. This is evident from the limited scale of operations, with total agricultural landholdings not exceeding 4 hectares and the maximum area allocated to alfalfa reaching only 1 hectare. Notably, 78.8% of producers reported cultivating alfalfa exclusively for sale, while a smaller proportion also uses it for dual purposes—primarily as forage for small animals such as guinea pigs and rabbits. Moreover, 56.3% of farmers indicated that they produce alfalfa throughout the entire year, including the most agronomically challenging months (June, July, and August), which are typically marked by adverse climatic conditions.

Another relevant finding is that most farmers rely on peers or seed suppliers (mainly based in Lima) as their primary sources of information for production-related decisions, such as seed quality or price volatility of inputs. Additionally, 86.3% reported having a standing agreement or contract with a buyer, which aligns with the fact that 100% of farmers sell their production through intermediaries.

Survey data also revealed the diversity of crops cultivated in both ecological zones. In the high-altitude zone, the main commercial crops reported were alfalfa, peas, fava beans, and potatoes, with a combined average of 73% of responses. Other crops with lower incidence included barley and aromatic herbs such as lemon verbena, rosemary, rue, and oregano. In contrast, the main crops reported in the lower-altitude zone were alfalfa, plums, fava beans, potatoes, avocados, and aromatic

herbs, accounting for an average of 68% of responses. Other less commonly cultivated products in this zone included peas, apples, cherimoya, and prickly pear.

### 3.2 Results of the economic evaluation

This section aims to assess the economic profitability of alfalfa cultivation, considered a permanent crop within a medium-term rotation horizon ranging from 24 to 48 months. To this end, the Net Present Value (NPV) was estimated as the discounted net benefit, treating the cultivation as an agricultural investment project. Discounting future cash flows eliminates temporal differences, expressing all economic values in terms of the base or investment year (Majerova et al., 2022).

Since each producer displays particular characteristics in terms of investment schemes, harvest schedules, and cutting frequencies—as reported in the surveys—the NPV analysis was conducted individually, using the specific information provided by each farmer. The main descriptive indicators related to the crop are presented in Table 2.

The initial investment includes costs associated with various agricultural tasks and inputs: fumigation, fertilization, labor, seed acquisition, machinery use, irrigation tapes, and other complementary irrigation accessories. The benefits are derived from the income generated through the sale of alfalfa during the harvest period. Additionally, recurrent costs per harvest include labor payments and irrigation materials such as tapes and water.

**Table 2: Economic Evaluation Results of Alfalfa Cultivation**

Indicator	Mean	Min	Max	Mode
Crop duration (months)	33	24	48	36
Months until first harvest	6	5	8	2
Harvest frequency (months)	2	1	2	2
Total investment (PEN)	26,562	10,800	42,080	27,920
Cost per harvest (PEN)	3,286	1,900	4,1450	3,400
Quantity harvested per event (kg)	770	400	1,000	800
<b>Net Present Value (NPV) (PEN)</b>	<b>159,555</b>	<b>82,669</b>	<b>310,124</b>	<b>143,433</b>

The results show that alfalfa cultivation yields an average NPV per hectare of PEN 159,555 per farmer, indicating substantial economic profitability under average investment and production conditions. However, it is important to note that in the study district, the average area allocated to alfalfa cultivation is only 0.33 hectares.

#### 3.2.1 Results of the probabilistic analysis

To capture the inherent uncertainty in agricultural activity, a MCS analysis was conducted on the Net Present Value (NPV) of alfalfa production. This procedure incorporated seasonal variability in market prices and the observed dispersion in both initial and recurrent investment costs, based on data collected during fieldwork.

Regarding prices, three distinct market seasons were identified:

- *High season (3 months)*: Average price PEN 29.26/kg.
- *Mid season (4 months)*: Average price PEN 16.49/kg.
- *Low season (remaining 5 months)*: Average price PEN 10.98/kg.

Empirical distribution functions were also incorporated for the main cost components, including seed acquisition, irrigation systems, and labor. The simulation was performed using the @Risk software, running 10,000 iterations per farmer, thereby generating a robust range of potential scenarios for individual NPVs.

The total expected NPV, considering all producers in the sample and simulated scenarios, was estimated at PEN 159,592 per farmer (Table 3). This figure aligns closely with the deterministic average NPV (PEN 159,555), suggesting considerable stability in economic returns under uncertain conditions. The 95% confidence interval for the NPV ranged from PEN 133,460 to PEN 182,201, indicating moderate dispersion in the results.

**Table 3: Probabilistic Evaluation Results of alfalfa cultivation**

Indicator	Expected	Min Expected	Max Expected	Mode	Std. Dev.
Total Average NPV (PEN)	159,592	133,460	182,201	160,208.37	7,361.32

It is worth noting that in 100% of the simulated iterations, the project remained profitable—that is, a positive NPV was achieved. This indicates that even under adverse price or cost scenarios, alfalfa cultivation remains an economically viable option within the local context.

These findings reinforce the case for sustained investment in forage crops such as alfalfa, especially in Andean territories with access to irrigation systems and relatively stable climatic conditions. Furthermore, the consistency between the simulated and deterministic NPV suggests that the crop exhibits a low-risk structure in the face of moderate economic shocks—an important strategic advantage for small-scale farmers with risk-averse profiles.

### 3.2.2 Profitability comparison across agroecological zones

In addition, considering the agroecological heterogeneity of the study area, the sample was classified into two zones based on altitude: high zone (up to 4,000 meters above sea level) and low zone (up to 2,500 meters above sea level). To determine whether there were statistically significant differences in profitability between the two zones, a student’s t-test for the difference in means was applied to individual NPV values. The results are presented in Table 4:

**Table 4: Results of the mean difference test**

Group	Obs	Mean	Std.Error	p-value
Total Average NPV	80	159,555	5,516	0.000***
Low zone	37	188,286	7,439	
High zone	43	134,832	5,848	

Note: \*\*\*  $p < 0.01$ , statistically significant at 1%

The analysis revealed a highly significant difference between the two zones ( $p < 0.01$ ), which justified the implementation of a disaggregated probabilistic analysis. Based on this, expected NPV values and variability ranges were estimated for each zone, again applying the MCS technique with functions adjusted to the specific conditions of each production zone (Table 5).

**Table 5. Expected NPV by agroecological zone**

Indicator	Expected Mean	Min Expected	Max Expected
NPV – Low Zone	188,332	156,973	215,454
NPV – High Zone	134,864	113,229	153,589

The results confirm that alfalfa cultivation is profitable in both zones under conditions of uncertainty, though with a substantial difference in the magnitude of net benefits. The low zone shows an expected NPV that is 39.6% higher than that of the high zone. This differential is primarily attributed to a higher harvest frequency and lower exposure to extreme climatic events, such as frosts.

Furthermore, although the NPV range in the low zone is wider, it consistently remains within high-profitability levels across all simulated scenarios. This indicates greater tolerance to market fluctuations without compromising economic viability. In contrast, the high zone exhibits tighter profit margins and a shorter productive horizon, which increases the crop’s sensitivity to changes in input costs or market prices.

### 3.3 Discussion

The economic assessment of alfalfa cultivation in the district of *San Andrés de Tupicocha* reveals sustained and consistent profitability, even under conditions of uncertainty. The average Net Present Value (NPV) obtained (PEN 159,555) and its expected value under MCS (PEN 159,592) exhibit minimal dispersion, suggesting a low exposure to economic risk. This degree of stability is

particularly relevant in the context of high-Andean smallholder agriculture, which is typically characterized by climatic variability and technological constraints.

Although alfalfa is the district's primary forage crop, farmers in the high-altitude zone also grow peas, fava beans, and potatoes, while those in the low zone diversify into fruit crops such as plum and avocado, as well as aromatic herbs like rosemary, rue, lemon verbena, and oregano. This diversity reflects strategic resource allocation decisions shaped by agroecological conditions. In this context, alfalfa stands out for its consistent income stream, short cutting intervals, and linkage to relatively stable markets—evidenced by the high proportion of producers who market their harvests through pre-established contracts or agreements.

International literature reports average alfalfa yields ranging from 400 to 630 bales per hectare per season under rainfed conditions (INIA, 2024). In Tupicocha, reported yields are comparable in competitiveness, largely due to access to water from communal reservoirs and the use of gravity-based irrigation systems. However, cutting frequency and crop persistence have declined in recent years, with productive cycles decreasing from up to 10 years—according to local accounts—to only 2 to 4 years. This contraction is associated with the genetic degradation of seed vigor and the progressive erosion of soil fertility (MINAM, 2019).

The comparison between agroecological zones within the district revealed statistically significant differences in profitability. The low-altitude zone reported an average NPV of PEN 188,286, compared to PEN 134,832 in the high zone—a highly significant difference ( $p < 0.01$ ). This gap stems from structural factors such as higher annual cutting frequency, more fertile soils, and reduced exposure to climatic extremes such as frost. These findings are consistent with studies such as Yao et al. (2022), which link altitude to reduced winter resilience and lower root productivity.

Methodologically, the incorporation of SMCS enhanced the economic analysis by capturing not only expected returns but also the range and probability of potential outcomes. In agricultural settings, where prices, yields, and costs fluctuate seasonally, this probabilistic approach represents a significant improvement over traditional deterministic evaluation (Traverso et al., 2021; Pawlak, 2024). In the present study, profitability was positive in 100% of the simulated scenarios, evidencing the technical and economic viability of the crop.

Furthermore, the benefit–cost ratio (B/C) – widely used in agricultural project appraisal (Frej et al., 2021) – constitutes a complementary metric for the economic evaluation of perennial crops. Although not estimated directly in this study, its relevance is supported by prior research on crops such as cacao, coffee, and tara in Peruvian contexts (Sarmiento, 2023; Hidalgo-Gonzales, 2021; Bashi-Pizarro, 2021; Gómez et al., 2022). In Mexico, Ríos-Flores et al. (2008) report that the B/C ratio for alfalfa increased from 1.53 to 1.69 between 1990 and 2005.

From a systemic perspective, agroecological conditions function as economic determinants. Although alfalfa is highly adaptable, it responds differently to variations in altitude, soil pH, and water availability. Dogbatse et al. (2020) found that productivity improves in alkaline soils and declines in acidic conditions, while Bover-Felices and Suárez-Hernández (2023) emphasize the importance of understanding agroecosystems as integrated units that shape both sustainability and economic efficiency.

In *San Andrés de Tupicocha*, these conditions delineate two contrasting agroecosystems: the low zone, characterized by greater thermal stability, fertility, and crop longevity; and the high zone, marked by harsher climatic exposure and lower yields. These differences impact not only profitability but also decisions around crop management, investment, and production planning. Although agronomic studies have examined alfalfa cultivation practices (Quispe-Guevara, 2022; Acharya et al., 2020), comparative profitability analyses by altitude remain scarce, despite their relevance for agricultural policy formulation.

In sum, the findings presented here demonstrate that alfalfa retains a comparative economic advantage over alternative productive options in the area. Its stable profitability, low risk profile, and technical adaptability position it as a strategic crop for high-Andean zones with functional irrigation infrastructure. The design of public interventions or technical assistance programs should account for intra-territorial differences, promoting tailored strategies based on agroecosystem characteristics, with an emphasis on improving agronomic sustainability and preserving the crop's remaining economic advantages.

#### 4. CONCLUSIONS

This study estimated the economic profitability of a permanent crop of growing importance in Peru. It also demonstrated that the Net Present Value (NPV) per hectare in alfalfa production differs statistically between the high- and low-altitude zones within the study district. The economic performance of producers in the lowland zone is superior, despite exhibiting lower yields and higher production costs. This is primarily due to shorter production cycles—an average of 38 days in the lowland zone compared to 58 days in the highland zone.

These outcomes are closely associated with the agroecological conditions inherent to elevation, which give rise to distinct types of production risks depending on the zone. Thus, despite certain limitations of the study, the findings suggest that the design and implementation of agricultural technical assistance programs should adopt a differentiated approach—even when dealing with a single crop produced within the same district.

Finally, it is recommended that future policies on agricultural extension, technical assistance, and rural finance explicitly account for intra-district agroecological heterogeneity. Tailoring strategies by zone could enhance the technical and economic sustainability of alfalfa cultivation, contributing to more efficient resource management and improved resilience among smallholder farmers.

#### REFERENCES

Acharya, J. P., Lopez, Y., Gouveia, B. T., de Bem Oliveira, I., Resende Jr, M. F., Muñoz, P. R., & Rios, E. F. (2020). Breeding alfalfa (*Medicago sativa* L.) adapted to subtropical agroecosystems. *Agronomy*, 10(5), 742. <https://doi.org/10.3390/agronomy10050742>

Amorim, F. R. D., Guimarães, C. C., Afonso, P., & Tobias, M. S. G. (2024). Forecasting Cost Risks of Corn and Soybean Crops through Monte Carlo Simulation. *Applied Sciences*, 14(17), 8030. <https://doi.org/10.3390/app14178030>

Bashi-Pizarro, M. S. (2021). Caracterización técnico-económica de sistemas agroforestales de café (*Coffea arabica* L.) en fundos cafetaleros de dos microcuencas de Pichanaki, Junín-Perú. Tesis pregrado

Bazán, R. V.; Yamada, A. G.; Coronado, S. L.; & Fuentes, N. N. (2017). Comportamiento Productivo de la Alfalfa (*Medicago sativa*) de la Variedad Caravelí Sometida al Pastoreo en el Valle de Huaral. *Revista de investigaciones veterinarias del Peru*, 28(3), 743. <https://doi.org/10.15381/rivep.v28i3.13359>

Ben-Horin, M., & Kroll, Y. (2017). A simple intuitive NPV IRR consistent ranking. *The Quarterly Review of Economics and Finance*, 66, 108–114. <https://doi.org/10.1016/j.qref.2017.01.004>

Blain, G., Assuero, S. G., & Berone, G. D. (2023). Altura de corte en alfalfa: producción y calidad nutritiva del forraje= Cutting height in alfalfa: production and nutritional quality of forage. *Revista de Investigaciones Agropecuarias*. <https://doi.org/10.58149/s1hb-hw75>

Bover-Felices, K., & Suárez-Hernández, J. (2023). Contribución del enfoque de la agroecología en el funcionamiento y estructura de los agroecosistemas integrados. Estación Experimental de Pastos y Forrajes Indio Hatuey, Universidad de Matanzas, Ministerio de Educación Superior.

Cantaro-Segura, J. L., Delgado-Palma, D., & Cayetano-Robles, J. L. (2021). Caracterización de la crianza de cuyes en una zona de la sierra de Huarochirí-Perú. *Revista de Investigación e Innovación Agropecuaria y de Recursos Naturales*, 8(2), 72-78. <https://doi.org/10.53287/hffs7980xc24q>

Celestin, M., Vasuki, M., Boakye, M. M., & Kumar, A. D. (2025). Monte Carlo simulations for assessing the impact of market uncertainty on investment portfolios. *International Journal of Scientific Research and Modern Education (IJSRME)*, 11(2), 19-29. <https://doi.org/10.5281/zenodo.14904146>

Cesca, I. G., Postali, F. A. S., & Parente, V. (2024). Economic flexibilities and opportunities for sugar cane plants: A real options valuation case. *Cleaner and Circular Bioeconomy*, 7, 100074. <https://doi.org/10.1016/j.clcb.2024.100074>

- Chizmar, S., Castillo, M., Pizarro, D., Vasquez, H., Bernal, W., Rivera, R., ... & Cubbage, F. (2020). A discounted cash flow and capital budgeting analysis of silvopastoral systems in the Amazonas region of Peru. *Land*, 9(10), 353. <https://doi.org/10.3390/land9100353>
- Crookston, B., Boren, D., Yost, M., Sullivan, T., Creech, E., Barker, B. & Reid, C. (2025). Irrigation technology, irrigation dose, and crop genetic impacts on alfalfa yield and quality. *Agricultural Water Management*. 311(1), 109366. <https://doi.org/10.1016/j.agwat.2025.109366>
- Das, T. K., Behera, B., Nath, C. P., Ghosh, S., Sen, S., Raj, R., ... & Paramanik, B. (2024). Herbicides use in crop production: An analysis of cost-benefit, non-target toxicities and environmental risks. *Crop protection*, 181, 106691. <https://doi.org/10.1016/j.cropro.2024.106691>
- Dogbatse, J. A., Arthur, A., Padi, F. K., Konlan, S., Quaye, A. K., Owusu-Ansah, F., et al. (2020). Influence of acidic soils on growth and nutrient uptake of cocoa (*Theobroma cacao* L.) varieties. *Commun. Soil Sci. Plant Anal.* 51, 2280–2296. <https://doi.org/10.1080/00103624.2020.1822384>
- dos Santos, I.G., Rocha, J.d., Vigna, B.B. (2020). Exploring the diversity of alfalfa within Brazil for tropical production. *Euphytica*, 216, 72 <https://doi.org/10.1007/s10681-020-02606-w>
- Durand, P. (2011). Sembrando y cosechando agua. Proceso de adopción tecnológica y gestión del agua en la comunidad campesina de Cullpe: Una experiencia de autogestión campesina y cambio social. *Revista Andina*, 51(1): 9-41.
- Feng, Y., Shi, Y., Zhao, M., Shen, H., Xu, L., Luo, Y., et al. (2022). Yield and quality properties of alfalfa (*Medicago sativa* L.) and their influencing factors in China. *Eur. J. Agron.* 141, 126637 <https://doi.org/10.1016/j.eja.2022.126637>
- Frej, E. A., Ekel, P., & de Almeida, A. T. (2021). A benefit-to-cost ratio-based approach for portfolio selection under multiple criteria with incomplete preference information. *Information Sciences*, 545, 487-498. <https://doi.org/10.1016/j.ins.2020.08.119>
- Gómez de la Torre Barrúa, J.; & Ibañez Blancas, A. N. (2023). Encuentros y desencuentros percibidos entre comuneros y docentes en torno a la innovación en las amunas de San Andrés de Tupicocha, Huarochirí, Perú. *Collectivus. Revista de Ciencias Sociales*, 10(1), 81- 110. <https://doi.org/10.15648/Collectivus.vol10num1.2023.3566>
- Gómez, R., Diez, R., Vasquez, C. & Vargas, J. (2022) Rentabilidad del cultivo de tara *Caesalpinia spinosa* (Molina) Kuntze en Apurímac, Perú. *Anales Científicos*. 83(2), 175-184. <https://doi.org/10.21704/ac.v83i2.1960>
- Hidalgo-Gonzales, C. D. R. (2021). Análisis comparativo de la rentabilidad económica de sistemas agroforestales y cultivos tradicionales de dos comunidades nativas, en el distrito de Irazola, Ucayali. Tesis pregrado
- Instituto Nacional de Estadística e Informática [INEI] & Ministerio de Desarrollo Agrario y Riego [MIDAGRI]. (2023). *Encuesta Nacional Agropecuaria 2022*. Instituto Nacional de Estadística e Informática. <https://www.inei.gob.pe>
- INIA. (2024). INIA lanza primera variedad de alfalfa de secano que destaca por su alta persistencia y potencial productivo | INIA. <https://www.inia.cl/2024/07/08/inia-lanza-primeravariedad-de-alfalfa-de-secano-que-destaca-por-su-alta-persistencia-y-potencial-productivo/>
- Inostroza, F. (2022). Alfalfa, una alternativa de alta rentabilidad para los productores de la precordillera de Ñuble. *Praderas. RedAgrícola*. <https://hdl.handle.net/20.500.14001/68783>
- Javadi, A., Ghahremanzadeh, M., Sassi, M., Javanbakht, O., & Hayati, B. (2024). Impact of climate variables change on the yield of wheat and rice crops in Iran (application of stochastic model based on Monte Carlo simulation). *Computational Economics*, 63(3), 983-1000. <https://doi.org/10.1007/s10614-023-10389-0>
- Jin, Y., Lee, S., Kang, T., Park, J., & Kim, Y. (2023). Capacity Optimization of Rainwater Harvesting Systems Based on a Cost–Benefit Analysis: A Financial Support Program Review and Parametric Sensitivity Analysis. *Water*, 15(1), 186. <https://doi.org/10.3390/w15010186>
- Kabir, M. J., Gaydon, D. S., & Cramb, R. (2025). Evaluation of crop and pond deepening adaptations to climate change in saline coastal Bangladesh: Benefit cost and risk analysis. *Agricultural Water Management*, 308, Article 109274. <https://doi.org/10.1016/j.agwat.2024.109274>
- Kunwar, S. R., Fonsah, E. G., & Escalante, C. L. (2025). An Assessment of Profitability Using Monte Carlo Simulation Approach: A Case of Georgia Blueberry Industry. *Journal of Food Distribution Research*, 56(1).
- Liu, J., Li, Y. P., Huang, G. H., Zhuang, X. W., & Fu, H. Y. (2017). Assessment of uncertainty effects on crop planning and irrigation water supply using a Monte Carlo simulation based dual-

interval stochastic programming method. *Journal of Cleaner Production*, 149, 945-967. <https://doi.org/10.1016/j.jclepro.2017.02.100>

Maaß, O., & Kehlenbeck, H. (2024). Cost–Benefit Analysis of Monitoring Insect Pests and Aerial Spraying of Insecticides: The Case of Protecting Pine Forests against *Dendrolimus pini* in Brandenburg (Germany). *Forests*, 15(1), 104. <https://doi.org/10.3390/f15010104>

Maggauer, K., & Fina, B. (2025). Monte Carlo simulation-based economic risk assessment in energy communities. *Energy Reports*, 13, 987-1003. <https://doi.org/10.1016/j.egy.2024.12.046>

Mahmudiono, T., Yasin, G., Jasim, S. A., Alghazali, T. A. H., Kadhim, M. M., Iswanto, A. H., ... & Panduro-Tenazoa, N. M. (2022). Analyzing food production risk with Monte Carlo simulation. *Food Science and Technology*, 42, e03522. <https://doi.org/10.1590/fst.03522>

Majerova, I., Michna, P., Lebiezlik, M., Nevima, J., & Turečkova, K. (2022). Implementation of a navigation system: Economic verification in a local hospital. *PLoS One*, 17(10), e0276996. <https://doi.org/10.1371/journal.pone.0276996>

McNulty, M. J., Kelada, K., Paul, D., Nandi, S., & McDonald, K. A. (2021). Techno-economic process modelling and Monte Carlo simulation data of uncertainty quantification in field-grown plant-based manufacturing. *Data in Brief*, 38, 107317. <https://doi.org/10.1016/j.dib.2021.107317>

Ministerio de Desarrollo Agrario y Riego [MIDAGRI] (2024). *Boletín Estadístico Mensual El Agro en Cifras – mayo 2024*. Dirección General de Estadística, Seguimiento y Evaluación de Políticas.

Ministerio de Desarrollo Agrario y Riego [MIDAGRI] (2025). Boletín estadístico mensual "El agro en cifras" - 2024 [Boletín].

<https://www.gob.pe/institucion/midagri/informes-publicaciones/5380407-boletin-estadistico-mensual-el-agro-en-cifras-2024>

Ministerio del Ambiente [MINAM]. (2019). Línea de base de la alfalfa con fines de bioseguridad en el Perú. MINAM.

[https://bioseguridad.minam.gob.pe/wp-content/uploads/2020/02/estudio\\_lb\\_alfalfa.pdf](https://bioseguridad.minam.gob.pe/wp-content/uploads/2020/02/estudio_lb_alfalfa.pdf)

Oktoviyany, P., Knobloch, R., & Korn, R. (2021). A machine learning-based price state prediction model for agricultural commodities using external factors. *Decisions in Economics and Finance*, 44(2), 1063-1085. <https://doi.org/10.1007/s10203-021-00354-7>

Pawlak, M. (2024). Valuation of real options using Monte Carlo simulation. *Procedia Computer Science*, 246, 3410-3419. <https://doi.org/10.1016/j.procs.2024.09.216>

Quispe-Guevara, R. Q. (2022). Producción De Medicago Sativa (Alfalfa), Aplicando Abonos Orgánicos En Época De Invierno. *Revista de Investigaciones*, 11(1), 55-67. <https://doi.org/10.26788/riepg.v11i1.3564>

Rahaman, S. U., & Abdul, M. J. (2025). Quantifying uncertainty in economics policy predictions: A Bayesian & Monte Carlo based data-driven approach. *International Review of Financial Analysis*, 102, 104157. <https://doi.org/10.1016/j.irfa.2025.104157>

Ríos-Flores, J. L., Ruiz-Torres, J., Cisneros-Vázquez, J. M., Cantú-Brito, J. E., Torres-Moreno, M., & Quiñones, A. M. (2008). Producción, productividad y rentabilidad de la alfalfa (*Medicago sativa* L) irrigada por bombeo en la Comarca Lagunera de 1999 a 2005. *Revista Chapingo-Serie Zonas Áridas VII (2)*. Universidad Autónoma Chapingo. Texcoco Edo. De México.

Roberts, M., Hawes, C., & Young, M. (2023). Environmental management on agricultural land: Cost benefit analysis of an integrated cropping system for provision of environmental public goods. *Journal of Environmental Management*, 331, Article 117306. <https://doi.org/10.1016/j.jenvman.2023.117306>

Sarmiento, N. (2023). Uso de abonos orgánicos e implicancia en el cultivo de cacao (*Theobroma cacao* L.) en la provincia de San Martín 2022. Tesis pregrado

Sistema Integrado de Estadísticas Agrarias [SIEA]. 2025. Perfil Productivo Regional.

Sokolov, M. V. (2024). NPV, IRR, PI, PP, and DPP: A unified view. *Journal of Mathematical Economics*, 114, 102992. <https://doi.org/10.1016/j.jmateco.2024.102992>

Traverso, L., Mazzoli, E., Miller, C., Pulighe, G., Perelli, C., Morese, M. M., & Branca, G. (2021). Cost Benefit and Risk Analysis of Low iLUC Bioenergy Production in Europe Using Monte Carlo Simulation. *Energies*, 14(6), 1-18. <https://doi.org/10.3390/en14061650>

Trejo-Pech, C. O., Rodríguez-Magaña, A., Briseño-Ramírez, H., & Ahumada, R. (2024). A Monte Carlo simulation case study on blueberries from Mexico. *International Food and Agribusiness Management Review*, 27(2), 359-377. <https://doi.org/10.22434/IFAMR2023.0052>

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Vilani, L., Zanin, A., Lizot, M., Trentin, M., Afonso, P., & Lima, J. (2024). A Framework for Investment and Risk Assessment of Agricultural Projects. *Journal of Risk and Financial Management*, 17(9), 378. <https://doi.org/10.3390/jrfm17090378>

Yao, X., Qian, L., Changhui, L., & Yi, S. (2022). Effects of altitude and varieties on overwintering adaptability and cold resistance mechanism of alfalfa roots in the Qinghai–Tibet Plateau. *Journal of the Science of Food and Agriculture*, 103(3), 1001–1012. <https://doi.org/10.1002/jsfa.12407>

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