Development of a Sustainable Replanting Simulation System

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Abstract. Replanting is a crucial agricultural procedure that entails the substitution of harvested crops with fresh onesThe process entails the acquisition of diverse data sets essential for comprehending the system under consideration for modeling purposes, alongside their integration into a cohesive database. In the realm of agricultural simulation system development, the necessary data encompasses several elements such as soil conditions, historical weather data, crop production estimates, market pricing, and additional economic aspects. A simulation model was designed to include machine learning methods for the purpose of predicting agricultural yields in varying environmental circumstances. The implementation of a sustainable replanting simulation system signifies a notable advancement in the promotion of agricultural methods that prioritize sustainability. This system offers decision-makers a robust tool for the planning and management of replanting efforts by incorporating data analytics and simulation methodologies.

Keywords: Machine learning, Management information system, Replanting simulation.

1 Introduction

Replanting is a crucial agricultural procedure that entails the substitution of harvested crops with fresh ones. It is vital to exercise caution and precision in executing this procedure in order to sustain the agricultural yield of the property [1]. For instance, specific agricultural crops have the potential to considerably diminish the availability of essential soil nutrients, hence necessitating the implementation of a prudent crop rotation strategy. The efficacy of the reforestation process is heavily contingent upon a multitude of interconnected variables. One illustrative instance involves the adverse impact of impoverished soil conditions on crop productivity, alongside the potential consequences of erratic climate patterns, which may result in the complete failure of crops. Furthermore, it is imperative to consider economic factors, including expenses related to seed acquisition and labor, while analyzing the situation. Nevertheless, conventional reforestation planning is sometimes characterized by a lengthy process and a lack of consideration for these many aspects [2].

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The significance of sustainability in agriculture is growing in light of ongoing global population expansion and the impact of climate change on agricultural circumstances [3]. Sustainable agriculture encompasses more than the mere attainment of elevated crop yields; it encompasses the imperative of safeguarding the environment from the detrimental impacts of agricultural activities [4]. One illustrative instance involves the phenomenon of soil degradation, which has the potential to gradually diminish the overall quality of agricultural land. Additionally, the emission of greenhouse gases stemming from agricultural activities has been identified as a contributing factor to the occurrence of climate change [5]. Hence, it is imperative for a sustainable replanting system to endeavor towards attaining a harmonious equilibrium encompassing maximum productivity, ecological sustainability, and economic steadiness [6]. Simulation and modeling have emerged as vital instruments in the realm of contemporary agriculture, facilitating informed decision-making processes [7], [8], [9]. This is due to its capacity to enable various stakeholders, including farmers, researchers, and policy makers, to evaluate and assess diverse situations without necessitating actual field experimentation. Simulation models can be employed by farmers to anticipate the impact of several variables, such as climate change or alterations in crop varieties, on their agricultural yields. Simulation technology facilitates the ability of stakeholders to make more informed decisions that are grounded in empirical evidence [10], [11].

This study presents a sustainable replanting simulation system that has been developed as a means to enhance agricultural sustainability. In this exposition, we shall provide a comprehensive elucidation of the methodologies employed in the acquisition and amalgamation of data pertaining to soil conditions, climatic patterns, yield projections, and economic considerations within the simulation system. Additionally, we will provide the findings of a case study that was undertaken utilizing this system in order to illustrate its efficacy in facilitating improved decision-making regarding replanting. In conclusion, this study provides a summary of the potential advantages and obstacles that may arise from the implementation of the simulation system in agricultural operations. The primary objective of this study is to enhance comprehension of the significance of adopting a sustainable approach in agricultural replanting. Additionally, this research aims to present an overview of how simulation technology can be effectively utilized to accomplish this objective.

2 Literatur Review

2.1 Sustainable Replanting

Sustainable replanting is an agricultural strategy that seeks to mitigate adverse environmental effects and sustain soil productivity in a manner that aligns with long-term sustainability goals [12]. Within this particular framework, the concept of sustainability entails that the procedures employed for replanting not only prioritize immediate high yields, but also take into account the long-term well-being and viability of the adjacent soil, water, and environment. The acknowledgement of the significance of preserving rich soil, minimizing pesticide usage, and mitigating soil erosion that may result in detrimental effects on the surrounding ecosystem is evident.as shown in Figure 1.

Fig. 1. Sustainable replanting scheme.

Sustainable replanting encompasses several essential variables [13]. First and foremost, prudent utilization of soil is vital. One effective strategy employed in agriculture is the implementation of crop rotation, which serves the purpose of mitigating soil nutrient depletion and preventing the accumulation of particular plant diseases. In addition, the careful selection of suitable crop varieties is a crucial factor to be taken into account. Certain types of plants may exhibit greater resistance to specific environmental circumstances or necessitate a reduced application of pesticides, hence potentially mitigating adverse environmental effects. Furthermore, the incorporation of organic fertilizers and the implementation of agricultural methods aimed at mitigating greenhouse gas emissions are crucial components of sustainable reforestation. The practice of sustainable replanting yields several advantages. Firstly, it aids in the preservation of soil quality. The presence of healthy and rich soil plays a crucial role in facilitating optimal plant growth and maximizing yield. Furthermore, the mitigation of water contamination and preservation of biodiversity can be achieved through the reduction of pesticide and chemical fertilizer usage. The implementation of sustainable replanting practices also yields economic advantages, as it has the potential to mitigate long-term production expenses by preventing soil deterioration and decreasing dependence for chemical inputs.

The implementation of sustainable replanting entails both advantages and obstacles. The process of choosing appropriate cultivars and devising crop rotation strategies necessitates a comprehensive understanding and meticulous consideration. Furthermore, the transition from conventional agricultural methods to more sustainable techniques may necessitate an initial financial investment and necessitate adjustments, hence potentially becoming a hindrance for certain farmers. In addition, it should be noted that the effectiveness of sustainable replanting can be influenced by various factors, including the unpredictable nature of climate change and the pressures exerted by the market. Hence, it is imperative to emphasize the significance of ongoing research and the provision of governmental and agricultural institutional backing in order to effectively tackle these difficulties and promote the use of sustainable replanting practices within contemporary agricultural systems.

2.2 Simulation in Agriculture

The utilization of simulation within the agricultural domain is a significant instrument that enables agricultural scientists and farmers to comprehend and effectively handle the intricacies inherent in agricultural systems [14]. Simulation refers to the utilization of mathematical models to depict agricultural processes, enabling stakeholders to evaluate and explore different possibilities without the need for costly or time-intensive field tests [15]. This comprehensive study encompasses a range of agricultural dimensions, including crop cultivation, pest control, and the impact of climate change on crop productivity. Agriculture employs various types of simulations. Physical simulation involves the testing of physical models of agricultural systems either in the field or on a smaller scale. However, computer simulation is frequently employed in numerous instances. This entails use computer software to simulate diverse facets of agriculture, including the growth of crops, utilization of water, and the impacts of alterations in weather patterns. Simulation models utilized in the field of agriculture can exhibit varying degrees of complexity, contingent upon their intended objectives. The example of this simulation can be seen in Figure 2.

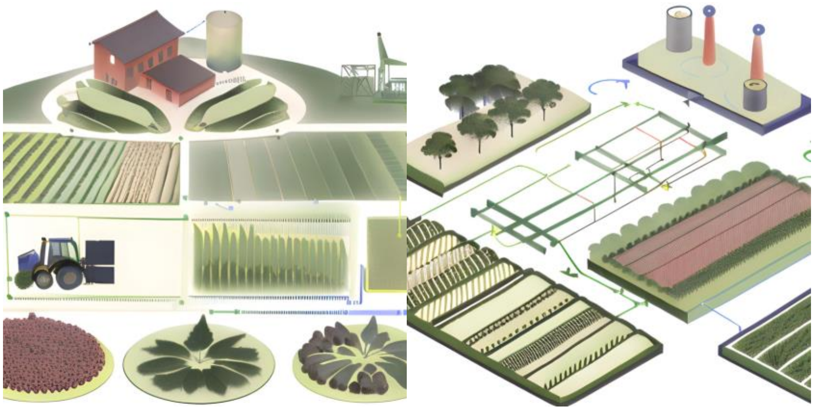

Fig. 2. Simulation in agriculture.

The utilization of simulation techniques in the field of agriculture offers a multitude of notable advantages. Simulation enables scientists to gain a comprehensive understanding of the intricate interplay between environmental elements and agricultural methods. Simulation models can be utilized to forecast the impact of weather fluctuations on crop productivity, enabling farmers to implement suitable preventive measures. Furthermore, simulations provide stakeholders with the opportunity to evaluate various farm management scenarios, including the selection of crop types and irrigation schedules, in order to ascertain their effects on agricultural output and sustainability. Simulation has been employed in a diverse range of agricultural applications. In the field of pest management, simulation techniques can be employed by researchers to gain insights into the temporal dynamics of pest populations and the impact of pesticide application on these populations. Simulation is a valuable tool in the field of irrigation management, as it enables the development of optimal watering schedules that are both effective and sustainable. These schedules are designed by taking into account various factors such as soil characteristics and prevailing climate conditions. Furthermore, simulations can play a crucial role in the process of replanting planning by aiding farmers in the selection of appropriate crop kinds and the establishment of an optimal cropping pattern that ensures the preservation of soil quality.

Although simulation has proven to be highly advantageous in the field of agriculture, it is not without its limitations. One of the factors to consider is the precision of the input data. The efficacy of simulation models is contingent upon the quality of the data utilized, thereby underscoring the significance of employing accurate and current data. Furthermore, the utilization of intricate simulations frequently necessitates the acquisition of costly gear and software, along with the requisite proficiency to effectively operate these resources. Hence, the availability of adequate training and resources can pose as a hindrance to the utilization of simulation techniques in the field of agriculture. However, the significant advantages associated with simulation in terms of enhancing farming techniques, promoting sustainability, and augmenting crop productivity establish it as a crucial instrument in contemporary agricultural practices.

2.3 Computer Simulation

Computer simulation is a methodology that employs computer software to construct a mathematical representation of a given system or process for the purpose of analysis and investigation [16]. Within the domain of agriculture, computer simulation entails the utilization of specialist software to construct models that elucidate diverse facets of agricultural systems, encompassing crop development, water utilization, and the impact of climate change [17]. These models enable researchers and farmers to evaluate various scenarios and assess their effects on agricultural output, therefore avoiding the need for expensive and time-consuming field tests. The progression of computer simulation models within the agricultural domain encompasses various pivotal phases. Initially, it is imperative to gather relevant data in order to provide a comprehensive description of the system that is to be represented. This may encompass information pertaining to the varieties of crops employed, soil characteristics, climatic patterns, and the agricultural methodologies employed. Subsequently, the aforementioned data is utilized to create a mathematical model that delineates the interrelationships among the various constituents inside the agricultural framework. Simulation software is utilized to integrate these models, enabling users to replicate a wide range of scenarios as shown in Figure 3.

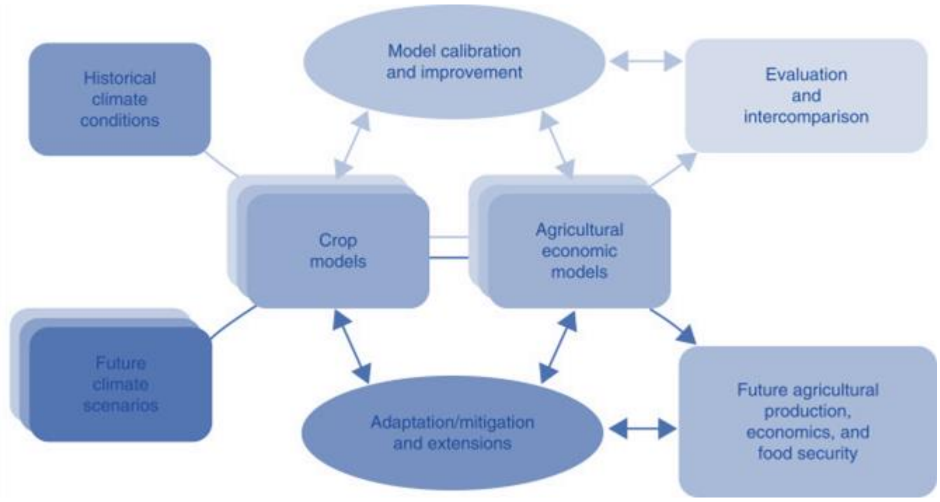

Fig. 3. Factors in agriculture simulation

The utilization of computer simulation in agriculture has numerous advantages that render it highly valuable in this field. One of the primary benefits is in its capacity to evaluate various circumstances without causing any interference with the regular farming activities. This implies that farmers and researchers have the ability to strategically plan alterations or experiment with novel approaches without incurring any immediate negative impact on crop productivity. Furthermore, computer simulation enables the modeling of intricate systems that may pose challenges or incur significant costs when subjected to real-world testing. This analysis offers a more comprehensive understanding of the various elements that can influence agricultural production. Computer simulation has found several applications within the field of agriculture. In the context of irrigation management, farmers have the option to employ simulation software as a means to strategize optimal watering schedules by taking into account pertinent weather data and prevailing soil conditions. Simulation can be utilized in the process of crop variety selection to forecast potential yields of diverse crop varieties across varied environmental conditions. Furthermore, the utilization of computer simulation models enables researchers to assess the potential impacts of climate change by examining the effects of variations in temperature and precipitation on crop productivity and water resources. Computer simulations offer numerous advantages; yet, their utilization is not without its obstacles that necessitate resolution. One of the primary obstacles is in the attainment of model correctness. In order to yield dependable outcomes, simulation models must exhibit congruence with actual data. The successful execution of this task necessitates a profound comprehension of the system under investigation as well as meticulous data gathering. Furthermore, the execution of computer simulations necessitates substantial resources, encompassing high-performance computing systems and costly software applications. Hence, the adoption and utilization of computer simulations in an agricultural environment may necessitate an initial investment and the acquisition of technical skills.

3 Method

3.1 Data collection and integration

The collection and integration of data play a pivotal role in the initial phase of constructing a simulation system. The process entails the acquisition of diverse data sets essential for comprehending the system under consideration for modeling purposes, alongside their integration into a cohesive database. In the realm of agricultural simulation system development, the necessary data encompasses several elements such as soil conditions, historical weather data, crop production estimates, market pricing, and additional economic aspects. The process of integrating this data facilitates the development of more precise and pertinent models in subsequent simulations. The process of data collection encompasses various stages, including conducting field surveys, employing sensor technology, and accessing pre-existing databases. In the context of assessing soil conditions, researchers often employ a combination of field-based physical and chemical testing, as well as laboratory-based analysis of collected soil samples. Furthermore, weather data can be acquired via nearby weather stations or through online sources of meteorological data. Crop production forecasts can be obtained by extrapolating from prior scientific investigations or pertinent historical records. It is imperative to meticulously gather all of the aforementioned data, ensuring that the methods employed for data collection are suitable for the specific requirements of the simulation project.

Table 1. Weather data on the year of 2022.

Months	Precipitation (mm)	Average temperature (°C)
January	120	30
February	100	31
March	80	31
April	60	32
May	70	32
June	90	31
July	110	30
August	120	30
September	130	30
October	140	31
November	150	31
December	140	30

The presented table provides monthly weather data for the year 2022. The weather data encompasses measurements of monthly precipitation in millimetres (mm) and monthly mean temperature in degrees Celsius (°C). The provided data serves the purpose of documenting the meteorological conditions experienced at a certain geographical site throughout the year 2022. As an illustration, during the month of January, the recorded precipitation amounted to 120 millimetres, while the mean temperature was approximately 30 degrees Celsius. Data of this nature holds significant importance within the field of agriculture due to its direct impact on crop growth, irrigation requirements, and soil health.

Table 2. Natural rubber and oil palm yield projections.

Year	Natural rubber (kg^3)	Oil palm (kg^3)
2021	200	5000
2022	225	5100
2023	230	5802
2024	235	6310
2025	245	6560

The following table presents projected yields of natural rubber in metric tons for the forthcoming years, commencing from 2021 and extending until 2025. The provided projections serve to depict the anticipated agricultural outputs of natural rubber plants. As an illustration, it is anticipated that the natural rubber production will amount to 230 tons in the year 2023. Projections of yield, such as the one presented, serve as valuable tools for farmers and decision-makers involved in the realm of agriculture, aiding them in the process of long-term planning and allocation of resources. The table additionally presents estimations of oil palm yields in metric tons for the forthcoming years, commencing from 2021 through 2025. The aforementioned forecasts offer an approximation of the expected oil palm crop yield. As an illustration, it is estimated that the oil palm yield in the year 2023 will amount to 5400 tons. This information plays a crucial role in facilitating the production planning and administration of oil palm plants. The yield predictions hold significance in formulating agricultural policies and allocating resources to effectively address market demand. The amalgamation of these three tables yields crucial data that is utilized in the process of agricultural decision-making. Weather data offers valuable insights into the environmental factors that impact the growth of crops. Projections of natural rubber and palm oil yields contribute to the strategic planning of future agricultural production. The aforementioned instances of data can be utilized in the creation of simulation or analytic systems with the aim of enhancing agricultural operations and proactively addressing potential obstacles that may emerge in the future.

3.2 Model development

A simulation model was designed to include machine learning methods for the purpose of predicting agricultural yields in varying environmental circumstances. In addition, the model incorporates economic variables, including as market pricing and production costs, in order to assess the economic viability of actions related to replanting. This section delineates the procedural steps involved in constructing a simulation model within the confines of a particular research endeavour or project. A simulation model refers to a mathematical depiction of the system under investigation. The process of model development encompasses several key steps, namely the selection of an acceptable model type, the design of the model structure, and the development of algorithms and parameters that align with the research or simulation objectives.

The selection of the simulation model type is a critical initial phase. The selection of models might vary from elementary mathematical models to intricate agent-based models or physics models. The determination of this selection is contingent upon the intricacy of the system to be simulated and the kind of the accessible data. For instance, in the context of a research study including the investigation of plant growth, the utilization of a mathematical model specifically designed to simulate and depict the dynamics of plant population changes over a given period of time can be employed. At this juncture, it is imperative to deliberate on the choice between a static or dynamic model, in addition to determining the specific data requirements essential for an accurate simulation of the system. The process of designing the model structure entails the development of a conceptual framework that delineates the manner in which the various components within the system engage in interactions with one another. This task entails elucidating the interconnections among variables and analyzing their impact on the outcomes of the simulation. In the process of model building, this particular component also plays a crucial role in determining the manner in which variables will be expressed, either through mathematical equations or rules, that effectively outline the system's behaviour. In the context of a plant development model, the configuration of the structure may encompass the interplay between the quantity of water accessible, soil nutrients, and the rate of plant growth.

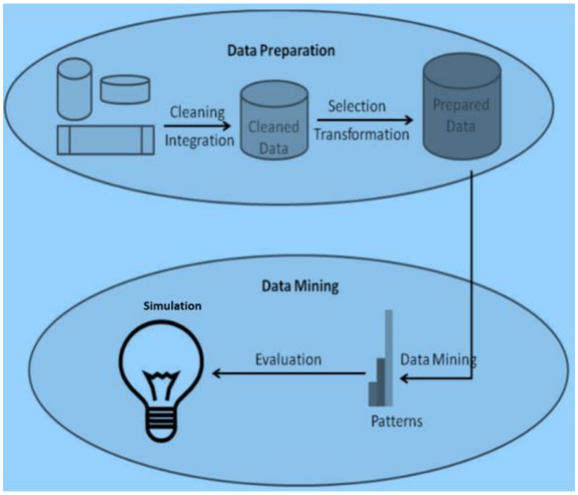

Fig. 4. Proposed simulation model.

The process of designing the model from Fig 4 structure entails the development of a conceptual framework that delineates the manner in which the various components within the system engage in interactions with one another. This task entails elucidating the interconnections among variables and analyzing the impact of these variables on the outcomes of the simulation. In the process of model building, this component also plays a crucial role in determining the manner in which variables will be expressed, specifically through mathematical equations or rules that elucidate the system's behaviour. In the context of a plant development model, the configuration of the structure may encompass the interplay between the quantity of water accessible, soil nutrients, and the rate of plant growth. After the formulation of the model structure, the subsequent stage involves the development of algorithms that will be employed in the simulation process. This encompasses the computational procedures that establish the manner in which the system will be assessed during its duration. Furthermore, it is imperative to ascertain or modify the parameters of the model in order to align with established empirical or experimental evidence. The process of constructing a plant growth model involves the formulation of an algorithm that characterizes the growth patterns of the plant population. Essential parameters, such as the growth rate and water consumption rate, are determined through the estimation process, which relies on empirical data or existing scientific investigations. This particular stage plays a crucial role in the advancement of a simulation system, since any flaws or uncertainties in the model's design can greatly influence the precision and applicability of the simulation outcomes. Hence, the careful selection of an appropriate model type, meticulous design of the structure, and precise creation of algorithms and parameters play a pivotal role in ensuring the success of a simulation project.

3.3 Scenario analysis

The scenario analysis holds significant importance within the simulation process as it facilitates the exploration of diverse scenarios or alternative events in order to comprehend their effects on the system under investigation. In the realm of simulation, a scenario refers to a composite arrangement of diverse variables or parameters employed to delineate distinct scenarios. Scenario analysis is a valuable tool that enables stakeholders to effectively discern and evaluate the potential risks, opportunities, and outcomes associated with different actions or alterations within the system's environment. The initial stage of scenario analysis involves the identification of pertinent scenarios that are applicable to the simulation's objective. This process entails the identification and prioritization of variables that exert significant influence on the system or possess notable research value. In the context of agricultural simulations, pivotal scenarios may encompass extreme weather fluctuations, alterations in farming methodologies, fluctuations in commodity prices, or shifts in government policies. The identification of these scenarios is predicated upon the utilization of preexisting knowledge and information, alongside the inclusion of stakeholder consultation.

After the identification of the essential situations, the subsequent phase involves the implementation of such scenarios within the simulation model. This process entails assigning values to variables or parameters based on the specified circumstances for each given scenario. In the context of agricultural simulations, this entails modifying the meteorological data to accurately represent a certain weather situation or adjusting parameters within a crop growth model to accurately reflect alterations in farming techniques. Subsequently, the simulation is executed for every individual scenario, and the outcomes are duly documented. Following the execution of the simulation for each scenario, the outcomes are assessed and examined. This necessitates comprehending the repercussions of each scenario on the system and the objectives to be attained. The outcomes of this research can be utilized by stakeholders to enhance decision-making processes, strategize risk mitigation measures, and examine potential possibilities that may emerge in different circumstances. Scenario analysis is a valuable tool for formulating plans that are adaptable and grounded on empirical evidence, particularly when confronted with uncertainties and shifts within the system's environment. Simulation is a crucial element in the application of decision-making processes, as it facilitates the exploration of multiple potential scenarios and enables stakeholders to make informed choices based on the outcomes of conducted simulations. The process of identification assumes a significant role in discerning superior and highly flexible resolutions when confronted with intricate and heterogeneous predicaments across several domains, including economics, environment, and agriculture.

4 Result and Discussion

The sustainable replanting simulation system was implemented in a case study conducted in North Sumatra. The findings of the study indicate that the utilization of the system has the potential to assist agricultural planners in enhancing their decision-making process regarding replanting strategies. This, in turn, can result in higher crop yields, less environmental consequences, and enhanced economic outcomes.The three scenarios were initially assessed by employing a consistent variation across all fields and during all seasons. The purpose of this action was to control for the impact of field selection by mitigating the potential influence of minor variations in the assortment of crops on the outcomes.

The results are compared in the "field selection" row of Table 3. The replant plan, which was developed using the field selection algorithm, resulted in a 0.6% increase in sucrose production compared to the existing replant plan seen across the four seasons. Nevertheless, it is worth noting that both replantation strategies yielded a marginal advantage of less than two percent compared to the situation when no planting was conducted. The findings indicate that the field selection algorithm exhibits a satisfactory level of effectiveness. However, it is worth noting that the potential for significant improvements through field selection is somewhat constrained.

A subsequent series of simulations was carried out in order to examine the impact of the altered field harvest sequence. The simulations utilized a comprehensive array of variations. The harvest plan for each scenario was initially determined using the "oldest first" cutting sequence, a commonly employed method by several estates. The scenarios were afterwards reassessed with the harvest sequence that was optimized for the purpose of maximizing sucrose production.

The findings are presented in Table 3 under the 'cutting sequence' category. In every situation, the altered cutting sequence resulted in a favourable outcome compared to the conventional procedure. The extent of the advantage was contingent upon the extent to which the replant plan included the variety with the most pronounced sucrose curve. According to the software's recommendation, this particular variety was deemed preferable in the plan, and the altered cutting sequence resulted in a 0.6% increase in sucrose yield compared to the regular cutting sequence.

Table 3. Natural rubber and oil palm yield projections.

	No Planting	Actual Planting	Recommended Planting
Field disposition	19881	20.815	21.152
Total field area (ha)			
Area replanted (ha)	0	8.152	8.210
Fields replanted	0	613	625
Field selection			
Crop yields with single variety	2.138 m	2.012 m	1.918 m
Benefit of planting (%)		1.2	2.5
Cutting sequence			

Crop yields with all varieties using oldest-first sequence (t)	1.284 m	1.314 m	1.515 m
Crop yields with all varieties using modified cut sequence (t)	1.288 m	1.358 m	1.384 m
Benefit of sequence optimisation (%)	0.6	0.8	0.8

The phenomenon of fields migrating within the cutting sequence towards their preferred time of harvest was readily apparent in each scenario, as observed by comparing the altered cutting sequence across consecutive seasons. The quantity of sucrose generated during the initial season was consistent, irrespective of the cutting sequence employed. The reason for this phenomenon can be attributed to the alteration in the cutting sequence of each field, which resulted in a deviation from the optimal age for cutting. Consequently, this counteracted the advantages associated with sucrose yield. Nevertheless, the benefits of the modified cut sequence shown a progressive increase over subsequent seasons, coinciding with the stabilization of the age at which the cut was made. In the fourth season, the altered cutting sequence resulted in a one percent increase in total sucrose production compared to the regular cut sequence, without any concurrent increase in cane productivity. The findings exhibited equal applicability across all three scenarios.

5 Conclusion

The implementation of a sustainable replanting simulation system signifies a notable advancement in the promotion of agricultural methods that prioritize sustainability. This system offers decision-makers a robust tool for the planning and management of replanting efforts by incorporating data analytics and simulation methodologies. Additional research and practical applications are required in order to enhance the system and evaluate its potential for scalability and adaptability across diverse agricultural locations [18][19]. Despite its relatively small size, this potential improvement in production was achieved without any corresponding rise in spending. The observed rise in productivity may be solely attributable to the improvement in decision-making processes. Furthermore, it is important to acknowledge that this estate is effectively administered and possesses solid field recordings through the Simulation, which provide as valuable resources for informed decision-making. The potential advantages of yield benefits are likely to be more pronounced in situations where estates face constraints in accessing technical competence and have restricted availability of information resources. One of the benefits provided by this simulation is the provision of access to technical expertise. The integration of technically intricate concepts, which are typically not easily accessible to commercial managers, can be effectively incorporated into a user-friendly interface inside a Management Information System (MIS) [20], [21], [22]. This integration aims to facilitate and enhance the process of commercial decision making.

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