Harvesting Efficiency: Mathematics applied to the land

Modeling Laboratory - Group Work. Optimization

Juan Agustín Lorca García

Paula Marín Turpín

Andrea Martos García

Rebeca Molina Bernal

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University of Murcia

Faculty of Mathematics

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Introduction

In today's world, where efficiency and strategic decision-making make the difference between moving forward or falling behind, task management within a company plays a fundamental role. Many times, behind a good product or service, there is precise planning, careful coordination, and optimal use of the available resources. In this context, mathematics, and more specifically, optimization, becomes a powerful tool for transforming complexity into clear and applicable solutions.

This work arises with the intention of building a bridge between theoretical knowledge and its practical application in the business environment. We have chosen Intercrop, a company based in Cartagena specializing in the agri-food sector, as our case study. Intercrop stands out for its commitment to sustainability and innovation in agricultural production, but like any company, it faces logistical and organizational challenges that require smart solutions. Intercrop not only operates at a national level but also maintains a close relationship with the international market. It exports a significant part of its production to various European countries, which demands high quality standards, strict deadline compliance, and a well-structured logistics system. This international dimension adds complexity to its operational management, as it must coordinate agricultural tasks with transport schedules, phytosanitary requirements, and commercial commitments abroad. All of this makes the company a particularly interesting environment for applying optimization tools that can help improve planning and efficiency in a real and demanding context.

Through this project, we will address the task scheduling problem within the company. The goal is to design an optimization model that efficiently organizes activities, taking into account real-world constraints: time, limited resources, task dependencies, and other logistical factors. This process will not only allow us to provide the company with a proposal for improvement, but also to apply in a practical way the mathematical concepts learned in the classroom, especially those related to linear programming and optimization.

Glossary

In order to facilitate the reading and understanding of this work, a glossary of the main technical and specific agricultural terms that will be used throughout the document is included below. This compilation is intended to provide a quick and accessible reference for the reader, especially with regard to practices, tools, crops and phases of the agricultural cycle. The terms are presented in alphabetical order for better location.

harvesting Collecting the different products once they have matured.. 3

hoops Usually iron arches placed on the row. The mesh is often placed on top, creating a space between the crops and the mesh. . 5

mesh Flexible structures placed over crops to protect the plants from external factors. . 5

row Elevated land surfaces where different crops are cultivated. Their length varies depending on the size of the farms, but they are usually 1.6 meters wide.. 3, 4

slope Narrow strips of land between the rows that allow farmers and tractors to work without damaging the crops.. 5

sowing Scattering seeds directly onto prepared soil for cultivation.. 4

transplanting The introduction of plants in their initial stage of development into the soil. . 3

Figure 1: Real view of the farm

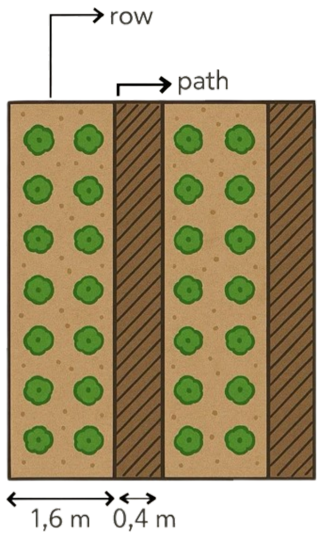

Figure 2: Aerial diagram of the parts of a farm

Problem Statement

Task planning in the agricultural sector represents a significant logistical and operational challenge, especially for companies operating under a made-to-order production model, as is the case with Intercrop. This company, located in Cartagena and specialized in horticultural products, organizes its production based on seasonal demand. During the summer campaign, both the quantity of product to be supplied and the specific delivery dates are established in advance. This means that all planning—from cultivation and growth to harvesting$^{(*)}$ and distribution—must be precisely aligned to meet deadlines, ensure the quality of the fresh product (with a shelf life of seven to ten days), and minimize operational costs.

Given the data of an order, we must take into account the number of rows$^{(*)}$ that need to be transplanting$^{(*)}$ for each variety in order to fulfill it. A small surplus is transplanted as a precautionary measure to ensure the required amount is met. This surplus does not need to be considered in the planning, as it generates no additional cost and is later offered to the clients.

The objective of this work is to address, from a mathematical and practical perspective, the problem of agricultural task scheduling within the real-world context of this company. To this end, we will focus on two main crops: lettuce and spinach, including two varieties of lettuce and five varieties of spinach.

- **Lettuce**: it is grown in two varieties, one with curly leaves (Apollo, Fig. 3) and the other with smooth leaves (Knox Cos, Fig. 4). The curly leaf lettuce is more delicate and requires special care. In contrast, the smooth leaf lettuce is more resilient and better suited to less precise conditions.
- **Spinach**: five varieties are grown: one with small leaves, both in its common version (Baby Spinach, Fig. 5) and in its organic version; medium-sized leaves in both green (Teen Spinach, Fig. 6) and a more reddish color (Red Spinach, Fig. 7). There is also a flat-leaf variety intended for soup preparation (Soup Spinach, Fig. 8). Regarding differences in treatment, there are no substantial changes in care.

The main difference between the varieties we are considering is the cultivation time required for each of them.

Figure 3: Lettuce variety Apollo.

Figure 4: Lettuce variety Knox Cos.

Figure 5: Variety Baby Spinach.

Figure 6: Variety Teen Spinach.

Figure 7: Variety Red Spinach.

Figure 8: Variety Soup Spinach.

Before breaking down the tasks involved in the cultivation process, it is important to highlight a fundamental difference between the two products. Lettuce is grown through transplanting: seeds are sent to a nursery and later the seedlings are transplanted into the field. In the case of spinach, the direct sowing method is used, placing the seeds directly into the soil. Due to the different nature of these methods, each crop will have its own specific timelines and requirements, which will influence task scheduling.

The list of tasks required to complete a cultivation cycle is as follows:

1. Soil preparation: a set of initial tasks in which the soil is broken up and turned to aerate it, and fertilized to ensure it is properly conditioned before cultivation. Next, using specialized machinery, the cultivation surfaces are arranged into rows(*).
2. Install paper: sheets are installed to prevent the growth of weeds, thereby reducing competition with the main crop.
3. sowing(*) or transplanting: depending on the crop variety, seeds are sown directly or previously grown seedlings from an external company are transplanted.
4. Placing hoops(*): metal arches are installed over the crops to support the subsequent protective

covering.

5. Installing mesh$^{(*)}$: the hoops are covered with a polyamide mesh that protects the crops and helps maintain the proper temperature for their development.
6. Installing irrigation: installation of sprinkler irrigation systems on the slopes$^{(*)}$ of the rows, essential for maintaining the crop.
7. Removing mesh: once the crop has matured, the protective mesh is removed.
8. Removing hoops: after the mesh has been taken off, the metal hoops are dismantled.
9. Removing irrigation: the previously installed irrigation system is disassembled.
10. Harvesting: final stage of the process, which can be done manually (with workers placing the products into boxes) or through automated methods.

Each of these tasks is carried out using different machinery, generally implements pulled by tractors, which implies different working speeds depending on the equipment used. In addition, Intercrop organizes its production through specialized work groups, which are not hired at the beginning of the season but are gradually incorporated as their tasks become necessary. This structure allows the company to adapt to the needs of the process, but it also creates delays when one group has to wait for another to finish before continuing.

During our visit to the company, we observed that this lack of synchronization between groups often leads to idle time: periods in which workers are present but unable to act, as the previous task has not yet been completed. These hours, though unproductive, are counted in the total working hours and represent a direct economic cost to the company.

The main objective of this proposal is to develop a scheduling model that minimizes unproductive time between work groups, while ensuring that the committed delivery deadlines are met. More efficient coordination of tasks would lead to significantly better resource utilization, reducing waiting times and increasing overall system productivity.

The problem is minimizing unproductive hours, not the costs of these hours, because all employees are paid the same regardless of the task they perform. We'll have to take into account the number of employees on each team, but there's no need to distinguish between them.

Model Simplifications

In order to approach the problem from a mathematical and computational perspective, it has been necessary to make certain simplifications, which allow us to focus on the essential aspects of the process without loss of generality:

- Scale reduction: the model is applied to only two farms, one dedicated to lettuce and the other to spinach. This decision allows us to work with two distinct and representative production lines, without the need to model the company's entire global operation.
- Medium-sized farms: We have selected two farms that, although they have different sizes, are representative of the average size of the company's properties, which allows the same planning scheme to be applied to each one without specific considerations regarding size or shape.
- Homogeneous cultivation: it is assumed that, within each farm, the tasks required for the care of the most delicate variety will be carried out. Therefore, we will assume that in the farm dedicated to lettuce, all tasks from the previously mentioned list are performed, while in the case of spinach, the use of mesh and hoops will be omitted. Thus, the first farm will carry out

all 10 tasks listed earlier, while the spinach farm will only perform tasks 1, 3, 6, 9, and 10. In addition, we will assume that only one type of variety is grown in each row; there will be no rows with mixed cultivation.

- Independent work groups: each crop is managed by a different work group, with its own machinery and resources. This allows both production lines to be treated in a parallel and simplified manner.
- Unit conversion: the machinery speeds, originally provided by the company in kilometers per hour, have been converted to rows per hour to simplify the formulation and adapt the units to the structure of the model.
- Ideal conditions: the model is developed under a scenario with no failures or weather-related interruptions. In other words, it is assumed that all tasks are completed within the estimated time and that there are no delays due to external factors.
- Fixed workday: a standard workday of 8 hours is considered, with no seasonal changes or holidays.

These simplifications do not eliminate the complexity of the problem, but they allow us to structure a realistic, functional, and computationally viable model that can serve as a foundation for future expansion or practical implementation.

Data

During our visit to the company, we were able to observe their working methods. This helped us gain a clear understanding of the workflow we needed to design and identify the data we would require. Subsequently, the company provided us with the specific data we requested.

For our study, we assume that the farms have a rectangular shape. We consider the lettuce farm to measure 100 x 300 meters, while the spinach farm measures 180 x 300 meters. Each row is 1.6 meters wide, with lateral paths of 0.4 meters to allow machinery to pass. This means each path has dimensions of 2 x 300 meters. As a result, the first farm contains 50 paths with their respective 50 rows, while the second contains 90 paths with 90 rows.

The tasks are mechanized, as each is carried out by a tractor equipped with a different implement. Therefore, we need to know the speed the tractor can reach depending on the implement used for each task. Although the company provided these speeds in kilometers per hour (km/h), we converted them to rows per hour to simplify our model formulation.

TASK	**SPEED (row/hour)**	**WORKERS**
Soil preparation	2	4
Install paper	4	2
Transplant	3	6
Sow	4	5
Install irrigation	3	2
Install hoops	3	3
Install mesh	3	2
Remove mesh	4	2
Remove hoops	3	2
Remove irrigation	3	2
Harvest seeds	3	7
Harvest plants	2	14

Table 1: Tasks, speeds, and number of workers per task

Our scheduling is designed to organize one month of work. Considering a standard workday of 8 hours, we work with a total of 240 hours per month.

On the other hand, workers join the campaign in a staggered manner. Each of them is specialized in a specific task, leading to the formation of specialized work groups. The number of workers per group varies depending on the task assigned.

Another important aspect to consider is the time required for each variety to grow. The company provided this information in days, although they noted that in the case of spinach varieties, the growth time is not fixed, as it depends largely on the amount of solar radiation received. For this reason, they gave us a range of days during which each variety is typically harvested, indicating which ones show greater or lesser variability in growth. Using this data, we estimated the optimal time for harvesting.

Moreover, since we work in hours, we converted the time scale: each day indicated by the company is expressed in our formulation as an eight-hour period. This way, we adjusted the growth times to fit our scheduling framework.

VARIETY	DAYS	HOURS
Apollo	24	176
Knox Cos	22	192
Baby spinach	24	192
Teen Spinach	23.4	208
Baby spinach organic	26	176
Soup Spinach	25.4	187
Red Spinach	22	203

Table 2: Table of Varieties and Growth Time

The company gave us a series of data on the quantity in kilograms they obtain of each type of product from one hectare of land. For lettuce, the yield is 10 000 kg, while for spinach, it's 12 000 kg. We adjusted this data to the size of our two plots of land to obtain the number of kilograms obtained from each type.

VARIETY	KG/ROW	KG ORDERED	KG PLANTED
Apollo	600	19374	21600
Knox Cos	600	7956	8400
Baby spinach	720	29919	32400
Teen Spinach	720	3153	3600
Baby spinach organic	720	8524	9360
Soup Spinach	720	7229	7920
Red Spinach	720	10237	11720

Table 3: Table of varieties and order in kilograms

Using last year's order records, pre-calculating the quantity of each product to be distributed on each row, and following the planting policy outlined in the "Problem Statement," we then allocate the corresponding number of plots to each variety of each product on the various plots to meet the stipulations.

VARIETY	RANGES	ROWS
Apollo	1-36	36
Knox Cos	37-50	14
Baby spinach	1-45	45
Teen Spinach	46-50	5
Baby spinach organic	51-63	13
Soup Spinach	64-74	11
Red Spinach	75-90	16

Table 4: Table of varieties and rows

Formulation

To address agricultural task scheduling in a structured and optimizable manner, we have developed a mathematical model that formally describes the constraints, resources, and objectives of the problem at hand. This formulation will enable us to find an efficient task allocation that minimizes unproductive time, ensuring that all tasks are performed in accordance with their technical and temporal requirements.

Parameters

The first step is to define a set of parameters that accurately represent the working environment in both farms, each dedicated to a different product (lettuce and spinach), and therefore, as previously mentioned, with distinct task sequences.

Set of Tasks

- Set of tasks for Farm 1, dedicated to lettuce:

$$T_1 := \{preptierra1, papel1, plantar1, ponerarquillo1, ponermalla1, ponerriego1, quitarmalla1, quitararquillo1, quitarriego1, cosechar1\}$$

- Set of tasks for Farm 2, dedicated to spinach:

$$T_2 := \{preptierra2, sembrar2, ponerriego2, quitarriego2, cosechar2\}$$

Varieties and Growth Times

Each farm contains different varieties of the same product, which are distributed homogeneously across the rows:

$$Q_1 := \{apollo, knoxcos\}$$
$$Q_2 := \{babyspinach, teenspinach, babyspinachorganic, soupspinach, redspinach\}$$

Each of them will have a specific growth time:

$$S_1 := \{s_{apollo}, s_{knoxcos}\}$$
$$S_2 := \{s_{babyspinach}, s_{teenspinach}, s_{babyspinachorganic}, s_{soupspinach}, s_{redspinach}\}$$

Rows and Time Horizon

For each farm, we define the corresponding set of rows (M_j), the total number of rows (N_j), and the set of working hours (H) available during the order period:

$$
\begin{aligned}
M_1 &:= \{1....50\} \\
M_2 &:= \{1....90\} \\
N_1 &:= 50 \\
N_2 &:= 90 \\
H &:= \{1...240\}
\end{aligned}
$$

Distribution od varieties

Below is a family of sets that structure the distribution of different varieties based on their planting location. Specifically, these sets refer to the specific plateaus or growing areas associated with each variety, thus providing a clear basis for model parameterization.

$$
\begin{aligned}
D_1 &:= \{D_{apollo}, D_{knoxccos}\} \\
D_2 &:= \{D_{babyspinach}, D_{teenspinach}, D_{babyspinachorganic}, D_{soupspinach}, D_{redspinach}\}
\end{aligned}
$$

Task Time Availability

The time availability is considered from the moment the work team is hired until a hypothetical last hour of performance, due to the non-heterogeneous speeds of the tasks, as the teams are paid from the moment they are hired until they are dismissed, it is not beneficial to hire them almost at the same moment since the previous work team is already acting if care is not taken since unproductivity quickly occurs if this task has a higher pace.

Now, as for the upper limit of these schedules, for the post-planting tasks of the variety, simply the harvesting task will have a limit of 240, and because of this the others will have 1 hour less consecutively. At the same time, for the pre-planting tasks, we will take as reference the irrigation task in both lands which is the beginning of the growth process, as the order has to be fulfilled this means that all the tasks have had to be carried out within the stipulated margin (neither too early, nor after 240 hours), therefore the variety with the shortest growth time is the one that will mark this limit.

As an example, we are in land 2, the variety is Baby Spinach Organic which has a growth time of 176, that means that for them to grow before hour 240, at most this task would have to have been completed in hour 64, but this will not be the quota since before harvesting we have to remove this irrigation, so the quota will be at hour 63, and as we have explained before, the other tasks will have 1 hour less consecutively in their quota (62, 61, ...). This perfectly simulates the work scheme that the company follows of "at most I have to have completed this task in this hour".

$$
\begin{aligned}
H_1 := \{&H_{preptierra1}, H_{papel1}, H_{plantar1}, H_{ponerarquillo1}, H_{ponermalla1}, H_{ponerriego1}, H_{quitarmalla1}, \\
&H_{quitararquillo1}, H_{quitarriego1}, H_{cosechar1}\} \\
H_2 := \{&H_{preptierra2}, H_{sembrar2}, H_{ponerriego2}, H_{quitarriego2}, H_{cosechar2}\}
\end{aligned}
$$

Working Speed of Machines

Each task is performed using different machinery, and therefore at different speeds. These are expressed in rows per hour:

$$V_{i_1} := \text{maximum number of rows performs task } i_1 \in T_1 \text{ in one hour.}$$

$$V_{i_2} := \text{maximum number of beds performs task } i_2 \in T_2 \text{ in one hour.}$$

Personnel Assigned to Each Task

Each task has an assigned work group, which includes the number of people required for its execution.

$$P_{i_1} := \text{number of people assigned to task } i_1 \in T_1$$

$$P_{i_2} := \text{number of people assigned to task } i_2 \in T_2$$

Decision Variables

To correctly model the execution of tasks on each rows and at each moment within the time horizon, the following binary variable is defined:

$$x_{i_jkl} = \begin{cases} 1 & \text{if task } i_j \text{ is performed on row } k \text{ at hour } l \\ 0 & \text{otherwise} \end{cases}$$

where:

- i_j represents a task belonging to the set T_j.
- $k \in M_j$ represents one of the rows in farm j.
- $l \in H_{i_j}$ represents an hour within the availability interval of task $i_j \in T_j$.

On the other hand, to know the hiring time of the work groups we introduce the following variable

$$w_{i_jl} = \begin{cases} 1 & \text{if task } i_j \in T_j \text{ can still be assigned to a row at hour } l \in H_{i_j} \\ 0 & \text{otherwise} \end{cases}$$

Constraints

The agricultural scheduling model must ensure that task execution aligns with operational capacities, the available calendar, and the logical order of the production process. To achieve this, the following constraints have been defined:

- We cannot assign more rows per hour than what the task allows. The execution speed of each task is determined by the tractor; therefore, we cannot assign more rows than can be handled in one hour. To enforce this, we fix a specific hour and task and iterate over all rows. The total number of assignments must not exceed the maximum number of rows the machinery can process per hour.
$$\sum_{k \in M_j} x_{i_jkl} \leq V_{i_j} \quad \forall i_j \in T_j,\ l \in H_{i_j}$$
- Each task can only be performed once on the rows where it is applicable. To ensure this, we fix a row and a task, and require that the sum over all hours in its schedule equals 1. Otherwise,

the task would either not be performed (if the sum is 0) or performed more than once (if the sum exceeds 1).

$$\sum_{l \in H_{i_j}} x_{i_j k l} = 1 \quad \forall i_j \in T_j, k \in M_j$$

- Tasks follow a specific order that must be respected. We cannot perform the next task on a row without having completed the previous one. We must ensure that the preceding task has been completed on that row before the current one can begin.

  To enforce this, we fix a row, a task, and a time, and verify that the previous task has been executed during the preceding hours.

$$x_{i_j k l} \leq \sum_{l' \in H_{prev(i_j)}, l' < l} x_{prev(i_j) k l'} \quad \forall i_j \in T_j \setminus \{first(T_j)\}, k \in M_j, l \in H_{i_j}$$

- The growth period of each variety must be respected. Once irrigation is in place, the plant begins to grow, and it must remain undisturbed for a certain period until it reaches maturity. This duration depends on the specific variety. Only after this growth time has elapsed can the subsequent tasks be performed.

$$x_{\text{quitarmalla1}kl} \leq \sum_{l' \in H_{ponerriego1},\ l' < l - s_q} x_{\text{ponerriego1}kl'} \quad \forall\ q \in,\ Q_1,\ k \in D_q$$

  For the varieties in the second farm, we will have:

$$x_{\text{quitarriego2}kl} \leq \sum_{l' \in H_{ponerriego2},\ l' < l - s_q} x_{\text{ponerriego2}kl'} \quad \forall\ q \in Q_2,\ k \in D_q$$

- Finally, we need a constraint that activates $w_{i_j l}$, that is, one that tells us whether a task can still be performed on a row at hour l.

$$w_{i_j l} \geq \frac{N_j - \sum_{l' < l, l' \in H_{i_j}, k \in M_j} x_{i_j k l'}}{N_j} \qquad \forall\ i_j \in T_j,\ l \in H_{i_j}$$

  In the summation, we count the rows on which a specific task has been completed. This ratio will be 0 when the task has been performed on all rows, and it will be greater than 0 and less than 1 when there are still some rows left to complete.

Objective Function

To define the target function, the first thing we have to try to do is to find the proportion of time lost for each task in each hour of the availability schedule. As each task has a maximum number of plateaus that can be performed in each hour, that proportion will be

$$\frac{V_{i_j} - \sum_{k \in M_j} x_{i_j k l}}{V_{i_j}}$$

To count the number of unproductive hours of each work team, that proportion has to be multiplied by the number of people, P_{i_j}, of each task.

As we have said previously, the beginning of the schedule of each task marks the hiring of this work team, that is why our variable w_{i_jl} helps us to determine at what moment our work team stops being hired since it has no more possible assignments and does not count any more unproductive hours.

The objective function is therefore:

$$min \sum_{i_j \in T_j, l \in H_{i_j}} P_{i_j} \left(\frac{V_{i_j} - \sum_{k \in M_j} x_{i_jkl}}{V_{i_j}} \right) w_{i_jl}$$

The presence of the product of binary variables x_{i_jkl} and w_{i_jl} makes the initial objective function nonlinear. Since linear optimization is considerably more efficient and allows for the use of more robust standard solving algorithms, we decided to linearize the model.

To achieve this, we introduce auxiliary variables defined as follows:

$$\delta_{i_jkl} = x_{i_jkl} w_{i_jl} \ \forall i_j \in T_j, k \in M_j, l \in H_{i_j}$$

These auxiliary variables are restricted by the following conditions, which ensure that their value is equal to that of the product:

$$\begin{aligned}
&\delta_{i_jkl} \leq x_{i_jkl} \quad \forall i_j \in T_j, k \in M_j,\ l \in H_{i_j} \\
&\delta_{i_jkl} \leq w_{i_jl} \quad \forall i_j \in T_j, k \in M_j,\ l \in H_{i_j} \\
&\delta_{i_jkl} \geq x_{i_jkl} + w_{i_jl} - 1 \quad \forall i_j, \in T_j, k \in M_j\ l \in H_{i_j}
\end{aligned}$$

Once these auxiliary variables have been introduced, the objective function is linearized as follows:

$$min \sum_{i_j \in T_j, l \in H_{i_j}} P_{i_j} \left(\frac{V_{i_j} w_{i_jl} - \sum_{k \in M_j} \delta_{i_jkl}}{V_{i_j}} \right)$$

This new formulation preserves the original intent of minimizing unproductive time, while also allowing us to take advantage of the computational efficiency and robustness of linear optimization.

AMPL Implementation

When implementing this problem in AMPL to obtain a solution, several issues arose. Initially, we implemented it using the objective function that included a product of binary variables. However, no solution could be obtained. After 9 hours of solver execution, it was not possible to reach an optimal solution. Although all the constraints were linear, the product of binary variables in the objective function made the problem extremely complex to solve.

To avoid this issue, we decided to introduce new variables to linearize the objective function. This increases the number of variables, but allows us to work with a linear objective function, making the problem easier to solve. We began by testing the model using a reduced number of beds to verify that the formulation was functioning correctly. After finding a feasible solution for this highly simplified case, we attempted to solve the model using the full number of beds. However, this approach was unsuccessful, as the problem still could not be solved within a reasonable amount of time. Using the Xpress solver, memory was exhausted in a short time. With Gurobi and CPLEX, the computation time limit was reached without obtaining a solution.

Since we were working with two independent farm, one for lettuce and the other for spinach, we decided to separate the computational part of the problem. We then proceeded to solve each subproblem individually. Nonetheless, computational difficulties persisted in Farm 1. An attempt was made to solve the problem using NEOS, but it failed due to insufficient memory. However, when trying to solve it on a standard computer, a feasible solution was obtained within two and a half hours. NEOS only allows 3GB of RAM, whereas the local machine used had 16GB of RAM, which explains why NEOS was unable to solve the problem.

In Farm 2, with 90 rows and 5 varieties, a solution was successfully found using one of our computer. This solution was estimated to be 11 hours away from reaching optimality. The problem remained complex, and we had no choice but to reduce the execution time in order to obtain a solution, even if it was not optimal.

Spinach requires fewer tasks, which means fewer variables are considered. This improves computational efficiency and allows us to increase the number of rows and varieties, thereby solving a problem that is closer to real-world conditions.

Results

Since we separated the implementation of the problem into distinct subproblems, the result we seek is obtained by summing the two corresponding objective functions. In this case, we determined that the number of unproductive hours in Farm 1 amounts to 29.666, while in Farm 2 it reaches 24.166. Therefore, the total number of unproductive hours in the problem is 53.832. This calculation represents the total idle time across all workers in the task groups involved in both farms.

However, it is not enough to know only the total number of unproductive hours; it is also essential to understand how the tasks are distributed throughout the process in order to achieve this result. The way in which activities are organized and assigned directly impacts the efficiency of the work and the optimization of the available resources.

For this reason, we have collected and analyzed the data in detail, allowing for a clearer understanding of task distribution in each farm. Additionally, to make the information easier to interpret, we chose to exclude from the charts the hours during which the crops are in their growth phase, since no active tasks are carried out by the workers during that period. This allows us to focus exclusively on the periods in which actual work is performed, thus providing a more accurate perspective on overall performance.

Figures 9 and 10 refer to the results for Farm 1, while Figures 11 and 12 show the tasks for Farm 2.

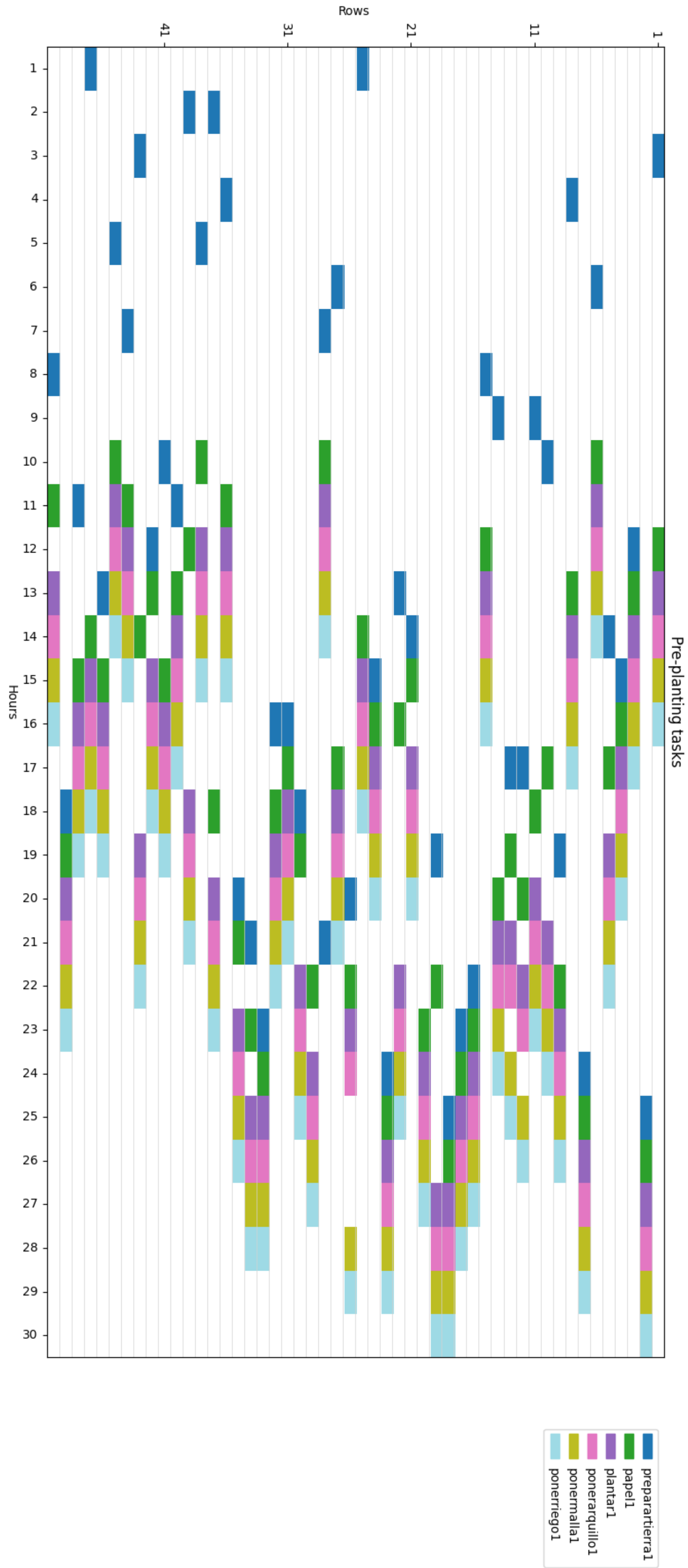

Figure 9: Results obtained from pre-planting task in Farm 1

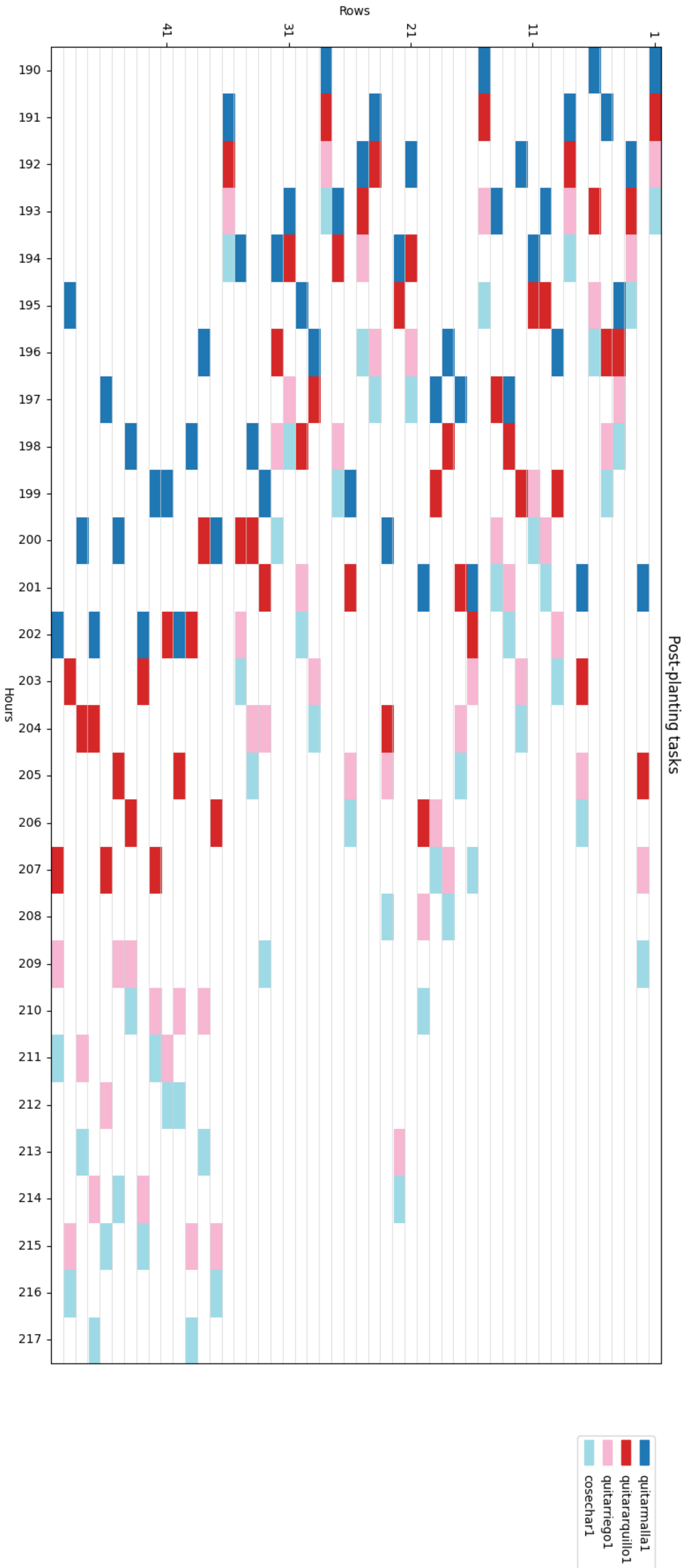

Figure 10: Results obtained from post-planting task in Farm 1

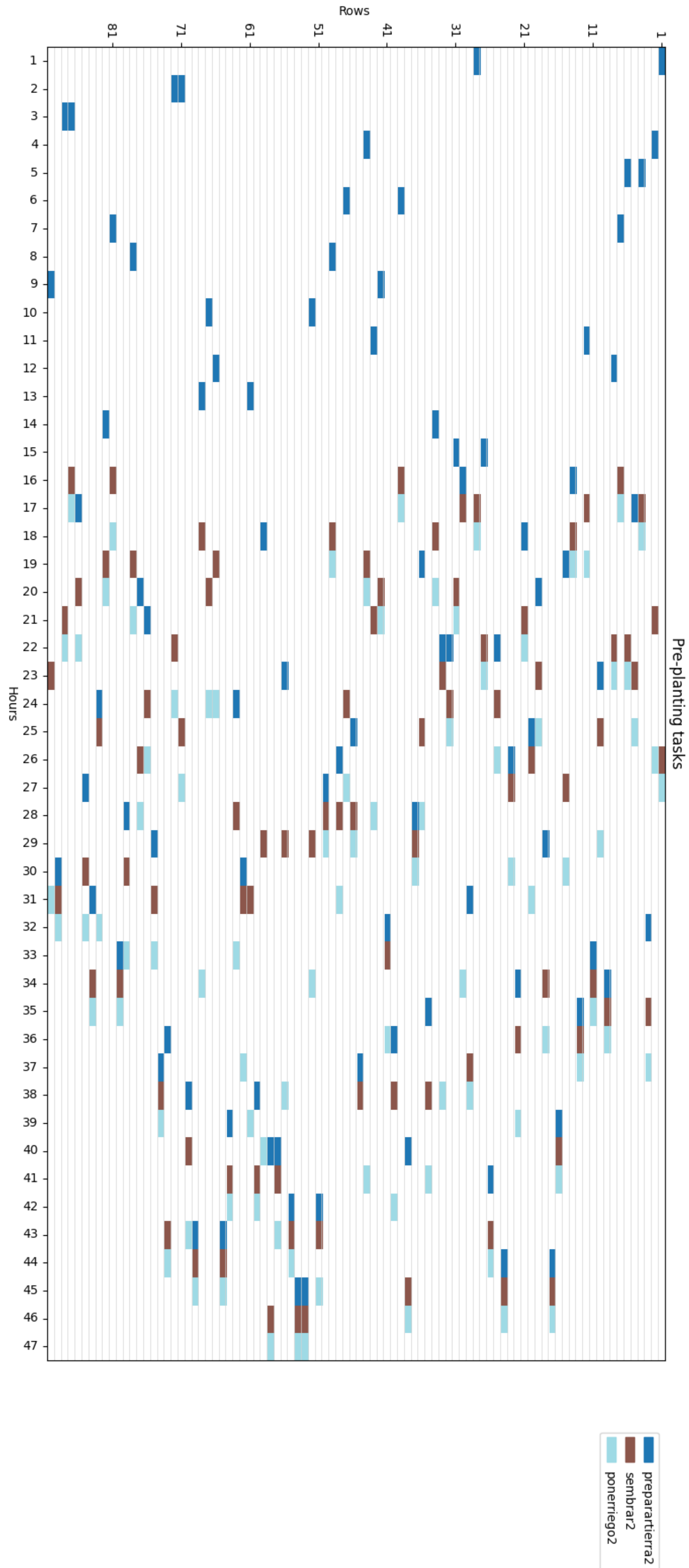

Figure 11: Results obtained from pre-planting task in Farm 2

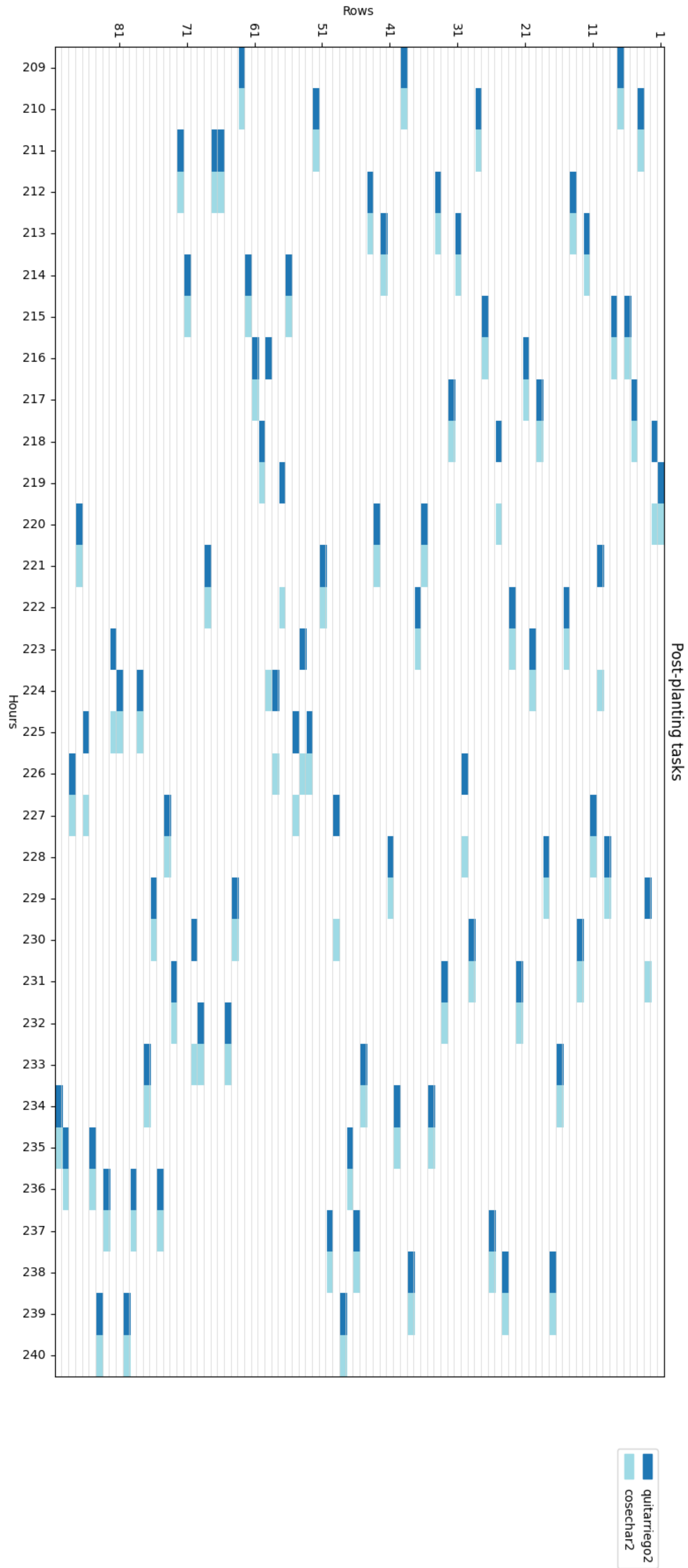

Figure 12: Results obtained from post-planting task in Farm 2

Conclusion

This work has made it possible to address a real agricultural scheduling problem from a mathematical perspective, applying optimization tools to improve work organization at the company Intercrop. Through the analysis of the various tasks required for the cultivation of lettuce and spinach—two key products in the company's production— the operational complexity involved in coordinating teams, machinery, and execution times has been highlighted.

Throughout the project, a simplified but representative model has been developed, with the main objective of minimizing idle time between work groups. This approach addresses a problem observed directly in the farm: the existence of unnecessary waiting periods when a task cannot begin until another one is completed. These idle hours, although inevitable to some extent, represent a direct cost to the company and reduce the overall efficiency of the production system.

The model has been built considering two independent farms, each with its own production line, and a task sequence that spans from soil preparation to harvesting. Despite the simplifications introduced—such as the standardization of field sizes, the absence of adverse weather conditions, or the strict separation between work groups— the approach retains a logical structure that remains faithful to the real process, allowing for practical and scalable conclusions to be drawn.

The development of this work has demonstrated how the mathematical knowledge acquired in the classroom can be successfully applied to real-world problems, providing concrete and quantifiable solutions to everyday situations in professional environments. Moreover, it has opened an interesting path for further exploration of the use of optimization models in agricultural contexts, where efficient decision-making can lead to significant improvements in performance and profitability.

In future phases, additional elements could be incorporated into the model, such as climate variability, mechanical failures, or the partial availability of machinery and personnel. It would also be interesting to extend the study to multiple interconnected farms or to explore more flexible strategies for staff hiring and rotation. All of these enhancements would contribute to building an even more robust decision-making tool for the daily management of companies like Intercrop.