LOGISTIC MODELS FOR DISTRIBUTION OF STRAW IN CROPS OF FRUIT TREE PLOTS WHERE MULCH IS APPLIED

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Abstract

This work presents three models for the linking of fruit tree plots which are receptors of rice straw that is applied as mulch, with other straw suppliers plots, whose straw is a byproduct of cultivating cereal. The mulch is applied to fruit tree plots in order to save irrigation water, to reduce the incidence of weeds and to reduce erosion. In other words, they intend to assign a set of supplier plots to each straw receiving plot. Each model solves the problem in one scenario. The first one considers the direct application of straw to a single plot which must be supplied to apply the mulch from several plots. Therefore, these must be selected from a set that act as suppliers. It is not considered prior storage or collection. The second scenario also involves a direct application but in several receiving target plots from several source supplier plots without storage or intermediate storage. The third scenario develops a model that groups provider plots with different collection points; It offers a system that selects the location of the storage points and associates each storage point with a group of receiving plots.

Keywords: feedstock distribution; mulch application; plot linking; borvelog

INTRODUCTION

Water consumption in woody crop plots in Mediterranean areas represents one of the highest cost factors for producers. So much so that its cost compromises the profitability of some plantations. Furthermore, water is a scarce resource that must be preserved and optimized for its use. On the other hand, erosion in sloping areas is another factor that reduces productive capacity since it influences soil depth and, in consequence, root development (Bakker et al., 2004; Ola et al., 2015). One of the possible techniques available to save water and reduce erosion is the use of mulch (Prosdocimi et al., 2016).

The application of straw mulch has proven to be effective in preventing water losses (Cerdá et al., 2016). Mulching in woody crops produces a micro-climate in the soil, which greatly delays the loss of water by evaporation, maintaining a higher and more uniform humidity regime in the soil, reducing the frequency of irrigation (Ramakrishna et al., 2006).

Furthermore, both Ossoml et al, (2001) and Rahman et al, (2005) verified that the mulch significantly reduced the growth of weeds under the mulch, since it prevented the penetration of certain wavelengths of light pivotal for weed seedlings growth.

On the other hand, the mulch of straw also affects the temperature of the soil, which in turn positively influences the growth of the crop, especially in winter. During this process, the mulch receives solar radiation and heats up. This heat is transmitted to the ground. Later, in days with low radiation the mulch acts as an insulator, reducing heat loss in the soil by convection and radiation. In other words, cold air does not cool the soil since it does not come into direct contact with it, thus keeping the temperature more stable. Also, losses by radiation is lower given that the heat is trapped by the "greenhouse effect" (Wu et al., 2007).

Mulch also promotes crop development and early harvest, and it further increases yields. The decomposition of rice straw is a source of nutrients for the soil, although its high C/N ratio requires an external supply of nitrogen. It must be considered that soil temperature and humidity interact non-linearly on microbial activity and therefore on processes such as decomposition (Chen et al, 1999).

The benefits described have led to an analysis of the use of rice straw mulch on the coast of the Valencian Community (Spain) where this crop predominates (1550 ha), along with fruit plantations, especially citrus (77541 ha of mandarin and 73775 ha of orange), persimmon (14659 ha) (MAPA, 2018).

Although the positive effects of applying rice straw as mulch in fruit crops has been demonstrated, the practical adoption of this technique would be contingent to it being economically profitable. The profitability depends on, the costs of collection, transport, loading and spreading of the straw, making it very important to quantify and reduce these costs evaluating the technical possibilities that currently exist on the market (balers, transport trucks and trailers, loading systems and straw spreading machines), with a greater or lesser degree of shredding. Paking can be done with conventional balers with small prismatic bales, with large rotary balers and with balers with large prismatic bales. This technology is totally commercial, and is adapted to dry fields, but in the case of rice, when working in flooded areas, the movement of the equipment is complicated and it is usually necessary to resort to machines with special tires, adapted track widths, etc. (Garzó, 2017). The spreading of straw in the citrus and fruit fields will require the use and adaptation of equipment that performs similar actions, such as manure spreading machines, machines for spreading straw as a bed for livestock. And although they exist commercially, they require adaptations to be able to travel through the fields mentioned beforehand.

Once the straw is packed, the next challenge is to transport it efficiently to the intermediate collection points and from these to the fields where it would be used. There are numerous techniques that can be used to optimize transport routes and strategies, such as purely manual approaches, graph models (Velázquez-Martí and Annexelink, 2009; Velázquez-Martí and

Fernández-González 2010; Gracia et al., 2014), neural network models, etc. (Buckmaster and Hilton, 2005; Amiama et al., 2008; Cascudo, 2017); but in all cases it is necessary to carry out the calculations considering the restrictions of the area where the action will be carried out. The study of costs, depending on the optimal routes and strategies for collection and transport, would allow maps to decide the extension of the optimal area of use of this technique. The general objective of this work is to develop a management system for mobilization of the rice straw that is generated in the Albufera of Valencia (Spain) and distribute it as a mulch in plots of fruit trees in neighboring municipalities. Three models are proposed to optimize the logistics system.

BASE INFORMATION AND ITS TREATMENT

The basic information is:

- Cadastral cartography of the municipalities with rice cultivation that surround the "Albufera de Valencia".
- Cadastral cartography of the municipalities of the destination parcels. In principle, parcels of persimmon and citrus crops.

All the models analyzed start from the location of the parcels of origin, the location of the destination parcels and the distances between them. Their areas are also required, given that both the production of straw in the source parcels and the amount of straw used for mulching in the destination parcels are proportional to their area.

The location of each parcel is obtained based on the UTM coordinates of its centroid. The centroid, the area and type of cultivation of each parcel can be obtained from the cadastral cartography publicly available in shape format at the cadastre headquarters. (https://www.sedecatastro.gob.es/).

Initially, we have obtained the cartography of the municipalities of Silla, Sollana and Sueca as they are the municipalities where rice production predominates. Subsequently, the Alzira and Carlet cartography where the potential receiving plots are located. From the cadastral cartography, a summary of those is presented in Table 1.

Table 1. Global assessment of resources

Municipality	Rice plots number	Rice hectares	Mean área of rice plot m^2	Citrus polts number	Citrus hectares	Mean área of citrus plot m^2	Fruit trees polts number	Fruit trees hectares	Mean área of fruit trees plot m^2
Silla	2373	1076	4535	2192	576	2629	12	3,6	3037
Sollana	2381	2263	9505	1682	614	3653	170	84	4947
Sueca	6987	6235	8924	5086	1293	2544	0	0	0
Alzira	20	11,37	5683	15004	4878	3251	457	158,73	3473
Carlet	0	0	0	5449	1966	2987	2287	786,14	3437

DEVELOPED LOGISTIC MODELS

A progressive analysis of logistics optimization is proposed, starting from simple heuristic models with simple restrictions, and then successively adding restrictions to evaluate the variations of the results obtained. The heuristic condition evidences that the solution obtained is not guaranteed to be optimal, but it does provide a good approximation.

Firtsly, there are some plots where rice is grown producing straw as a by-product that will be applied as mulch in plots of fruit trees. The rice parcels will act as origin parcel and fruit tree plots will act as receiving or destination parcels. Optimal management of this resource involves evaluating different scenarios, shown in Figure 1.

If the application is direct, the straw is cut in the source (rice plots), then it is packed, transported and applied directly to the target plots (fruit trees plots) without intermediate storage. This type of problem will consist of making univocal links between origin and destination parcels. In this case, two situations can occur: it is desired to obtain the supplier parcels of a specific destination parcel; or, for a set of destination parcels, it is necessary to link each one to sets of supplier parcels. Once the link between provider and recipient parcels has been made, the logistics problem becomes a route problem. The trafficability of the route, according to its width, will determine the type of trucks usable for transport; and the load capacity of trucks will influence the number of trips needed.

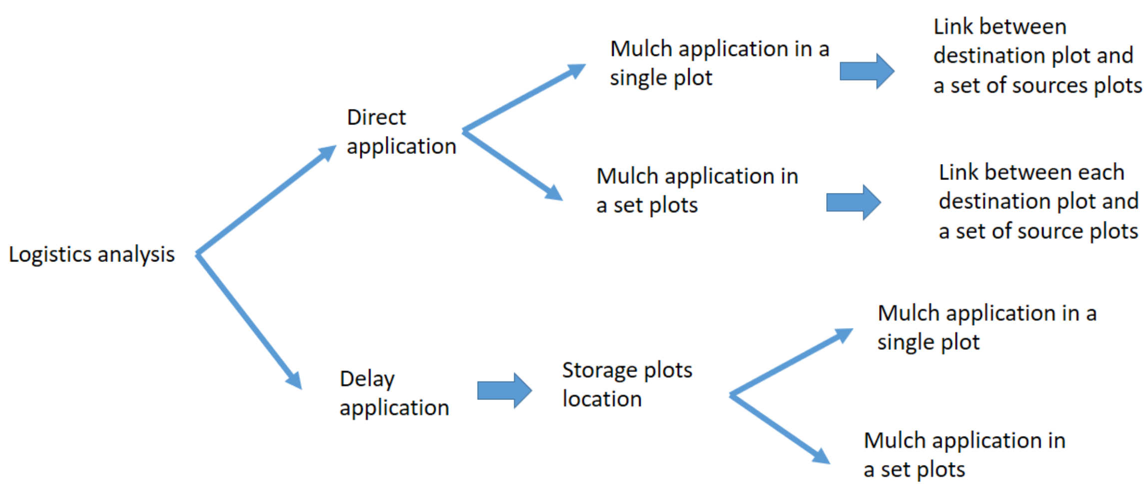

Figure 1. Different logistics analysis scenarios.

On the other hand, the application of the mulch can be carried out in delay. That is to say, when the straw is collected from the producer plots, this is stored for an undetermined period of time until it is convenient to apply it as a mulch in the recipient plots. This case presents a different problem than the previous one. In this case, the initial problem is the optimal location of the collection plots. Subsequently, a link must be made between the straw supply parcels and the collection points, and between the collection points and the destination parcels. After linking them, analysis becomes a route problem.

The calculation algorithms for the three scenarios are presented below. The costs of harvesting or deposition are not considered but, only exclusively the distances between the plots. With this, the steps to be followed in the QGIS Geographic Information Systems software have been developed. After the development of these algorithms, the corresponding modifications are developed to consider the harvesting and deposition costs and the number of trips corresponding to each case.

SCENARIO 1. DIRECT APPLICATION TO A SINGLE PLOT

It is the simplest model. Actually, the complexity of a global model lies in the very high number of origin and destination points. This happens together with the determination of the distances between them. But if the destination parcel (receiving plot) is already known, the problem consists of determining the optimal supply parcels that act as origin. The starting variables are shown in Table 2.

Table 2. Starting variables

Yield of straw producing plots (t/ha)	p_i
Straw requirement of fruit plots (t/ha)	r_j
Coordinates receiving plot (destination) r_j	(x_{rj}, y_{rj})
Coordinates producing plot (possible origin) p_i	(x_{pi}, y_{pi})
Area of receiving plot (destination) r_j	S_{rj}
Area of possible origin plot p_i	S_{pi}

The calculation procedure is iterative:

Iteration 1

If the coordinates of the receiving-destination plot are (x_{r1}, y_{r1}), from the possible set of origin parcels, that with the coordinates (x_{p1}, y_{p1}) that minimizes the producer-receiver plot distance (equation1) must be selected.

$$\text{Min} \quad d_{p1r1} = \sqrt{\left(x_{p1} - x_{r1}\right)^2 + \left(y_{p1} - y_{r1}\right)^2} \qquad (1)$$

Instead of using the Euclidean distance, the one given by the communication routes can be used. For this, the Network Analysis application of the QGIS Geographical Information System must be used.

If the condition $p_1 \cdot S_{p1} < r_1 \cdot S_{r1}$ is satisfied, it is necessary to supply straw from more plots, so it will be necessary to select another of the possible producing plots (x_{p2}, y_{p2}), going to iteration 2.

Iteration 2

For the selection of the second supply plot p_2. The one that is the closest to the plot p_1 and r_1 is chosen, so that it meets equation (2).

$$\min\left(d_{p2p1} + d_{p2r1}\right) = \min\left(\sqrt{\left(x_{p1} - x_{p2}\right)^2 + \left(y_{p1} - y_{p2}\right)^2} + \sqrt{\left(x_{p2} - x_{r1}\right)^2 + \left(y_{p2} - y_{r1}\right)^2}\right)$$

If the condition $p_1 \cdot S_{p1} + p_2 \cdot S_{p2} < r_1 \cdot S_{r1}$ is satisfied it is necessary to stock up on more plots, so it will be necessary to select another of the possible ones with iteration 3.

Iteration 3

The third plot for the grouping is sought, p_3, such that the distance to the already selected plots p_1, p_2 and destination plot r_1 is minimal.

$$\min\left(d_{p3p1} + d_{p3p2} + d_{p3r1}\right)$$

If *a* is the number of plots that make up the first grouping, the equation $\sum_1^a p_i \cdot S_{pi} > r_1 \cdot S_{r1}$ must be verified. If this equation is not satisfied, it is necessary to supply from more plots, such that to select another source plot from the possible ones that fulfills the equation 3.

$$\min \sum_{i=1}^{a}\left(d_{p_a p_i} + d_{p_a r_1}\right) \qquad (3)$$

The algorithm ends when $\sum_1^a p_i \cdot S_{pi} > r_1 \cdot S_{r1}$

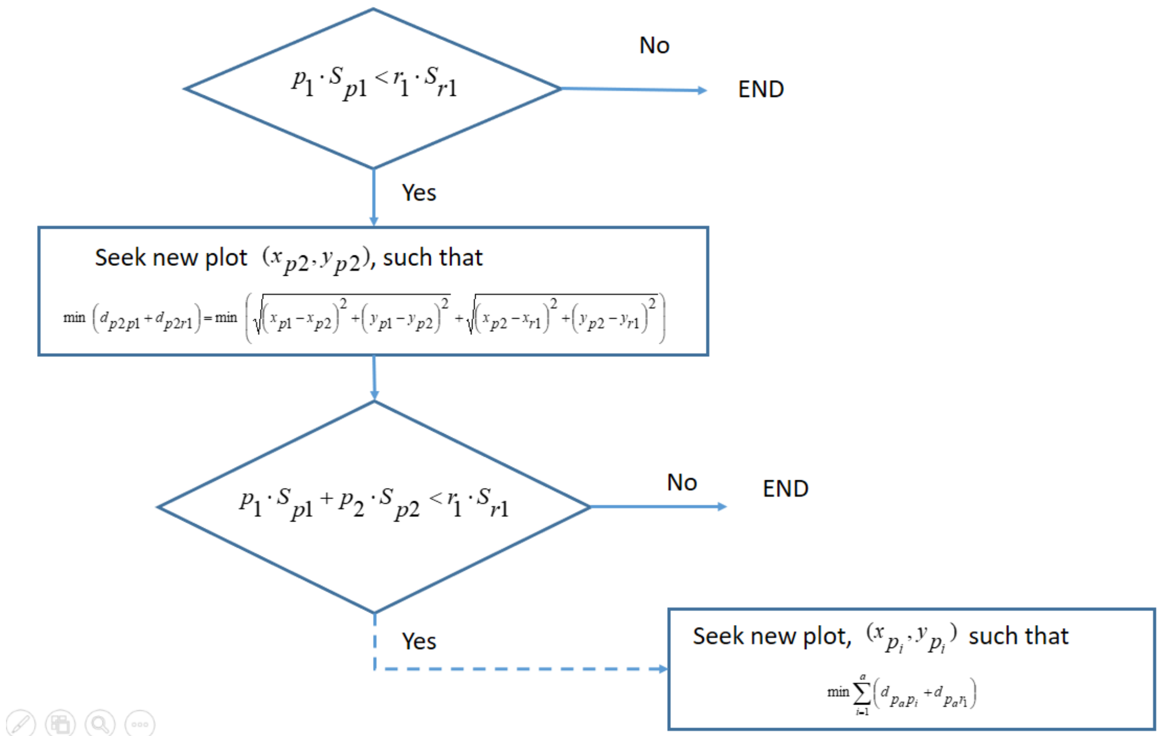

Figure 2. Process diagram

This algorithm has been applied using the QGIS Geographic Information Systems software with the following steps:

1. Download the shape file of the land cadastre of the plots of the municipalities involved.
2. Filter the plots cultivated with rice, and those cultivated with fruit trees.
3. Initially the plot that will act as destination is selected and saved in a separate shape file.
4. In the same way, the possible plots that will act as origin. The straw source, are selected and these will also be saved in another shape file.
5. In each of the shapes (the one of the origin parcels and the other of the destination parcel) the centroids of the parcels are extracted with their coordinates.
6. The distances between the destination parcel and the possible origin parcels are calculated (with both files the distance matrixes are calculated). Then, the origin parcel closest to the destination is selected. If there is enough straw to supply the needs of the destination parcel, the algorithm ends here. If not, continue with the following steps:
7. The centroid of the selected source parcel and destination plot are extracted and saved in a separate shape file.
8. The same is done with the rest of the centroids of the unselected source plots. In other words, they are saved in another independent shape file.

9. With both files, the distance matrix is calculated, and the second centroid of the origin parcels is chosen, such that their distance from the first selected centroid and destination is minimal.
   If there is enough straw to supply the needs of the target parcel, the algorithm ends here. Otherwise, continue with the following steps:
10. The two centroids of the selected origin parcels and destination (the p_1, p_2 and r_1), are extracted, and saved in a separate shape file.
11. The same is done with the rest of the centroids of the unselected source plots. In other words, they are saved in another independent shape file.
12. With both files, the distance matrix is calculated, and the third centroid of the origin parcels is chosen, such that their distance from the previous selected centroid and destination plot is minimal.

Sequence of the collection route

Once the set of source parcels has been selected, an optimal sequence can be calculated for the collection of straw from the producer parcels. The objective is to start the collection in one of the origin parcels. Then, to go through all those that make up the group and then take the straw to the recipient-destination parcel.

If trucks with a capacity of Q tons / trip are available, the number of trips to be made is given by:

$$Trips = \frac{\sum_{1}^{a} p_i \cdot S_{pi}}{Q}$$

If the transportation were done ith a single trip, the pick-up sequence would be solved by the known traveler problem. If the load limitation forces multiple trips for transportation, the following algorithm can be used

Route of each trip

The organization of each trip's route would be carried out with the following algorithm:

Iteration 1 route algorithm

If the coordinates of the receiving-destination parcel are (x_{r1}, y_{r1}), from the possible set of origin parcels with the coordinates (x_{p1}, y_{p1}) that has a shorter distance (equation 1) is selected.

$$\min \quad d_{p1r1} = \sqrt{\left(x_{p1} - x_{r1}\right)^2 + \left(y_{p1} - y_{r1}\right)^2} \qquad (1)$$

If $p_1 \cdot S_{p1} < Q$, only one trip will be made. Otherwise the number of the trips between the first origin parcel and the destination parcel, $V_{p_1 r_1}$, will be the integer of the relation:

$$V_{p_1 r_1} \text{(Trips from } p_1 \text{ to } r_1\text{)} = \frac{p_1 \cdot S_{p1}}{Q}$$

Iteration 2 route algorithm

When you have finished collecting the straw from plot p_1, you will have to select another one of the possible ones (x_{p2}, y_{p2}).

Furthermore, to select the second supply parcel p_2, you must choose the one that is closest to parcel p_1, so that it meets the equation:

$$\text{Min} \quad d_{p1p2} + d_{p2r1} = \sqrt{\left(x_{p1} - x_{p2}\right)^2 + \left(y_{p1} - y_{p2}\right)^2} + \sqrt{\left(x_{p2} - x_{r1}\right)^2 + \left(y_{p2} - y_{r1}\right)^2}$$

The number of trips from p_2 to r_1, V_{p2r1}, will be given by the integer of the relation:

$$V_{p2r1} = \frac{p_1 \cdot S_{p1} - V_{p1r1} \cdot Q + p_2 \cdot S_{p2}}{Q}$$

Iteration 3 route algorithm

For the selection of the third supply parcel p_3, the one closest to parcel p_2, is chosen, so that it meets the equation:

$$\text{Min} \quad d_{p2p3} + d_{p3r1} = \sqrt{\left(x_{p2} - x_{p3}\right)^2 + \left(y_{p2} - y_{p3}\right)^2} + \sqrt{\left(x_{p3} - x_{r1}\right)^2 + \left(y_{p3} - y_{r1}\right)^2}$$

The number of trips from p_3 to r_1 will be given by the integer number of the relation:

$$V_{p3r1} = \frac{p_1 \cdot S_{p1} - V_{r1p1} \cdot Q + p_2 \cdot S_{p2} - V_{r1p2} \cdot Q + p_2 \cdot S_{p3}}{Q}$$

Iteration *i* route algorithm

Iteration *i* will be performed such that a plot will be sought to minimize the equation:

$$\text{Min } d_{p_{i-1}p_i} + d_{p_i r1} = \sqrt{\left(x_{p_{i-1}} - x_{p_i}\right)^2 + \left(y_{p_{i-1}} - y_{p_i}\right)^2} + \sqrt{\left(x_{p_i} - x_{r1}\right)^2 + \left(y_{pi} - y_{r1}\right)^2}$$

The number of trips from p_i to r_1 will be given by the integer number of the relation:

$$V_{p_i r1} = \frac{\sum_{i=1}^{i} p_i \cdot S_{pi} - \sum_{i=1}^{i-1} V_{r1pi} \cdot Q}{Q}$$

SCENARIO 2. DIRECT APPLICATION TO SEVERAL PLOTS

In this scenario there are several straw receiving parcels, together or separately, and must be supplied from several possible straw producing parcels. The objective is to determine which are the parcels that act as the source for each destination parcel. That is to say that each destination parcel is linked to a set of origin parcels. To make the connections, the QGIS software can be used, which is a free Geographic Information Systems program. The operations are structured in iterations.

Iteration 1. Supply of the parcel r_1

1. The parcels that will act as destination are selected from the parcel cadastre and are saved in a shape file.
2. In the same way, the parcels that will act as source are selected. These are also to be saved in another shape file.
3. From both files the centroids of the parcels are obtained and saved in independent shape files.
4. The distance matrix between the centroids of the source parcels and the destination parcels is calculated.
5. The couple with the shortest distance is selected, so that the first relationship is established. These parcels constitute the p_1 producing parcel and the straw receiving parcel r_1.
6. After the first linking, the criterion of Figure 2 is followed to link more than one source parcel to the selected destination parcel, until the straw requirements of the destination parcel r_1 are supplied.

After the selection of the last producing parcel linked to the parcel, part of its production may be free for having exceeded the needs of the destination parcel. In other words, there is a surplus. Therefore, it is necessary to redefine a new parcel with the same coordinates as the last one selected but with a production equivalent to the excess. If the last selected origin parcel is p_a, the excess production of straw comes from the following equation:

$$P_{p_a} = \sum_{i=1}^{a} p_i \cdot S_{pi} - r_1 \cdot S_{r1}$$

A new parcel will have coordinates (x_{p_a}, y_{p_a}), but instead of being associated to p_a as performance, it must be associated to a performance P_{p_a}, to apply iteration 2.

Iteration 2. Supply of plot r_2

1. When the needs of the destination parcel r_1 are covered, the centroid of the parcel selected in iteration 1 is excluded from the shape of the centroids of the destination parcels; and, in the shape of the centroids of the possible origin parcels, those corresponding to those selected in iteration 1, $\{p_1, p_2, ..., p_a\}$, are also excluded.
2. With the new centroid shape files, both origin and destination, the distance matrix is calculated.
3. The origin-destination centroid pair that has the smallest distance is selected.
4. After linking them, the criterion of Figure 2 is followed to link more than one origin parcel to the selected new destination parcel r_2, until the straw requirements of the destination parcel are supplied.

There will happen as many iterations as the number of destination parcels existing, as long as there are source parcels available.

SCENARIO 3. DEFERRED SUPPLY OF SEVERAL PLOTS

When the supply must be carried out in deferred, in other words, when the collected straw has to be stored to be applied as a mulch at another time, the new scenario radically changes the type of problem. In this case, the solution for managing the straw produced in various plots involves finding the optimal location for collection centers, also defining their dimensions.

It starts from a set of straw-producing plots $P = \{p_1, p_2, ..., p_n\}$ and a set of receiving plots $R = \{r_1, r_2, ..., r_m\}$.

The points of storage $A = \{a_1, a_2, ..., a_k\}$ consist of plots where $X \cdot Y \cdot Z$ m^3 prismatic bales or cylindrical bales of volume $\pi D^2 h / 4$ m^3 with a density of ρ t/m^3 are stored. The bales are stored in stacks of 6. Therefore, the storage capacity will be calculated by equation 4, where V is the volume of the bales. 20% less capacity has been considered for the spaces intended for loading and unloading maneuvers of the straw bales.

$$A = 0{,}8 \cdot \frac{10000}{X \cdot Y} \cdot 6 \cdot V \cdot \rho \qquad \text{(t/ha)} \qquad (4)$$

Intuitively, the optimal option would be to have a single collection point. However, the limitation of the capacity of the available plots forces to devise several points of collection. Taking into account that the average area of the plot is $\overline{S}$; if the objective is to cover all the needs of the receiving plots, the number of collection points would be given by equation 5:

$$N_A = \frac{\sum_{1}^{m} r_i \cdot S_{ri}}{A \cdot \overline{S}} \qquad (5)$$

If the objective is to store all the straw produced in the producing plots in a way that a part of the straw would be used for mulch and other part for other uses; the number of collection points would be given by equation 6:

$$N_p = \frac{\sum_{1}^{n} p_i \cdot S_{pi}}{A \cdot \overline{S}} \qquad (6)$$

Since each collection point is supplied from a set of producer plots, it is necessary to group them. Each grouping of producing plots will be linked to a collection point. An original algorithm has been devised for grouping, the *Borvelog Grouping Algorithm*.

Borvelog Grouping Algorithm

This algorithm is applied iteratively. The objective is to group source parcels so that each group supplies a collection plot for a_1

Iteration 1. Grouping of plots that supply a_1

1. The plot with the highest production is selected: max $p_i S_{p_i} \rightarrow p_1$
2. If $p_1 \cdot S_{p1} < A \cdot \overline{S}$ the second plot of group p_2 is searched with the following formula:

$$\min d_{p1p2} = \min \sqrt{\left(x_{p1} - x_{p2}\right)^2 + \left(y_{p1} - y_{p2}\right)^2}$$

3. If $p_1 \cdot S_{p1} + p_2 \cdot S_{p2} < A \cdot \overline{S}$ the third plot of group p_3

$$\min\left(d_{p3p2} + d_{p3p1}\right) = \min\left(\sqrt{\left(x_{p3} - x_{p2}\right)^2 + \left(y_{p3} - y_{p2}\right)^2} + \sqrt{\left(x_{p3} - x_{p1}\right)^2 + \left(y_{p3} - y_{p1}\right)^2}\right)$$

More plots will continue being searched while $\sum_{1}^{h} p_i \cdot S_{pi} < A \cdot \overline{S}$. In this case plot p_{k+1} will be selected, so that equation 7 is minimal.

$$\min \sum_{i=1}^{a} d_{p_a p_i} \qquad (7)$$

The interaction ends when $\sum_{1}^{a} p_i \cdot S_{pi} > A \cdot \overline{S}$.

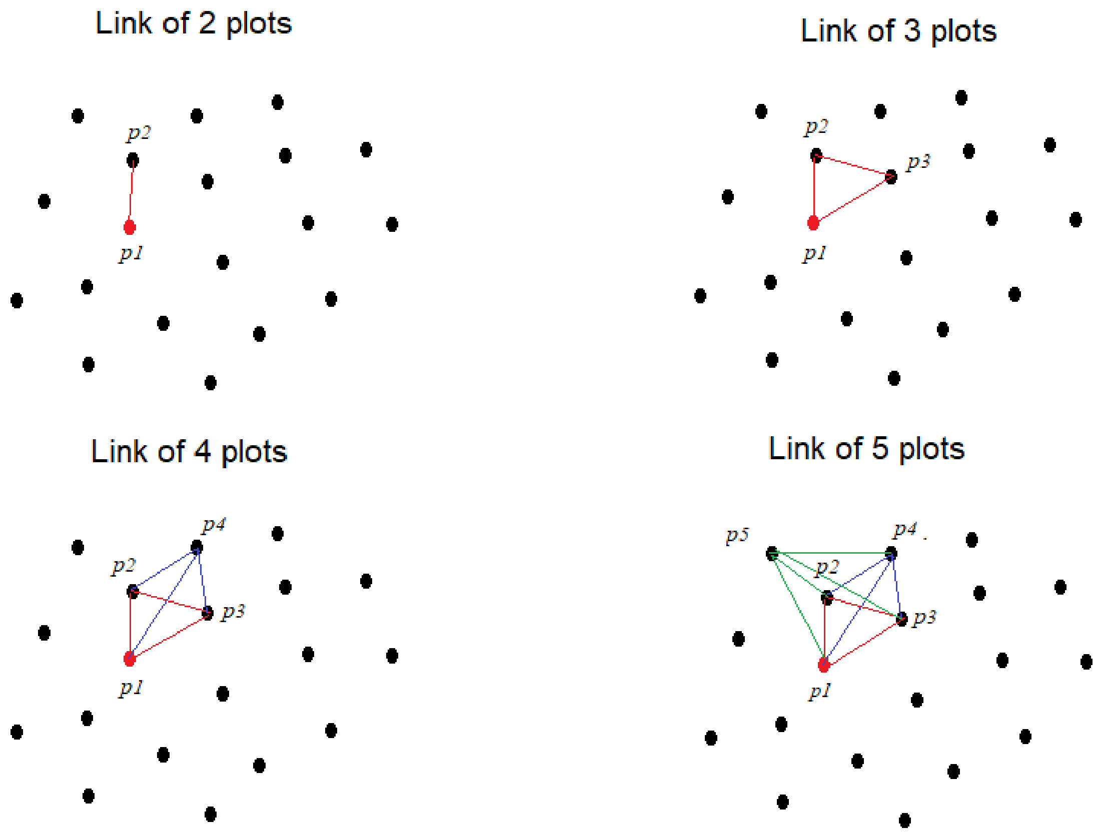

Figure3. Borvelog grouping algorithm

Iteration 2. Grouping of plots that supply a_2

1. For the second iteration we search among the plots that have not been previously grouped. The one with the highest production according to equation, max $p_i S_{p_i} \rightarrow p_{b1}$
2. If $p_{b1} \cdot S_{pb1} < A \cdot \overline{S}$ the second plot of group is searched for p_{b2} such that:

$$\min d_{p_{b1} p_{b2}}$$

3. If $p_{b1} \cdot S_{pb1} + p_{b2} \cdot S_{pb2} < A \cdot \overline{S}$ the third parcel of the group is searched for p_{b3}

$$\min\left(d_{pb3\,pb2} + d_{pb3\,pb1}\right)$$

Plots will continue to be searched for as long as $\sum_{1}^{a} p_{bi} \cdot S_{pbi} < A \cdot \overline{S}$ is completed. In this case, plot p_{ba} will be selected, so that equation 8 is minimal.

$$\min \sum_{i=1}^{a-1} d_{p_{ba} p_{bi}} \qquad (8)$$

The iteration ends when $\sum_{1}^{a} p_{bi} \cdot S_{pbi} > A \cdot \overline{S}$.

The algorithm ends when a number *k* of groupings have already been established.

When the producing plots are exclusively considered, from a theoretical point of view the optimal location of the collection points in each of the groups is determined by the center of gravity (Equations 9).

$$x_{cdg} = \frac{\sum_{i=1}^{a} x_{pi} \cdot p_i \cdot S_{pi}}{\sum_{i=1}^{a} p_i \cdot S_{pi}} \qquad y_{cdg} = \frac{\sum_{i=1}^{a} y_{pi} \cdot p_i \cdot S_{pi}}{\sum_{i=1}^{a} p_i \cdot S_{pi}} \qquad (9)$$

If the location of the receiving parcels is also taken into consideration, the center of gravity is calculated by equations 10:

$$x_{cdg} = \frac{\sum_{i=1}^{a} x_{pi} \cdot p_i \cdot S_{pi} + \sum_{i=1}^{a} x_{ri} \cdot r_i \cdot S_{ri}}{\sum_{i=1}^{a} p_i \cdot S_{pi} + \sum_{i=1}^{a} r_i \cdot S_{ri}} \qquad y_{cdg} = \frac{\sum_{i=1}^{a} y_{pi} \cdot p_i \cdot S_{pi} + \sum_{i=1}^{a} y_{ri} \cdot r_i \cdot S_{ri}}{\sum_{i=1}^{a} p_i \cdot S_{pi} + \sum_{i=1}^{a} r_i \cdot S_{ri}} \qquad (10)$$

Equations 10 would provide the optimal location of the collection point for a grouping from a theoretical point of view. However, this solution may not be realistic due to two circumstances: First, its application requires having a preselected grouping of target parcels; secondly and in more relevant fashion, not all locations are suitable for collection. It may occur that the location obtained results in a plot with a high productivity, or the owner simply wants to give that plot another use. This circumstance also occurs if equations 9 are applied. Therefore, a more practical way to proceed is to select the possible collection points. In this case, a bonding problem arises again.

The starting point is established by the three classes of parcels: possible origin parcels, possible collection parcels and destination parcels. The variables are defined in Table 3.

The procedure to be followed is divided into two steps: In the first step, the location of the receiving parcels is ignored. On the one hand, the possible collection points are the main focus, and on the other, on the possible sources of straw. To link a collection point with a set of producer plots (origin), the algorithm described in scenario 2 can be applied. As a second step, this algorithm will be applied again to link the receiving plots with the collection points.

Table 3. Starting variables for linking producer, recipient and collection points.

Yield of straw producing plots (t/ha)	p_i
Straw requirement for fruit plots (t/ha)	r_j
Storage capacity of storage plots (t/ha)	a_h
Coordinates receiving plot (target) r_j	(x_{rj}, y_{rj})
Coordinates producing plot (possible origin) p_i	(x_{pi}, y_{pi})
Coordinates possible storage plot a_h	(x_{ah}, y_{ah})
Area of receiving plot (destination) r_j	S_{rj}
Area of possible origin plot p_i	S_{pi}
Area of possible storage plot a_h	S_{ah}

Step 1. Linking producer parcels with the possible collection parcels

Iteration 1. Supply of the collection point a_1.

1. Initially, the parcels that will act as possible storage points a_h are selected from the cadastre parcel, and are saved in a separate shape file.
2. In the same way, the plots that will act as origin p_i straw source are selected. These will also be saved in another shape file.
3. From both files, the centroids of the plots are obtained, and stored in independent shape files.
4. The distance matrix between the centroids of the source plots and the collection plots is calculated.
5. The couple with the shortest distance is selected, so that the first relationship is established.
6. After the first linking, the criterion of Figure 2 is followed to link more than one source plot to the selected storage plot and so forth until the straw storage capacity of parcel a_1 destination parcels are supplied.

After the selection of the last producing parcel linked to the storage parcel a_1, part of its production may be free due to exceeding the storage capacities. In other words, there is a surplus. Therefore, it is necessary to redefine a new origin parcel with the same coordinates as the last one selected, but with a production equivalent to the excess. If the last plot selects p_a, the excess production of straw comes from the following equation:

$$P_{p_a} = \sum_{i=1}^{a} p_i \cdot S_{pi} - r_1 \cdot S_{r1}$$

A new parcel will have coordinates (x_{p_a}, y_{p_a}), but instead of associating it with a performance of p_a, it must be associated with a performance of P_{p_a} to apply iteration 2.

Iteration 2. Supply of collection parcel a_2

1. When the capacities of parcel a_1 are covered, the centroid of this parcel selected in iteration 1 is excluded from the shape of the centroids of the collection parcels. Moreover, regarding the shape of the centroids of the possible origin parcels; the ones corresponding to those selected in iteration 1 are also excluded.
2. With the new centroid shape files, both origin and collection, the distance matrix is calculated.
3. The pair of origin-storage centroids that has the smallest distance is selected.
4. After linking, the criterion of Figure 2 is followed to link more than one origin parcel to the selected collection parcel, until the straw requirements of parcel a_2 destination are supplied.

There will be made as many iterations as the number of collection plots existent, as long as there are source plots available.

Step 2

To associate the collection parcels a_h with the destination straw mulch parcels r_j receivers; the same algorithm from step 1 will be applied again between these two groups.

APPLICATION OF THE MODELS

The exposed models have been applied to the municipalities of Silla, Sollana and Sueca, (Spain) due to rice production is predominant; also, to the municipalities of Alzira and Carlet (Spain) where the potential recipient fruit tree plots are located.

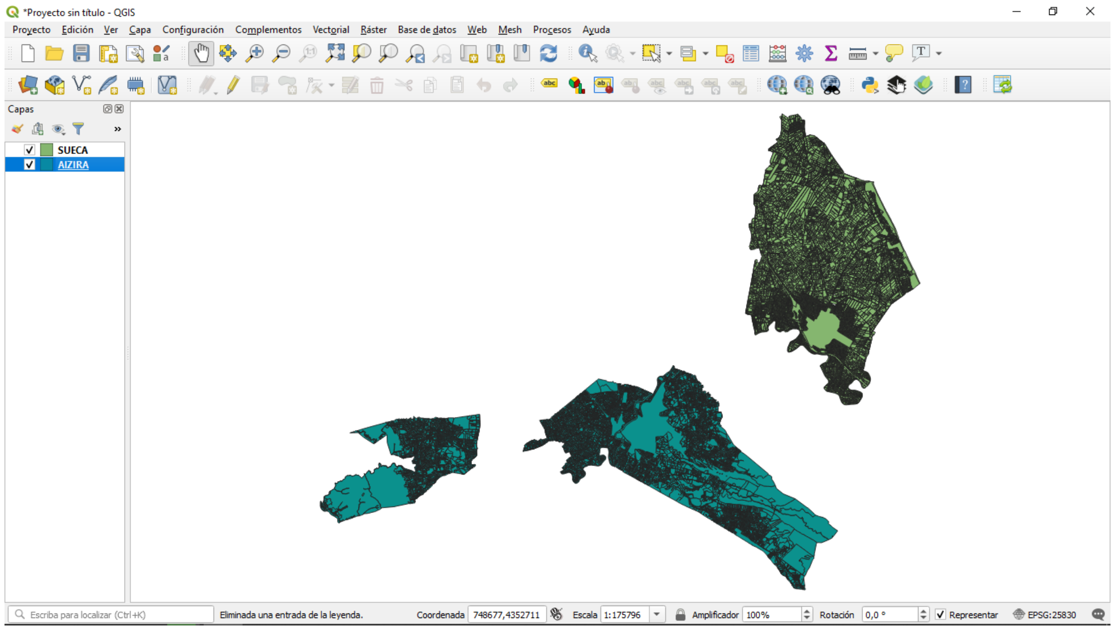

Figure 4. Plot cadastres of two of the downloaded municipalities: Sueca (in green) and Alzira (in blue)

Application model: Scenario 1

From the shape files of the cadastre parcel of the municipalities involved. For the application of scenario 1, the plot that will act as destination is selected with the cadastral reference 46017A00600025, with coordinates UTMX 724331.99, UTMY 4340001.70, with an area of 44300 m².

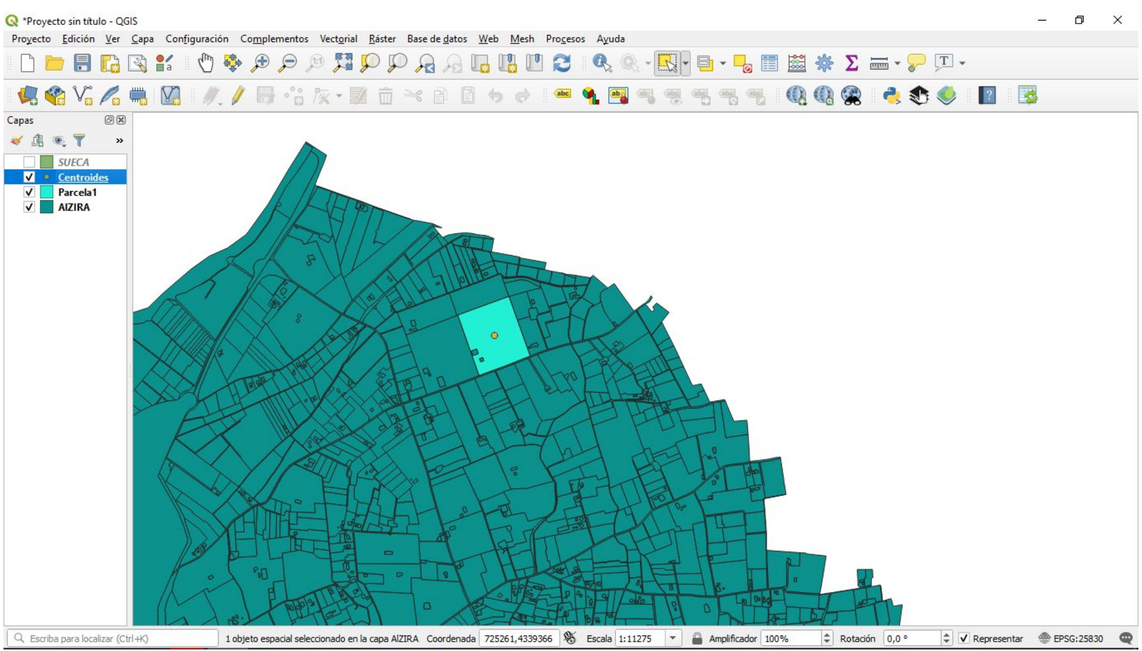

Figure 5. View of the selection of the destination plot 46017A00600025 in the municipality of Alzira.

The possible plots that will act as possible sources of straw are shown in Figure 6. The cadastral references are shown in Table 4. The coordinates of the centroids and the area in square meters are also shown.

Table 4 Selected as possible sources of straw sources for mulch.

UTM-X	UTM-Y	AREA	REFCAT
729367,52	4345270.23	45561	46237A02200221
728515,69	4345034.77	29468	46237A02200202
728867,05	4345990.94	23996	46237A02200063
728867,05	4345990.94	23996	46237A02200063
728341,13	4345122.52	21424	46237A02200203
728349,96	4345888.53	20204	46237A02200028
728623,51	4345433.61	19937	46237A02200212
728679,91	4345812.11	18964	46237A02200411
728156,46	4345244.07	17894	46237A02200148
728069,07	4344752.9	17581	46237A02100053
728881,84	4345637.45	16343	46237A02200164
728771,94	4344767.57	16225	46237A02200140
728592,29	4345614.57	14731	46237A02200105
729025,61	4344584.17	14392	46237A04300005
728162,59	4345482.97	8795	46237A02200149

In each of the shapes (the one of the origin parcels and the one of the destination parcel) the centroids of the parcels are extracted with their coordinates.

Figure 5 shows the centroid obtained in the selected target plot. Figure 6 shows the centroids of the possible parcels of origin.

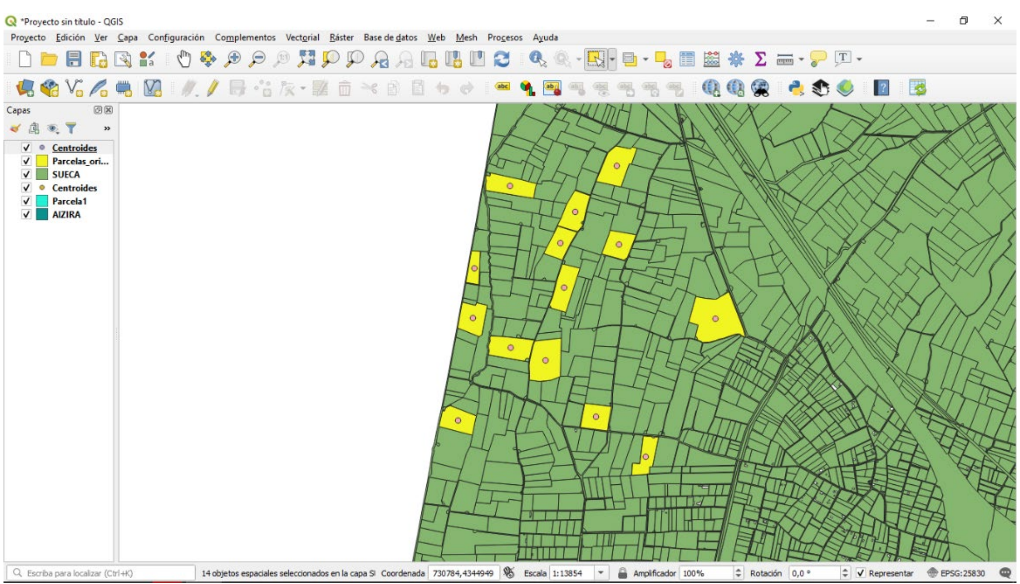

Figure 6. View of the centroids obtained from the origin plots.

The distances between the destination parcel and the possible origin parcels are then calculated (Figure 7).

Matriz de distancia :: Objetos totales: 14, Filtrados: 14, Seleccionados: 0

	InputID	TargetID	Distance
1	6	1	7133,563396434...
2	9	1	6505,241188060...
3	8	1	6046,740564639...
4	11	1	6697,666814755...
5	10	1	6492,539845877...
6	13	1	6539,340966714...
7	12	1	7220,986203043...
8	14	1	6490,184693486...
9	1	1	7049,636841806...
10	3	1	6550,823663155...
11	2	1	7216,400949174...
12	5	1	7264,710587935...
13	4	1	6887,696350152...
14	7	1	7520,657629623...

Figure 7. View of the output of the distance matrix. Application of the algorithm of Figure 2 using excel spreadsheet

Iteration 1

From the distance matrix, the pair of centroids (origin-destination) with the smallest distance is selected. In this case, the closest plot is the one with the cadastral reference 46237A02100053 at a distance of 6046.74 m.

Assuming that the amount of straw produced per hectare in the source plot is equivalent to the amount of straw required to mulch in the target plot, the areas should be compared. If $p_1 = r_1$ the inequality to check $p_1 \cdot S_{p1} < r_1 \cdot S_{r1}$, becomes $S_{p1} < S_{r1}$.

As the area of the source parcel is less than that of the destination, more parcel must be searched for to cover the straw needs of the destination parcel.

Origin area (17581 m^2) < Target area (44300 m^2)

Iteration 2

In the second iteration, it is necessary to find the closest plot to p_1 and r_1 . For this, the same operations are performed as those described in iteration 1.

1. The centroid of plot p_1 and r_1 are selected, and saved in a separate shape fil
2. The rest of the centroids of the p_i plots are selected as candidates to be source plots. They are also saved in a separate shape file.
3. Through the distance matrix, the closest centroid to p_1 and r_1 must be selected.

In this case, the resulting parcel is the cadastral reference 46237A02200203, with UTM-X coordinates: 728341,13, UTM-Y: 4345122,52. The area of the parcel is 21424 m2. This parcel constitutes parcel p_2, which is located at a distance of 443.81 m from p_1 and 6490,18 m from r_1.

If the amount of straw produced per hectare in the source parcels is equivalent to the amount of straw required for mulching in the destination parcel, the areas would need to be compared. If $p_i = r_j$; for any *i*, *j*, the inequality to be checked, $p_1 \cdot S_{p1} + p_2 \cdot S_{p2} < r_1 \cdot S_{r1}$, must become $S_{p1} + S_{p2} < S_{r1}$.

Source area 1 (17581 m2) + Source area 2 (21424 m²) < Destination area (44300 m²).

Then, due to the quantity needed in the destination plot is greater than the quantity available in the selected source plots, it is necessary to find a new origin parcel, using iteration 3.

Iteration 3

In the third iteration we must find the plot p_3, such that it is the closest to p_1, p_2 and r_1. For this, the same operations are performed as those described in iteration 2.

1. The centroids of plot p_1, p_2 and r_1 are selected, and they are saved in a separate shape file.

2. The rest of the centroids of plots p_1 are selected as candidates to be source parcels. These are also saved in a separate shape file.

3. Through the distance matrix, the centroid whose distance to p_1, p_2 and r_1 is minimum, is selected.

To do the operation in a comfortable way, the output of the matrix is selected and carried out in the form N x T. They are copied in Excel and the sum of each column is calculated by selecting the minimum. Table 5 shows the output.

Table 5. Matrix of distances of each of the plots p_i (candidate source plots) to the p_1, p_2 and r_1 plots are already selected.

Ref. cadastral	46237A0220 0105	46237A0220 0411	46237A0220 0202	46237A0220 0212	46237A0220 0221	46237A0220 0028
46237A0210 0053 (p_1)	1012.28	1182.06	525.82	840.97	1370.02	1186.63
46237A0220 0203 (p_2)	572.78	743.00	184.21	398.28	1023.99	798.99
46017A0060 0025 (r_1)	7049.64	7216.40	6550.82	6887.70	7264.71	7133.56
Sum of distances	8634.7	9141.46	7260.85	8126.95	9658.72	9119.18

Ref. cadastral	46237A0220 0063	46237A0220 0140	46237A0220 0148	46237A0220 0149	46237A0220 0164	46237A0430 0005
46237A0210 0053 (p_1)	1481.48	682.81	509.62	755.75	1176.80	946.88
46237A0220 0203 (p_2)	1039.23	543.27	237.00	431.80	737.63	858.08
46017A0060 0025 (r_1)	7520.66	6505.24	6492.54	6697.67	7220.99	6539.34
Sum of distances	10041.37	7731.32	**7239.16**	7885.22	9135.42	8344.3

As it can be checked, the plot with minimum distance with p_1, p_2 and r_1 is the cadastral reference 46237A02200148, with UTM-X coordinates: 728156.46, UTM-Y: 4345224.07. The area of the plot is 17894 m². This parcel represents parcel p_3 which is situated at a distance of p_1, p_2 and of 7239.16 m.

If the amount of straw produced per hectare in the source parcels is considered equivalent to the amount of straw required to mulch in the destination parcel, a comparison between the areas would be needed. If $p_i = r_j$ for any *i*, *j*, the inequality to be checked $\sum_{i=1}^{a} p_i \cdot S_{pi} < r_1 \cdot S_{r1}$ would become $S_{p1} + S_{p2} + S_{p3} < S_{r1}$.

Such as:

Original area (17581 m^2) + original area 2 (21424 m^2) + original area 2 (17894 m^2) > target area (44300 m^2).

$$56899 \text{ m}^2 > \text{target area } (44300 \text{ m}^2)$$

The algorithm ends.

The set of plots that supply straw to plot r_1 are plots p_1, p_2 and p_3. (Table 6).

Table 6. Set of plots that supply straw to plot r_1

Straw producing plots (p_1, p_2 y p_3)	Straw receiving destination plot (r_1)
46237A02100053 46237A02200203 46237A02200148	46017A00600025

Scenario 2 application. Direct application to several parcels

In this case an example of the application of the algorithm developed for the second possible scenario is shown. Here several receiving parcels r_j, must be supplied from several possible straw-producing plots p_i.

Figure 8 shows the rice-producing plots taken for the example of the municipality of Sueca. Figure 9 also shows the destination receiving plots taken for the example of the municipality of Alzira. Tables 7 and 8 show the cadastral references and their coordinates taken from the cadastre parcel of both municipalities.

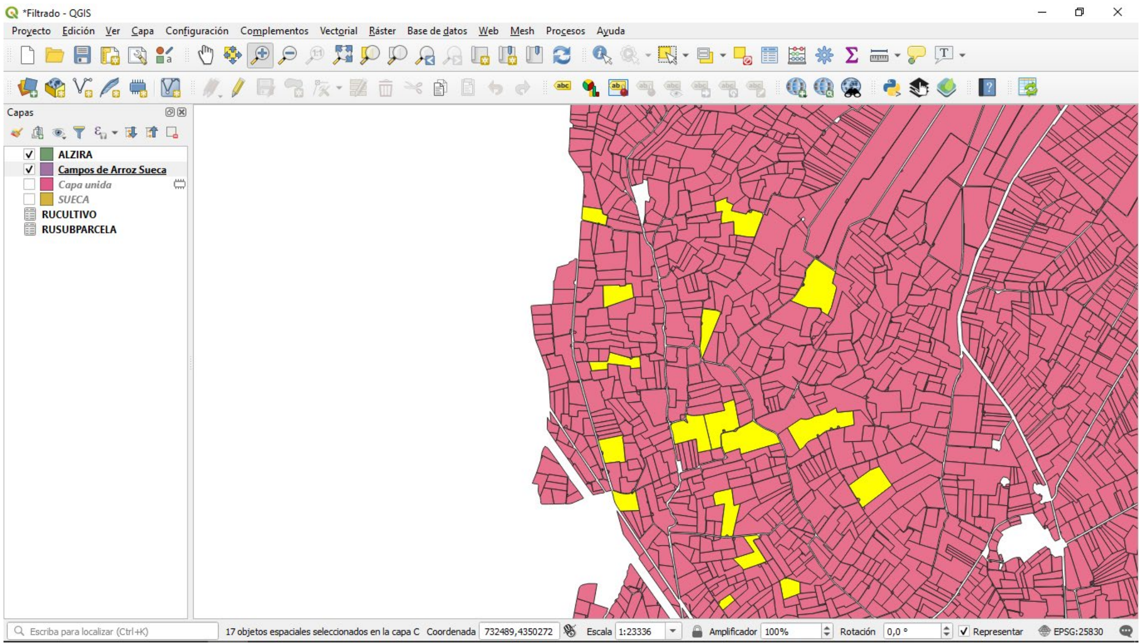

Figure 8. Rice producing plots selected from the municipality of Sueca.

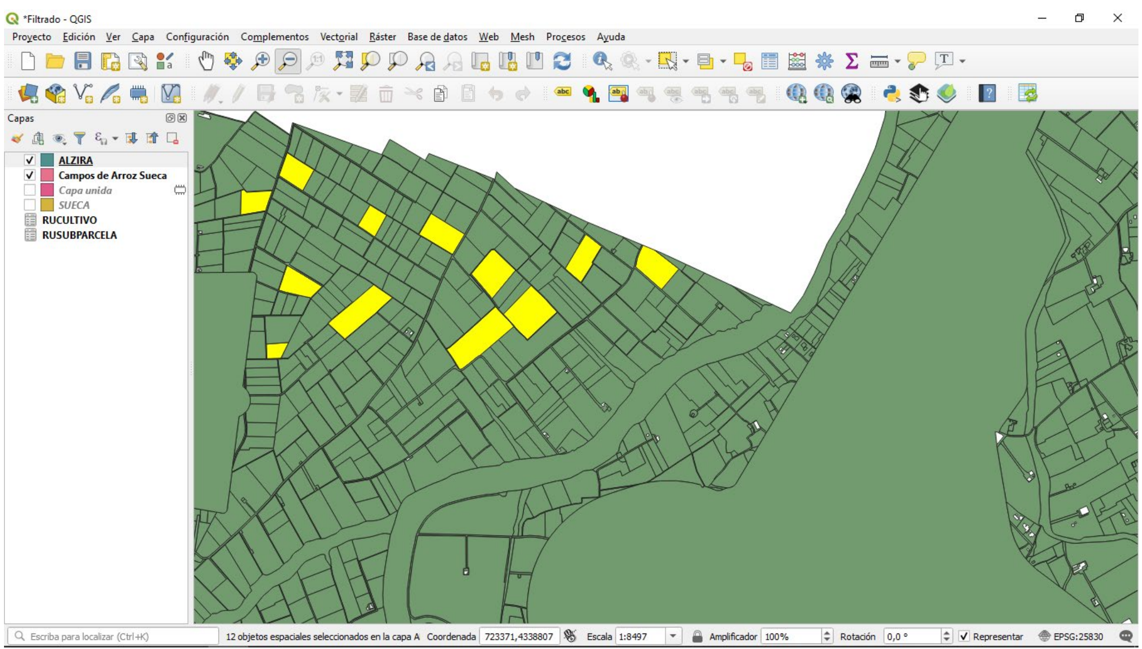

Figure 9. Straw receiving plots for mulch selected from the municipality of Alzira.

Table 7. Data from the Sueca rice straw producing plots.

REFCAT	COORX	COORY	AREA
46237A02300137	729600.11	4347869.31	65754
46237A02500001	729348.87	4348693.18	29240
46237A00200096	728478.36	4349491.69	18447
46237A02400014	729261.8	4347848.09	52541
46237A04600039	730096.07	4347945.74	69189
46237A00200001	728721.27	4347360.69	22332
46237A00200041	728619.03	4347757.86	31665
46237A04600113	730536.57	4347463.82	51062
46237A02300205	729480.83	4347258.67	38896
46237A02300162	729633.08	4346936.54	26693
46237A00200104	728633.42	4348898.7	28946
46237A02500018	730167.13	4348965.49	81221
46237A02300004	729924.39	4346748.79	17982
46237A02300061	729477.51	4346645.67	7079
46237A00200025	728501.74	4348374.31	26478
46237A02400008	729472.8	4348027.12	52164
46237A02500307	729515.07	4349473.2	52010

Table 8. Data from the Alzira rice straw receiving plots for mulch.

REFCAT	COORX	COORY	AREA
46017A00200153	721096.19	4338956.37	2039
46017A00300124	721790.36	4339055.15	10758
46017A00200054	721160.34	4339438.01	5246
46017A00200016	721566.42	4339284.63	6895
46017A00300094	721944.2	4339230.5	6156
46017A00300087	721709.91	4339170.63	8168
46017A00300085	721666.33	4339013.25	12723
46017A00300046	722144.51	4339189.85	7403
46017A00200202	721047.85	4339383.29	4393
46017A00200111	721364.57	4339333.32	3546
46017A00200119	721356.02	4339098.05	10235
46017A00200157	721180.87	4339138.73	5612

Iteration 1

For the application of the first iteration, the distance matrix between the origin and destination centroids must be calculated. Then, the plots with the smallest distance must be chosen. Table 9 shows the matrix of distances between the origin and destination centroids, calculated using QGIS. The plots located at the shortest distance are 46237A02300061 and 46017A00300046, with a value of 10444.79 m. Therefore, these would be the first linked plots constituting p_1 and r_1 respectively.

Assuming that the amount of straw produced per hectare in the source parcels is equivalent to the amount of straw required to mulch in the destination parcel, the areas would be compared. If $p_i = r_j$ for any i, j, the inequality to check will be $\sum_{i=1}^{a} p_i \cdot S_{pi} < r_1 \cdot S_{r1}$ which in turn would become $S_{p1} < S_{r1}$

Given that:

Source area1 (7079 m^2)> Target area (4393 m^2)

Iteration 1 ends, but to start iteration 2, a new centroid must be defined. The new one will have the same coordinates as p_1 but with a straw production yield equal to the excess that has been obtained. In this case, it would be equivalent to the production of Origin Area1 7079 m^2 - 4393 m^2 = 2686 m^2. This can be achieved by modifying the area of the parcel in the attribute table.

ID	46017A00300087	46017A00300094	46017A00200016	46017A00200054	46017A00300124	46017A00200153	46017A00200157	46017A00200119	46017A00200111	46017A00200202	46017A00300046	46017A00300085
46237A00200001	10799.41	10611.13	10811.17	10955.16	10816.92	11345.14	11171.40	11115.32	10910.22	11090.49	10505.74	10956.88
46237A00200025	11557.85	11380.09	11558.54	11676.02	11584.43	12083.61	11905.46	11860.37	11646.86	11809.37	11285.30	11720.44
46237A00200041	11032.89	10849.44	11039.49	11171.30	11054.66	11569.59	11393.73	11342.71	11133.61	11305.79	10749.01	11192.83
46237A00200096	12353.94	12187.50	12343.46	12433.68	12389.57	12857.40	12675.49	12641.72	12420.56	12564.46	12103.77	12521.06
46237A00200104	11968.85	11795.45	11965.13	12071.81	11999.00	12486.04	12306.30	12265.69	12049.04	12204.20	11704.95	12133.30
46237A02300004	11184.22	10977.81	11216.66	11407.15	11184.11	11761.48	11597.53	11521.87	11334.39	11544.54	10852.79	11330.18
46237A02300061	10769.37	10566.17	10798.00	10980.36	10772.61	11341.38	11175.51	11103.33	10912.46	11117.52	**10444.79**	10917.67
46237A02300137	11750.18	11556.56	11767.54	11923.56	11762.80	12305.06	12133.63	12072.38	11871.61	12059.55	11445.35	11904.68
46237A02300162	11143.21	10941.59	11169.86	11347.46	11148.06	11712.36	11545.43	11475.20	11282.48	11484.45	10821.89	11292.62
46237A02300205	11251.29	11054.34	11272.51	11437.72	11260.75	11812.29	11642.70	11577.66	11380.20	11574.19	10939.68	11403.76
46237A02400008	11702.49	11511.91	11716.52	11864.92	11717.94	12251.91	12079.01	12020.97	11817.50	12000.48	11403.93	11858.74
46237A02400014	11510.20	11321.30	11522.45	11666.91	11527.17	12056.65	11883.02	11826.65	11621.80	11802.23	11215.12	11667.36
46237A02500001	12180.44	11997.14	12186.63	12316.49	12202.35	12716.23	12540.06	12489.74	12280.12	12450.78	11896.61	12340.48
46237A02500018	12927.30	12738.20	12939.48	13082.69	12944.10	13473.47	13299.64	13243.65	13038.50	13217.88	12631.55	13084.38
46237A02500307	12958.61	12779.47	12960.40	13079.36	12984.06	13486.21	13308.29	13262.47	13049.51	13212.76	12683.01	13120.62
46237A04600039	12180.89	11983.16	12202.80	12368.85	12189.60	12742.88	12573.49	12507.99	12310.95	12505.33	11867.49	12332.89
46237A04600113	12137.32	11932.62	12167.49	12352.17	12139.00	12711.40	12546.13	12472.79	12283.05	12489.37	11809.33	12284.56

Iteration 2

To apply the second iteration, the two other closest centroids must be found. For this, the matrix of Table 9 can also be used.

The closest origin and destination parcels correspond to the cadastral reference 46237A02300061 and 46017A00300094 respectively. These are located at a distance of 10566.17 m.

Supposing once again that the amount of straw produced per hectare in the source parcels is equivalent to the amount of straw required to mulch in the destination parcel, the areas must be compared. If $p_i = r_j$ for any i, j, the inequality that would have to be checked would be

$\sum_{i=1}^{a} p_i \cdot S_{pi} < r_2 \cdot S_{r2}$; and would end up being $S_{p1*} < S_{r2}$

As Source area1 (2686 m²) <Destination area (6156 m²), it is necessary to find another origin parcel to supply r_2. Of the possible ones, ones with a mínimum distance to p_1 * and r_2 will be selected.

Table 10 shows the sum of distances. It can be verified that the plot closest to p_1 * and r_2 is the one corresponding to the cadastral reference 46237A02300162 with a total distance of 11335.17 m.

The straw produced is checked once more so that it is sufficient to supply r_2. In other words, $S_{p1*} + S_{p2} < S_{r2}$ is verified.

Source area1 (2686 m²) + Source area2 (26693 m²)> Target area (6156 m²).

Since straw production is greater than then one required in r_2, the second iteration ends.

To start the third iteration which means to search for r_3 and associate it to a set of origin parcels, it is necessary to redefine the parcel p_2 * with the same coordinates as p_2 , but with an associated area equal to the excess available straw. For instance,

26693 m² +2686 m² - 6156 m² = 23223 m²

The same process would be continued in the following iterations until completing the groupings associated with all the receiving parcels, as long as there are originating producer parcels available.

Table 10. Matrix of distance to p_1 * and r_2

ID	46017A00300094	46237A02300061	Sumatorio de distancia
46237A02500018	12738.20	2425.35	15163.55
46237A02300004	10977.81	483.01	11460.82
46237A00200025	11380.09	1956.65	13336.74
46237A02400008	11511.91	1325.94	12837.86
46237A02500307	12779.47	2841.88	15621.35
46237A02300137	11556.56	1220.99	12777.54
46237A00200096	12187.50	3029.64	15217.14
46237A02500001	11997.14	2039.80	14036.94
46237A04600039	11983.16	1477.42	13460.58
46237A02400014	11321.30	1284.77	12606.07
46237A00200001	10611.13	1052.86	11663.99
46237A00200041	10849.44	1409.46	12258.90
46237A04600113	11932.62	1372.58	13305.19
46237A02300162	10941.59	393.58	**11335.17**
46237A02300205	11054.34	673.34	11727.68
46237A00200104	11795.45	2423.58	14219.03

IMPROVEMENT OF THE ALGORITHM

In the algorithms presented, it has been considered that the costs of straw harvest or mulch deposition of straw does not influence the choice of groupings of the plots in the logistic model. In this section these costs will be considered.

It can be appropriate to assume that these costs are different in each plot and that they will be conditioned by various factors such as the area, surface and the type of soil, since they will influence the machinery being used.

The difficulty of this algorithm improvement is that it requires a prior study of the corresponding variables in each plot; and then, implement them in additional fields to those provided by the cadastre. With the new fields created, the operations indicated in the algorithm must be done and this slows down the calculation and application process.

Scenario 1. Direct application to a single parcel

Once a destination receiving parcel is known, it consists of determining the supply parcels that act as origin. The starting variables are shown in Table 11.

Table 11. Starting variables

Yield of straw producing plots (t/ha)	p_i
Straw requirement for fruit plots (t/ha)	r_j
Producing parcel coordinates (possible origin) p_i	(x_{pi}, y_{pi})
Coordinates receiving parcel (destination) r_j	(x_{rj}, y_{rj})
Area of possible origin parcel p_i	S_{pi}
Area of receiving parcel (destination) r_j	S_{rj}
Harvest cost of straw in the producing plot p_i (€/ha)	C_{pi}
Straw deposition cost in the receiving parcel r_j (€/ha)	C_{rj}
Cost of each trip back and forth between plots p_i and r_j (€/km)	Cv_{pirj}
Transport truck capacity	Q

The calculation procedure is iterative:

Iteration 1

If the coordinates of the receiving-destination parcel are (x_{r1}, y_{r1}), the source plot with coordinates (x_{p1}, y_{p1}) is selected from the possible set of origin plots such that the total cost for harvest, transport and deposition is minimum.

$$\text{Min } C_{p1} \cdot S_{p1} + Cv_{p1r1} \cdot \frac{p_1 \cdot S_{p1}}{Q} \cdot d_{p1r1} + C_{r1} \cdot S_{r1} \qquad (11)$$

Where the distance is calculated by the equation 12

$$d_{p1r1} = \sqrt{\left(x_{p1} - x_{r1}\right)^2 + \left(y_{p1} - y_{r1}\right)^2} \qquad (12)$$

Instead of using the Euclidean distance, you can use the one given by the communication routes. For this, the Network Analysis application of the QGIS Geographical Information System must be used.

If $p_1 \cdot S_{p1} < r_1 \cdot S_{r1}$ is accomplished, for completing the r_1, requirements it is necessary to stock up on more plots. In that case, it will be necessary to select another plot (x_{p2}, y_{p2}) from possibility plot set, which leads to iteration 2.

Iteration 2

The selection of the second plot that supplies r_1 will be p_2 such that the equation 13 will be minimal. It should be noted that equation 13 is not a cost equation, but rather establishes the heuristic search criteria. The cost equation would be calculated more precisely with equation 14. However, equation 13 allows the choice to be made such that collection and supply logistics are as cheap as possible

$$\min\left(C_{p2} \cdot S_{p2} + Cv_{p2r1} \cdot \frac{p_2 \cdot S_{p2}}{Q} \cdot d_{p2r1} + Cv_{p1p2} \cdot d_{p1p2} \right) \quad (13)$$

Therefore, to search p_2, it is required that equation 13 be minimal.

$$\begin{aligned} &C_{p1} \cdot S_{p1} + C_{p2} \cdot S_{p2} + Cv_{p1r1} \cdot \frac{p_1 \cdot S_{p1}}{Q} \cdot d_{p1r1} + Cv_{p2r1} \cdot \frac{p_2 \cdot S_{p2}}{Q} \cdot d_{p2r1} + \\ &Cv_{p1p2} \cdot d_{p1p2} + C_{r1} \cdot S_{r1} \end{aligned} \quad (14)$$

On the other hand, it should be warned that after finding plot p_1, meeting the minimum of equation 13 is equivalent to searching p_2 from available producing plots by equation 15, which exclusively considers the addends that are added by the equation 11. The search for equation 13 can be simplified by finding equation 15.

$$C_{p2} \cdot S_{p2} + Cv_{p2r1} \cdot \frac{p_2 \cdot S_{p2}}{Q} \cdot d_{p2r1} + Cv_{p1p2} \cdot d_{p1p2} \quad (15)$$

Once p_2 is found, the following formula must be verified $p_1 \cdot S_{p1} + p_2 \cdot S_{p2} < r_1 \cdot S_{r1}$. If the amount of available straw is less than the requirements of the receiving parcel, it is necessary to supply from more plots. So, it will be necessary to select another of the possible ones with iteration 3.

Iteration 3

The third plot for the group p_3, is searched such that the heuristic criterion of equation 16 must be achieved. This criterion provides an approximation to find the plot that has the minimum cost of harvesting, transport and deposition, given by equation 17.

$$\min\left[C_{p3}\cdot S_{p3}+Cv_{p3r1}\cdot\frac{p_3\cdot S_{p3}}{Q}\cdot d_{p3r1}+Cv_{p3p2}\cdot d_{p3p2}+Cv_{p3r1}\cdot d_{p3r1}\right] \quad (16)$$

Therefore, to search p_3 , it is required that equation 16 be minimal.

$$\sum_{i=1}^{3}C_{pi}\cdot S_{pi}+\sum_{1}^{3}Cv_{p1r1}\cdot\frac{p_i\cdot S_{pi}}{Q}\cdot d_{p_ir1}+\sum_{1}^{2}Cv_{p3pi}\cdot d_{p3p_i}+C_{r1}\cdot S_{r1} \quad (17)$$

In general, it must be verified that if a is the selected parcel number, $\sum_{1}^{a}p_i\cdot S_{pi}<r_1\cdot S_{r1}$ should be satisfied. In such case, it is necessary to stock up on more plots, so it will be necessary to select another from possibility plot set such that complies with equation (18).

$$\min\left(C_{p_a}\cdot S_{p_a}+Cv_{p_ar1}\cdot\frac{p_a\cdot S_{p_a}}{Q}d_{p_ar_1}+\sum_{i=1}^{a-1}\left(Cv_{p_ap_i}d_{p_ap_i}\right)\right) \quad (18)$$

The cost borne by the harvest, transport and deposit to plot r_1 would be:

$$\sum_{i=1}^{a}C_{pi}\cdot S_{pi}+\sum_{1}^{a}Cv_{p1r1}\cdot\frac{p_i\cdot S_{pi}}{Q}\cdot d_{p_ir1}+\sum_{1}^{a-1}Cv_{p_ap_i}\cdot d_{p_ap_i}+C_{r1}\cdot S_{r1}$$

The algorithm ends when: $\sum_{1}^{a}p_i\cdot S_{pi}>r_1\cdot S_{r1}$

Scenario 2. Direct application to a several parcels

There are several parcels receiving straw, together or separately. They must be supplied with several possible parcels that produce straw. The objective is to determine which parcels act as the source of each of the destination parcels. Each destination parcel is linked to a set of origin parcels. To make the links, you can use the QGIS software, which is a free Geographic Information Systems program. The operations are structured in iterations.

Iteration 1.

Supply of the parcel r_1.

1. Initially, the parcels that will act as destination are selected from the cadastre parcel and are saved in a shape file.
2. In the same way, the plots that will act as the source of straw are selected. These will also be saved in another shape file.
3. From both files, the centroids of the parcels are obtained and stored in independent shape files.
4. The cost matrix between the centroids of the source parcels and the destination parcels is calculated.
5. The pairing with the shortest cost is selected so that the first relationship is established. These parcels constitute the producer parcel p_1 and the recipient parcel r_1.

$$\text{Min } C_{p1} \cdot S_{p1} + Cv_{p1r1} \cdot \frac{p_1 \cdot S_{p1}}{Q} \cdot d_{p1r1} + C_{r1} \cdot S_{r1}$$

6. After the first connection, the criterion of *scenario 1* is followed to link more than one source parcel to the selected destination parcel r_1, until the straw requirements of the destination parcel are supplied.

   After the selection of the last producing parcel linked to the parcel, part of its production may be free for having exceeded the needs of the destination parcel. In other words, there is a surplus. Therefore, it is necessary to redefine a new plot with the same coordinates as the last one selected but with a production equivalent to the excess. If the last plot selected is the excess production of straw, the following equation follows:

$$P_{p_a} = \sum_{i=1}^{a} p_i \cdot S_{pi} - r_1 \cdot S_{r1}$$

A new parcel will have coordinates (x_{p_a}, y_{p_a}), but instead of associating a performance p_a, it must be associated with a performance P_{p_a} to apply iteration 2.

Iteration 2. Supply of the plot r_2

1. When the needs of the target parcel are covered, the centroid of the parcel selected r_1 in iteration 1 is excluded from the shape of the centroids of the target parcels; and in the shape of the centroids of the possible origin parcels, those corresponding to those selected in iteration 1 $\{p_1, p_2, ..., p_a\}$ are also excluded.

2. With the new centroid shape files, the cost matrix is calculated from both origin and destination.
3. The origin-destination is selected $p_{b1}\ \ r2$ centroid pair that has the condition:

$$\min\left(C_{p_{b1}}\cdot S_{p_{b1}} + Cv_{p_{b1}r2}\cdot\frac{p_{b1}\cdot S_{p_{b1}}}{Q}\cdot d_{p_{b1}r2} + C_{r2}\cdot S_{r2}\right)$$

4. After being linked, the criterion of *scenario 1* is followed to link more than one origin parcel to the new selected destination parcel $r2$, until the straw requirements of the destination parcel are supplied.

There will be as many iterations as the number of existent destination parcels, as long as there are source parcels available.

Scenario 3. Deferred supply of several plots

In this case, the solution for managing the straw produced in various plots involves finding the optimal location of collection centers, in which their dimensions must be defined as well.

As discussed in the distance-based analysis, the collection points consist of plots where bales are stored. Considering the average surface of the parcel $\overline{S}$, if the objective is to cover all the needs of the receiving parcels, the number of collection points would be given by equation 5. If the objective is to store all the straw produced in the producing parcels, in such a way that a part of the straw would be used for mulch and another one for other uses, the number of collection points would be given by equation 6.

Since each collection point is supplied by a set of producer plots, it is necessary to group them. Each grouping of producing plots will be linked to a collection point. An original algorithm has been devised for grouping, called the *borvelog2 grouping algorithm*.

Borvelog2 grouping algorithm

This algorithm is applied iteratively. We start from three classes of parcels: possible origin parcels, possible collection parcels and destination parcels. The procedure to be followed is divided into two steps: In the first step, the location of the receiving plots is ignored, and we focus on the possible collection points and the possible sources of straw. As a second step, this algorithm will be reapplied to link the receiving parcels with the collection points. Variables are defined in Table 12.

As not all points can be collection points, it is necessary to pre-define a set of possible collection points $A = \{a_1, a_2, ..., a_h\}$.

Table 12. Starting variables for linking producer plots, recipient plots and collection points.

Yield of straw producing plots (t/ha)	p_i
Straw requirement for fruit plots (t/ha)	r_j
Storage capacity of storage plots (t/ha)	a_h
Coordinates receiving parcel (destination) r_j	(x_{rj}, y_{rj})
Coordinates producing plot (possible origin) p_i	(x_{pi}, y_{pi})
Coordinates possible collection plot a_h	(x_{ah}, y_{ah})
Area of receiving parcel (destination) r_j	S_{rj}
Area of possible origin parcel p_i	S_{pi}
Area of possible storage plot a_h	S_{ah}
Harvest cost of straw in the producing plot p_i (€/ha)	C_{pi}
Straw deposition cost in the receiving plot r_j (€/ha)	C_{rj}
Cost of each trip back and forth between plots p_i and a_h (€/km)	$Cv_{p_i a_h}$
Cost of each trip back and forth between plots a_h and r_j (€/km)	$Cv_{a_h r_j}$
Transport truck capacity	Q

Step 1. Linking producer plots with possible collection plots.

Iteration 1. Supply of the plot a_1

1. Initially, the parcels that will act as storage plot are selected from the cadastre parcel and saved in a shape file.
2. In the same way, the plots that will act as the source of straw are selected. These will also be saved in another shape file.
3. The centroids of the plots are obtained from both files and stored in independent shape files.
4. The matrix of costs between the centroids of the origin parcels and the destination parcels are calculated.
5. The pair with the cheapest cost is selected so that the first relationship is established. These parcels constitute the producing parcel p_1 and the receiving parcel a_1.

$$\min\left(C_{p1} \cdot S_{p1} + Cv_{p1a1} \cdot \frac{p_1 \cdot S_{p1}}{Q} \cdot d_{p1a1} \right)$$

If $p_1 \cdot S_{p1} < a_1 \cdot S_{a1}$ is met to cover the storage capacity a_1, it is necessary to restock more plots, so it will be necessary to select another one (x_{p2}, y_{p2}), going to iteration 2. For this, the criterion of *scenario 1* is followed to link more than one origin parcel a_1 to the selected destination parcel, until the straw requirements of the destination parcel are supplied.

After the selection of the last producing parcel linked to the parcel r_1, part of its production may be free for having exceeded the needs of the destination parcel. In other words, there is a surplus. Therefore, it is necessary to redefine a new plot with the same coordinates as the last one selected but with a production equivalent to the excess. If the last plot selected is p_a which is the excess production of straw, the following equation follows:

$$P_{p_a} = \sum_{i=1}^{a} p_i \cdot S_{pi} - a_1 \cdot S_{a1}$$

A new parcel will have coordinates (x_{p_a}, y_{p_a}), but instead of associating a performance p_a, it must be associated with a performance P_{p_a} to apply iteration 2.

Iteration 2. Supply of the plot a_2

1. When the storage capacity of the plot a_1 is covered, the centroid of the plot selected in iteration 1 is excluded from the shape of the centroids of the possible collection plots; and in the shape of the centroids of the possible origin parcels, those corresponding to those selected in iteration 1, are also excluded.
2. With the new centroid shape files, both origin and destination, the distance matrix is calculated.
3. The origin-storage centroid pair p_{b1} a_2 has the condition:

$$\min \left(C_{p_{b1}} \cdot S_{p_{b1}} + Cv_{p_{b1}a2} \cdot \frac{p_{b1} \cdot S_{p_{b1}}}{Q} \cdot d_{p_{b1}a2} \right)$$

4. After linking, the criterion of *scenario 1* is followed to link more than one origin parcel a_2 to the selected destination parcel, until the storage capacity with straw of the destination parcel a_2 are supplied.

   There will be as many iterations as the number of destination parcels existent, as long as there are source parcels available. The cost of storing straw in a given plot a_h from to producing plots *a* is given by the equation:

$$\sum_{i=1}^{a} C_{pi} \cdot S_{pi} + \sum_{1}^{a} Cv_{p_i a_h} \cdot \frac{p_i \cdot S_{pi}}{Q} \cdot d_{p_i a_h}$$

Step 2

To associate the collection parcels a_h with the destination parcels r_j, recipients of straw for mulch, the same algorithm from step 1 is applied again between these two groups.

The cost of supplying mulch in a given plot from to collection plots r_j is given by the following equation:

$$C_{r_j} \cdot S_{r_j} + \sum_{1}^{a} Cv_{a_i r1} \cdot \frac{a_i \cdot S_{ai}}{Q} \cdot d_{a_i rj}$$

CONCLUSIONS

Three models to link mulch straw receiving plots with straw suppliers plot has been developed. Each model solves the problem in one scenario. The first one considers the direct application of straw to a single plot for mulching from several supplier plots. It is not considered intermediate storage. The second scenario also involves a direct application but in several receiving parcels originating from various suppliers also without intermediate storage. The third scenario develops a model that groups provider plots with different collection points; It offers a system that selects the location of the storage points and associates each storage point with a group of receiving plots.

It has been shown that the exposed algorithms can solve the problem of assigning mulch supplier plots to mulch receiving plots considering both the distance or the costs.

The developed methods can be applied through geographic information system programs when the selection criteria are based only on distances. However, the application of economic criteria requires prior studies of harvesting, transportation and deposition costs.

It can be put forward the problem of allocating the straw destination plots with producer plots within any of the three scenarios that were analyzed.

If the input data is available, the algorithms can be automated using specific apps.

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