

Rethink its crop system to integrate a robot: a look back at four years of experimentation in sugar beet

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Abstract

Robotic technology is still not widespread in field crops such as wheat or maize. Sugar beet is one of the few crops that has experienced significant growth in the use of agricultural robots in recent years. In 2025, more than 50 robots were operating in sugar beet fields, with the FarmDroid® robot being the most widely adopted model. This technology can perform both sowing and weeding and is mainly used in organic sugar beet fields. ITB (Institut Technique de la Betterave) has been conducting trials over the last four years using its own robot to identify the strengths and weaknesses of this technology.

The robot enables precise and efficient in-row mechanical weeding, which is difficult to achieve with conventional implements. It can also perform weeding at very early sugar beet growth stages (two-leaf stage) without damaging the crop. Furthermore, in some cases, it can replace manual weeding, which is expensive and time-consuming. Farmers using robots would not go back to a sugar beet cropping system without one.

However, several challenges remain with this technology. First of all, to achieve efficient in-row weeding, the robot must operate at very low speeds, which requires farmers to rethink their work organization and take weather conditions into account. Furthermore, calling this technology an “autonomous machine” can be misleading, as close human supervision is still necessary to ensure proper operation.

Despite its numerous advantages, robotics in sugar beet has proven its value. Its future adoption will depend on the willingness of producers, sugar manufacturers, and consumers to support sugarbeet production with reduced herbicide use.

Keywords: Robotic / Weeding / Sowing / Agroecology / Precision / Autonomy

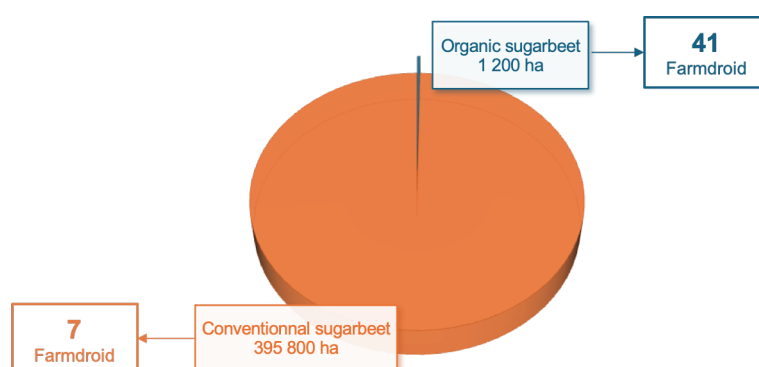
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Introduction

The sugar beet sector is the field-crop sector in which agricultural robotics has developed most rapidly. The launch of “made in France” organic sugar beet production in the early 2020s was the real driver behind this development. In fact, growing organic sugar beet requires a lot of handwork for weeding the fields. Workers who want to do this job are becoming increasingly difficult to find, and a robot makes it possible to significantly reduce this constraint. With about fifty robots now operating across France, most of them being FarmDroid robots, farmers who have adopted this technology have identified clear benefits. Although the organic sugar beet sector is currently facing a slowdown, these robot users would not go back to their previous farming practices.

Figure 1 below presents organic sugar beet production in France in 2025 and the number of FarmDroid® regarding the type of production:

Figure 1: Surface of sugar beet production regarding the type of production in 2025 in France and number of Farmdroid® robot



Source: Cultures Sucre, Farmdroid®

However, installing a robot in a sugar beet field is not simply a matter of watching the robot carry out its task. **The entire crop management strategy must be reconsidered**, from sowing to harvesting, and in some cases, this reflection may even extend to the scale of the crop rotation. From an agronomic perspective, many of the farmers' usual benchmarks and decision-making processes need to be reconsidered: When should the robot be deployed? What settings should be used? Which weeds should be targeted?

Figure 2: Field trials made with the FarmDroid® by ITB through the years

2023	2024	2025	2026
			
First trial Small surface (4,5 ha) Conventional farmer First study of sowing and weeding efficiency in conventional context Recommended robot setting	Big field (10,5 ha) Organic farmer First study of sowing and weeding efficiency in organic context Recommended robot settings	Big field (10 ha) Organic farmer First study of the blind seeding with the robot Aggressive weeding setting tested Multicriterial analysis	Big field (10 ha) Organic farmer First study of the 'half blind' weeding with the robot, first study of early-stage weeding Multicriterial analysis

Like farmers, the Institut Technique de la Betterave (ITB) has had to learn through experience when implementing these technologies in the field. The figure 2 above shows how our institute took charge of this technology through the years from trials at small scale to a complete study of the robot at field scale (the words written in bold are the new changes made through the years). Regarding our results and FarmDroid® user's feedback, we adapted our trials through the years to study what seemed interesting to gain work efficiency.

How should the crop management strategy be redesigned to integrate a robot into a sugar beet cropping system, and what are the real challenges and implications of these technologies for this production sector?

Materials and Methods

The trials conducted over the years differed considerably from one year to another, but they were all made in farmers' fields, under uncontrolled conditions. Except for the first year (2023), the whole field was managed by the robot. The robot used for our trial was the FarmDroid® robot configured for sugar beet with these specific configurations:

Model name	FD20
Working width	3 m
Weight	900 kg
Inter-row distance	50 cm
In-row distance	18 cm (except in 2026: 19 cm)
Sowing speed	700 m/h
Weeding speed (at early stages)	400 m/h
Weeding speed (at late stages)	900 m/h
In-row knives aggressivity	Normal (except for 2025 trial)

In all our trials, the solar panel on the robot was the only source of energy, we did not use extra battery. Robot settings were managed jointly by the farmer and ITB.

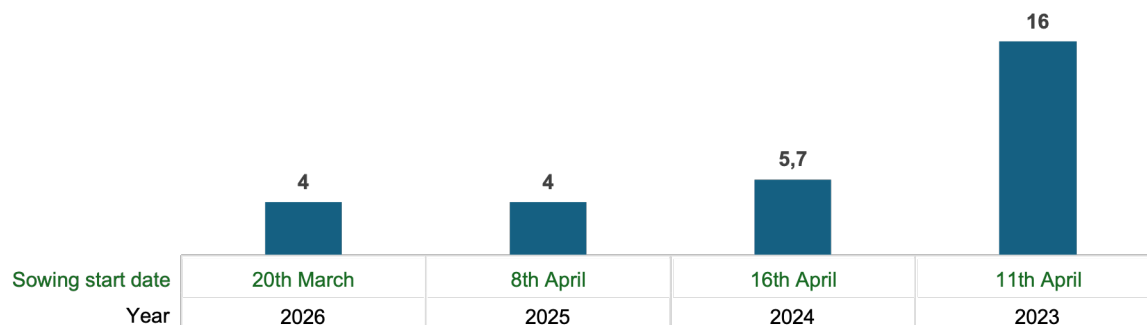
Results and discussion

In this part of the article, the results and discussion are divided into different topics to highlight the specificity of the robot and understand how crop systems have to be rethought. The different topics are working time, weeding efficiency and multicriterial analysis with a final chapter dedicated to a crop system comparison.

○ Working time

The FarmDroid® robot stands out for its high work precision, enabled by slow workflow rates (sowing at 700 m/h and weeding at 900 m/h). The manufacturer claims a daily sowing capacity of 4 hectares per day. However, our experiments showed an even slower workflow rate for sowing, as illustrated in the figure below (figure 3). Since this operation is carried out in late March/early April, the days are still short with limited sunlight, reducing the robot's autonomy. As a result, the robot stops sowing in the middle of the night and waits for sunrise. Of course, the robot also stopped when the seed hoppers were empty. In this case, the farmer receives an alert notifying them to fill the hoppers (sometimes during the nighttime).

Figure 3: Time (in day) to sow* 10 ha with the FarmDroid® each year in our trials



**All times have been recalculated and adjusted to a 10-hectare basis. The days indicated include delays caused by rain during sowing.*

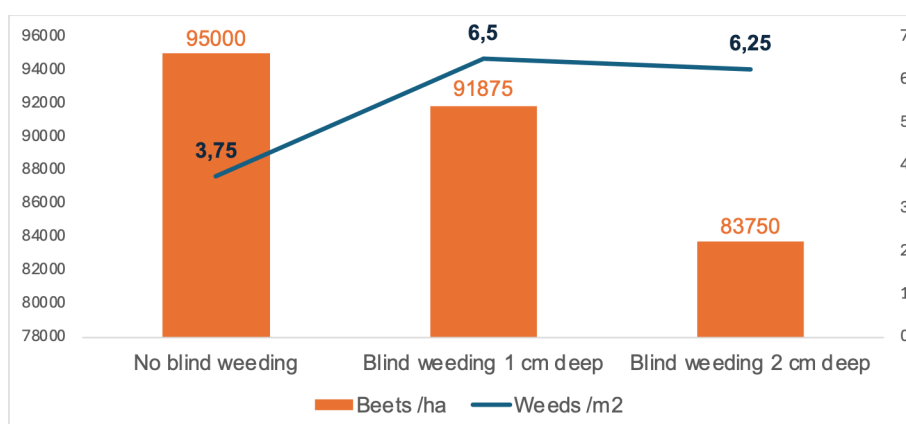
What must be emphasized above all with technologies like robots, which have a low workflow rate, is the need to strongly anticipate, sometimes on a weekly scale, the possibility of carrying out the work under good conditions. In 2023, spring was particularly wet, with regular rainfall that significantly delayed sowing. In subsequent years, sowing was anticipated more precisely based on weekly weather forecasts.

In terms of work organization, farmers who are already used to working with weather forecasts must **be even more attentive to predictions** when using a robot. They must also accept that sowing may sometimes need to be spread out when weather conditions are not ideal. This observation also applies to weeding operations.

○ Weeding efficiency

In the different trials, ITB tried to determine whether the robot provided a real advantage in early weeding operations, where traditional mechanical weeding tools cannot intervene. Therefore, we studied the benefits of blind weeding (performing superficial weeding just after sowing, above the sowing depth, to destroy weeds that were just emerging) and weeding at the two-leaf stage of sugar beets.

Figure 4: Effect of the blind weeding on beets and weeds population (2025 trial)



In our 2025 trial (figure 4), a greater number of weeds were recorded in the blind weeding treatments than in the 'no blind weeding' control after sowing. The pre-emergence hoeing operation may have created favourable conditions for the germination of previously dormant weed seeds in the soil.

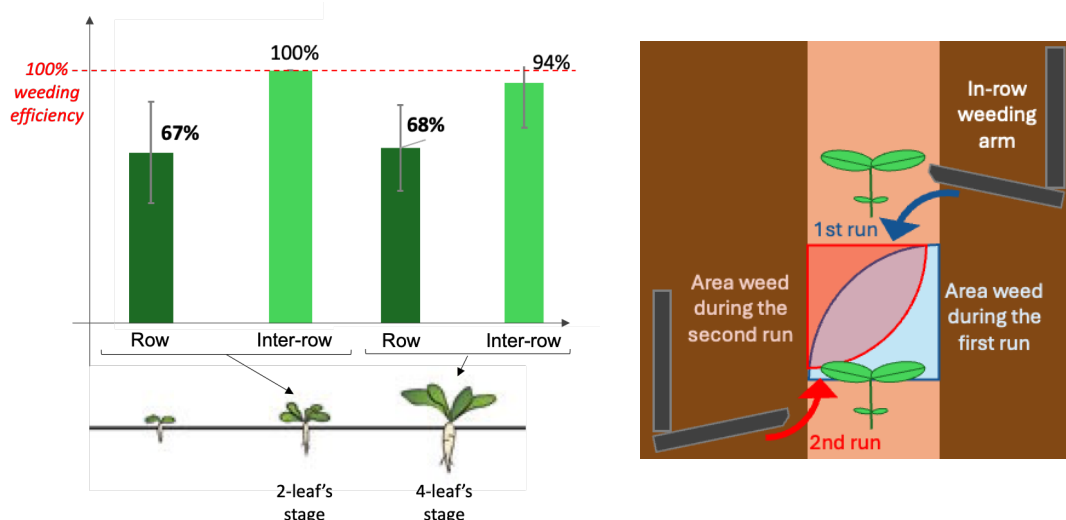
However, these results should be interpreted with caution, as it cannot be ruled out that the initial weed seed bank was higher in the blind-weeding plots than in the 'no blind weeding' control. In fact, we observe here the same conclusions as in our false seedbed trials: a superficial soil working before or after sowing can have **a rather random effect on weed populations**.

Regarding sugar beet emergence, lower plant populations were observed in the blind weeding modalities. This pre-emergence operation also tends to move soil back onto the row, artificially increasing the sowing depth, which was already relatively deep (3 cm). Plant populations were particularly reduced in the treatment where the row was cultivated to a depth of 2 cm.

Despite these discouraging results, the ITB still recommends performing a weeding operation, if possible, right after sowing by using a kind of "half-blind weeding", where only the inter-row area is superficially worked. By this way, no soil is added to the row, which could otherwise impact the emergence of germinating sugar beets.

In 2026, we conducted a comprehensive study of the weed population before and after the robot weeding, including row and inter-row counting. Above all, the early-stage weeding has been conducted (weeding at 2-leaf stage), where all conventional mechanical weeding implements would severely damage sugar beet plants. The results are presented in the figure 5 below.

Figure 5: Weeding efficiency (inter-row and in-row) of the FarmDroid® at sugar beet early stages (2026 trial), and in-row weeding principle



It appeared that the in-row weeding enables a weeding efficiency of 67%, which is quite good. This figure can be explained by the movement of the in-row weeding tool of the robot that is doing an arc of a circle in the row to avoid beet damage.

The in-row weeding can be completed with another FarmDroid® hoeing but running in the contrary direction than the first run (as explained in the figure 5). In this way, weeds that were out of reach during the first run can be weed during the second run. ITB experimented 'aggressive setting' with the weeding in-row tool, but it was too destructive for the sugar beet.

Even if it seems to be a good result, weeds remain in the row. In our 2026 trial, we counted at 4 leaves stage after the robot work (in the contrary direction as the first run) 23 weeds/m² on average which is still a lot, mainly when we know that 1 chenopod per square meter can result in a 3,7-t/ha yield loss.

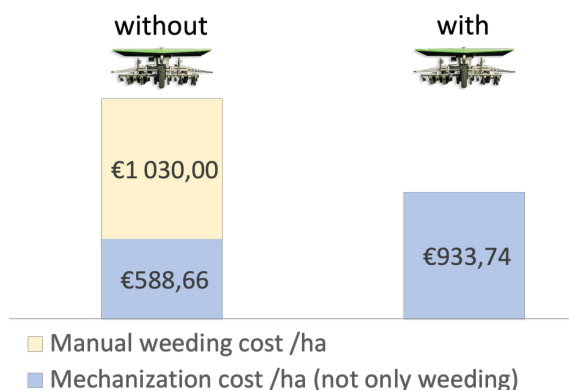
In this context, the in-row weeding should be completed by manual weeding (the time for which will be drastically reduced compared to a non-robot system).

Such as every mechanical weeding tool, **the balance has to be found between being efficient enough to destroy the weeds and being selective enough to avoid damage on sugar beet.** Robot allows a precise and efficient in-row weeding at very early stage, and FarmDroid® users use this advantage wisely. Tolerance to weeds is then specific to each farmer, the one looking for a really clear field will add manual weeding later, but with a lower time dedicated to this task compared to non-robot users.

○ **Multicriterial analysis**

A multicriterial analysis was also launched in 2025 and continued in 2026 to study the robot beyond technical aspects. One of the main criticisms made to these technologies is that they are expensive, so we did a factchecking regarding this affirmation in an organic sugar beet crop system. The FarmDroid® robot purchase price considered in this study was €75,000, with an annual subscription fee of €995 (2026 price announced by the manufacturer). The cost calculated for manual weeding was €1,030/ha (60 h/ha for the cropping system without the robot).

Figure 6: Weeding cost with or without FarmDroid® robot in organic sugar beet



Source: ARTB, ITB with Systerre®

Mechanization costs were lower for the cropping system without the robot than for the system incorporating the robot. This difference is mainly explained by the high purchase price of the FarmDroid®, its depreciation being allocated to a single crop (sugar beet only), and its annual subscription fee of €995. However, in our case study, when manual weeding costs are included in the system without the robot, total costs increase sharply and may even exceed those of the FarmDroid-based system. In this context, the robot demonstrates its economic value through its ability to substitute for manual in-row weeding.

It should be noted, however, that although the robot provides effective in-row weed control, it does **not achieve the same level of field cleanliness** as a cropping system completed with manual weeding. During wet spring conditions, the robot may struggle to keep the crop row sufficiently weed-free, which can have a significant negative impact on final yield.

The working time of both the farmer and the robot was also studied in the multicriterial analysis. Manual weeding takes up the majority of the working time without a robot. For sowing and weeding, the robot operates for approximately 23.5 hours per hectare (due to its intervention speed), which is nearly three times less than the time dedicated to manual weeding (60 h/ha). However, these results should be interpreted with some caution. In this study, the robot handles operations that are highly dependent on weather conditions: sowing and mechanical weeding. This means that from April to early June, weather conditions must be optimal over an extended period. This constraint does not apply to the same extent in the traditional organic crop system, which uses classical sowing implement and mechanical weeding tools with higher workflow rates.

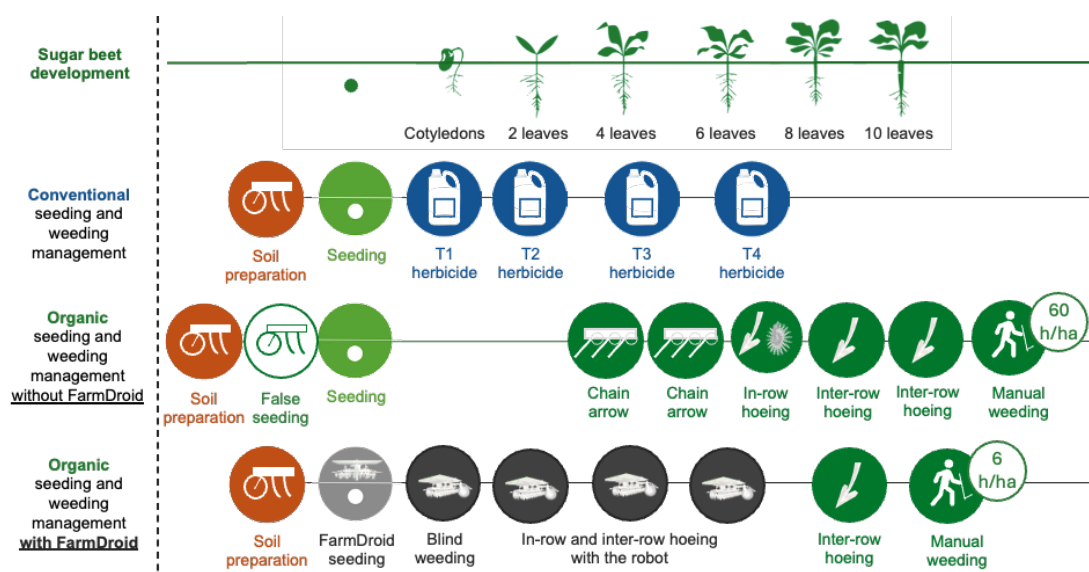
Additionally, an unquantifiable **supervision time** must be added for the robot, involving monitoring various operations, alerts, and potential malfunctions that can occur at any time of the day or night. What is important to note is that it is not the robot that decides whether the conditions are good or bad for performing the required work. **The decision belongs to the farmer**, who must closely monitor its field and assess the agronomic relevance of the task, which can be time-consuming.

A final focus was done on energy and fuel consumption across the entire sugar beet crop system, from fertilization to harvest. Since the robot operates with a large solar panel that produces electricity, it does not require fuel for its sowing and weeding operations. However, soil preparation, organic fungicide protection, and harvesting remain fuel-dependent in the crop system with robot. As a result, fuel consumption and greenhouse **gas emissions from fuel use are still half** those of the non-robot organic crop system (132 l/ha for the non-robot vs. 63.2 l/ha with FarmDroid®).

○ A crop system for the robot

The figure 7 presents 3 different crop systems (conventional, organic with or without FarmDroid®) regarding the sugar beet development stages. A focus was made on the seeding and the weeding, where the robot is involved. These 3 systems were designed with keeping **the same level of field cleanliness** at the end of weeding operations. We assume that the robot's work on the rows was particularly effective and reduced the time required for manual weeding by a factor of 10.

Figure 7: Comparison of 3 crop systems (seeding and weeding) of sugar beet: conventional, organic with and without FarmDroid®



The first difference in the crop system using a robot is noticed before the sowing operation. Since the FarmDroid® is a robot equipped with lightweight sowing and seed-firming tools, the soil must be finely prepared and level to ensure high-quality sowing. While a single preparation pass is generally enough for conventional sowing, two passes are usually required for the robot's sowing to ensure the soil is sufficiently fine and to allow a proper seed placement. The farmer must anticipate this specific soil preparation using the appropriate equipment. Proper levelling of the field, also recommended in organic farming, is crucial for the success of the next mechanical weeding operations to come.

The shape of the field must also be suited to the robot's operation; fields with triangular headlands or irregular boundaries make the robot's work more challenging. It may therefore be necessary to redesign the field layout, sometimes deciding to take certain areas out of production to ensure optimal robot performance.

Unlike conventional or organic farming methods, where there is a brief delay before the first weeding operations, the robot must begin work immediately after sowing by initiating "blind weeding". Once this step is complete (taking about one week for just over 10 ha), the farmer must prepare to deploy the robot again when the beet plants reach the two-leaf stage for the first in-row weeding pass. As with organic farming, some loss of beet plants during mechanical weeding passes is acceptable; however, total losses across all operations must not exceed 10%.

Farmers must **closely monitor weeding operations**. They need to ensure the robot operates at a stage when weeds can be easily destroyed, taking advantage of the favourable drying conditions that follow the intervention. Since the goal is to effectively eliminate weeds within the crop row, the farmer must take considerable time to fine-tune the tool settings, aiming the right balance between selectivity and efficacy. In fact, just as with a hoe or a chain harrow in organic cropping system, significant time spent on adjustments is essential to ensure the weeding process goes right. Furthermore, no intervention other than the robot is planned between sowing and the six-leaf stage, even though a pass with a hoe or chain harrow could be considered. This is due to the aim of avoiding tractor wheel tracks in the areas worked by the robot; our trials showed that ruts, even shallow ones, could impair the robot's precision.

From the 8-leaf stage, the Farmdroid® can still operate; however, since it now focuses primarily on the area between the rows, it is more efficient in terms of operating speed to prioritize a pass with a hoe.

Conclusions and prospective

Sugar beet, which is a row crop, is particularly well suited to robotization. Since weed competition can cause significant yield losses, weeding is an essential operation in its crop management. With the rise of organic sugar in the 2020s, robots (mainly FarmDroid®) have developed well in this crop, and the ITB has gradually supported their deployment among farmers. Users are satisfied with this technology and its advantages, the main one being the ability to weed sugar beets at an early stage. The robot also drastically reduces the manual weeding, which is painful, expensive and time-consuming. The FarmDroid® can be economically affordable by farmers in this context.

However, many challenges remain with robots in sugar beet. Installing this equipment in a field requires rethinking the overall farming approach: revising soil preparation, field layout, adopting more agronomic decision-making, and being available to troubleshoot the robot 24/7. These technologies are likely to develop further if they can be used not only for one crop but for several crops within the rotation. And it is precisely on this last point that technological progress needs to advance, because, for the moment, few field crops can be managed by a robot.

To take the reflection further, we can try to imagine what **robotic development in sugar beet might look like in 10 years**. We can choose a rather realistic and optimistic premise, which would be as follows: less herbicides are available (government restrictions), sugar producers encourage greener practices with for example financial incentives, organic farming is slowly increasing again. In this scenario, robots will be no longer targeted for organic sugar beet producers but for all famers. This change will impact various links in the agricultural chain:

- **Agricultural machinery dealers:** sell more robot at affordable prices, mainly ensure a good start-up of these technologies and a very good after-sales service (24/7) such as the example of the milking robot.
- **Farmers:** enhancing agronomic skills and weed identification capabilities, be ready to rely on autonomous machine, rethink the land parcel layout to suit for robots, be available for the robot 24/7 (even during nighttime).
- **Robots' manufacturers:** develop wider robot which can work faster, adapt robot to conventional farmers (spot spray technology for example), support the after-sales service with dealers.
- **Sugars' manufacturers:** financial incentive for greener practices and promote these actions at the consumer's scale.
- **French government:** financial incentive for greener practices.
- **Private and public research:** continue field research and trials, train technical agronomic adviser to make them able to answer to farmer's questions.

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