Introduction of Products

Full Automatic Planter D61EM-23

Hirokazu Asaka

Shinichi Yonezawa

Komatsu received a request from the Brazilian paper manufacturing industry for cooperation in their efforts to mechanize the planting of seedlings for raw paper pulp in their silviculture business that traditionally relied almost entirely on manual operation.

Accordingly, in collaboration with the industry, Komatsu developed the automatic, high-speed planter D61EM-23, which offers high-speed, one-man operation and precision planting based on satellite positioning information. An overview of the planter is presented in this paper.

Key Words: *Automated planting, D61EM-23, Planter, Brazil, Eucalyptus, Silviculture*

1 Introduction

Well before the global surge in environmental awareness in recent years, the paper manufacturing industry started cultivating and harvesting enough raw material to fulfill requirement for their papermaking operation.

In Brazil, fast-growing eucalyptuses are widely cultivated, and vast stretches of land around paper mills are filled with single-storied eucalyptus plantations. The total planted area across Brazil reaches as large as 8.3 million hectares (in 2016). Assuming the plants are harvested every six years, seedlings need to be planted over an area of around 1.4 million hectares every year.

Cultivation is almost completely systematized, characterized by, among other things, selective mass production of optimum varieties based on cloning technology and fully-mechanized, efficient felling and log hauling. On the other hand, the planting of seedlings, which is repeated every four to eight years, has relied almost entirely on manual operation. However, in recent years, field renewal prompted by declining land fertility, creation of new plantations to expand business and other factors have combined to push worksites away from suburbs and further into remote areas. This is making it even more difficult to secure enough planting workers, who are subjected to a scorching environment under the sun, even with rising wages, with the industry increasingly feeling compelled to address the labor shortage.

Facing the situation described above, a trade group of Brazil's papermaking industry contacted Komatsu, long a manufacturer of felling and bucking equipment, seeking help in their efforts to mechanize afforestation operation (planting process).

Trying to meet the group's request, Komatsu developed a full automatic, high-speed core machine in their perceived mechanized operation and launched it as the fully automated, high-speed planter D61EM-23 (**Fig. 1**). This paper presents an overview of the machine and its planting method.

Fig. 1 Automatic planter D61ME-23

2 Development targets and means to achieve the targets

Many of planting fields in Brazil are located in hilly areas of sub-highlands at mid-latitudes, an ideal location for the growth of eucalyptuses. Those areas are characterized by, among other things, basically-flat, gently undulating terrain, and a dry climate, other than during the rainy season, normally requiring several irrigation sessions until seedlings are firmly settled after planting. Those findings from site investigation provided clues as to what targets to fulfill in the course of developing the machine, such as the capability to operate on moderate slopes (up to around 10 degrees) and a structure that enables carrying irrigation water. In addition, applying intelligent machine control and satellite communication technologies, which are becoming the norm in construction and large agricultural machines, enables a number of things including precision operation, visualization of operation and the availability of planting position information in following processes. The series of those exercises led to the firm belief that the perceived system would comprehensively modernize the whole processes involved in the conventional manual planting.

The perceived system began to turn into a concrete form, one that would meet the papermaking companies' expectations by being a highly mechanized operation (**Fig. 2**) even involving site preparation (tilling/ridging (sub-soil) process) prior to the planting of seedlings.

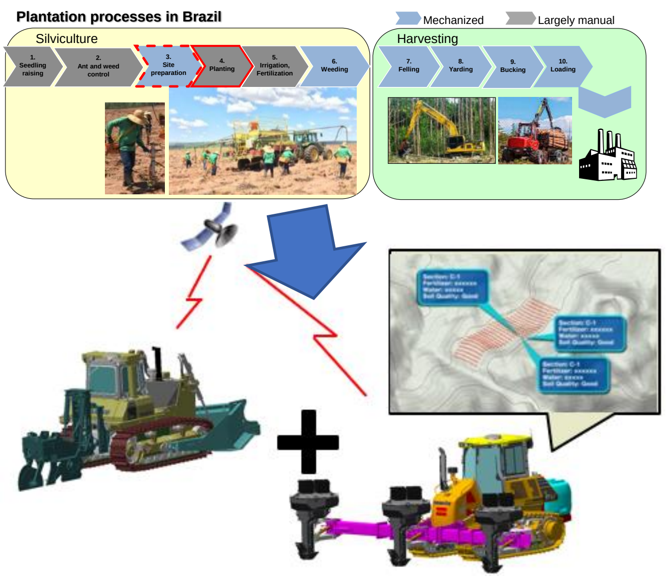

Fig. 2 Mechanization of afforestation operation

Based on the above, the following concepts were established for the new planter being developed.

Automatic planter

(1) High-speed, automatic planting presided over by one person
 1) High-speed, automatic planting using newly developed three planting heads
  ・High-speed planting rate of 900 seedlings/h
  ・Large capacity seedling magazine (196 seedlings/unit) offering long, uninterrupted operation
 2) Autopilot-aided autonomous driving
  ・Autonomous driving using GNSS position information
  ・Automatic measuring of in-row spacing between plants, Automatic drive shutoff

(2) High precision planting using as-built data from a sub-soiler used in site preparation
 1) Use of as-built data from a sub-soiler
  ・Automatic generation of planting positions based on as-built data from a sub-soiler
  ・High precision planting by tracing the as-built lines
  ・High precision planting using an automatic adjuster of inter-row spacing (+/-150 mm)

(3) Planting position logging
 1) Logging of planting position of every seedling
  ・Visualization of progress in planting process
  ・Efficient irrigation operation (Irrigation with pinpoint accuracy)
  ・Automated subsequent felling and harvesting

As the base unit of the machine that must meet the listed requirements, Komatsu chose the D61-23 bulldozer from the existing products because of its ample output as well as its electric control and hydraulic systems both being highly adaptable to automatic control. At the same time, collaboration was sought from and established with Bracke Forest AB, Bracke, Sweden, a forerunner in planting attachments at that time, for the development of a planting head, and also with Hexagon Agriculture, Florianopolis - SC, Brazil, an established brand in the agricultural sector in Brazil for satellite-based positioning and autonomous driving of tractors.

The tripartite scheme was aimed at minimizing the time needed for the development and securing a support organization after the launch.

Externally, the machine features a bulldozer as the base unit as mentioned earlier and three planting heads replacing the original blade at the front of the machine that are mounted on a common long beam (**Fig. 1**). The machine is capable of simultaneously planting three seedlings on three rows, one on each row, that have been prepared normally 3 to 3.5 m apart from each other, substantially cutting the cycle time, an issue that has been preventing similar machines from becoming widely used. A platform is mounted on the beam at the rear of each planting head and the three platforms are connected by a catwalk, providing easy and safe access to the planting head whenever refill of seedlings becomes necessary (**Fig. 10**).

The planting heads are mounted on the beam via parallel linkages capable of moving the planting heads both vertically and laterally. By electrohydraulically controlling the parallel links, any variation in height and inter-row spacing between the planting heads can be corrected.

In addition, provided at the rear of the machine are a tow hitch for a tanker trailer and auxiliary hydraulic ports for an irrigation tank and a related distribution pump, both mounted on the tanker trailer. By towing the tanker trailer, the machine is capable of planting seedlings and irrigating the plants (with pinpoint accuracy) simultaneously. Furthermore, the tanker trailer is equipped with a rack to carry refill boxes preloaded with seedlings, enabling an uninterrupted operation on its own for an extended period of time (around 3 to 4 h).

Table 1 shows the main specifications of the machine.

Table 1 Main specifications

SPECIFICATIONS		Automatic planter D61EM-23
Operating weight	kg	21500
Engine output	kW (HP)	125 (168)
Overall length	mm	6920
Overall width	mm	8800
Ground pressure	kPa	55.6
Travel speed	km/h	Forward: 3.4 Reverse: 4.1
Automatic control	-	Autonomous driving, Automatic steering, Automatic planting
No. of planting heads	Heads	3
Inter-row spacing range	m	3.0/3.5
Preloadable seedlings (per head)	Seedlings	196
Rated planting cycle time	sec/cycle	12 sec/3 seedlings
Planting rate	Seedlings/h	900
Planting position accuracy	mm	+/- 200
Irrigation per seedling	L/seedling	Max. 3.0
Total Irrigation water carried on tanker	L	(Customizable)
Auxiliary hydraulics for irrigation pump	MPa × L/min	10 × 35
Shipping dimensions (Length × Width)	mm	6770 × 2730 (with beam disassembled)

3. Mechanized planting by the machine

3.1 Site preparation (Subsoiling)

In many cases, planting is performed repeatedly in the same field, i.e. harvesting the first plants followed by a second (and a third) cultivation. The land used as eucalyptus plantations for several years needs to be subsoiled and fertilized before being planted with next seedlings. Subsoiling operation has been performed using wheeled tractors. With this method, however, stubbles left in the field cannot be removed successfully. As an alternative, Komatsu has proposed using a bulldozer as the base unit combined with a sub-soiler (**Fig. 3**). The proposed subsoiler is equipped with a shear blade at the front for shearing stubbles and large-diameter harrow discs at the rear for breaking up soil and roots as well as ridging. As such, the subsoiler is capable of carrying out those operations simultaneously, and also its weight enables the discs to cut deeper. The ridging lines are logged as positional data, which then is used to guide the subsequently operating planter. This eliminates the need to set the path for the planter and at the same time should ensure precision planting.

Fig. 3 D155EX-6 modified as a subsoiling version

3.2 Planting of seedlings

Automatic planting operation by the D61EM-23 is explained below, highlighting the unique features of the machine.

3.2.1 Automatic planting system

The planting system mounted on the beam at the front of the base machine was developed by Bracke Forest AB as mentioned earlier.

The planting system is based on a planting attachment developed for hydraulic excavators (P11. a), and has additionally incorporated the features i) to iv) below exclusively for the D61EM-23 planter.

i) As the system has multiple units for simultaneous planting mounted on the bulldozer-based tractor, a raise/lower mechanism using a parallel link is added to the system.

ii) For system handiness, the pneumatic-type seedling feeder was not adopted.

iii) Increased total seedling-preload capacity through magazine improvement
(= longer uninterrupted operation)

iv) The planting system is designed to work with software for integral control of the three planting heads. The planting system is shown in **Fig. 4**, and its operating principles are described below.

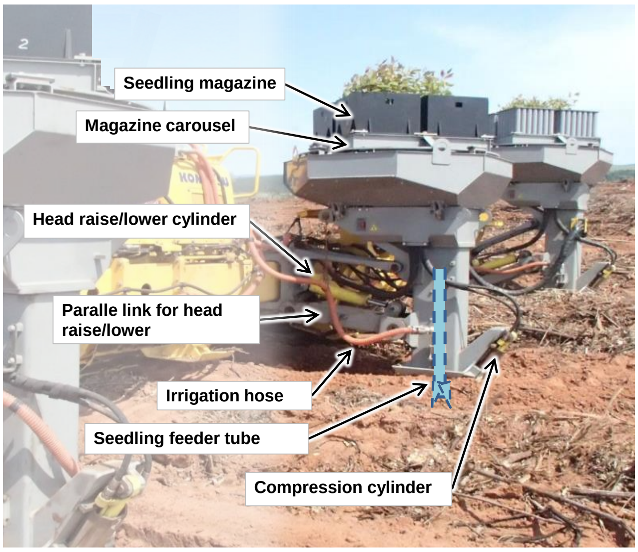

Fig. 4 Planting heads

When the planting process starts, the planting heads lower until they reach the ground surface. After the planting heads stop on the ground, the seedling feeder tubes are inserted into the soil so that planting can start. Seedlings are preloaded into a magazine, which is placed on top of the planting head. The magazine is divided into 49 small chambers, which are arranged in a 7-rows-by-7-columns layout. Each chamber is preloaded with a seedling. At each planting position, the bottom gate of the small chambers opens sequentially to drop the seedling into the feeder tube. Four magazines can be set on each planting head. When all 49 seedlings in the first magazine are planted, the carousel rotates to set the next magazine in the active position. This process is repeated and all 196 seedlings in all of the four magazines are planted in an uninterrupted sequence.

When the seedling reaches the bottom of the feeder tube, the tube is lifted while the seedling stays there in the soil. After the seedling is irrigated, the side cylinder compresses the soil, which has become wet and muddy with the water, to stabilize the soil around the seedling before the planting head is raised. This is the end of a planting cycle.

The planting head takes only 8 sec to complete this whole sequence.

A dent is made on the ground when the planting head lowers onto it. This dent holds irrigation water, preventing it from going away. The retained water has been found to help the seedling grow better (**Fig. 5**).

Fig. 5 Planted and irrigated seedling

3.2.2 Automatic planting operation

When all of the three planting heads finish planting, completion signals together with the planting results are sent to the autonomous driving controller. The controller records the planting positions and results (planting successful/failed) and switches the vehicle control mode from the planting mode to the driving mode for onward travel to the next planting positions. The machine drives along the logged subsoiling line until the preset planting pitch (in-row spacing between plants) is traveled and then stops. As this occurs, the positions of the left and right planting heads are calculated based on the vehicle's position as it drives along the center line, and then those positions are compared with the positions of the left and right subsoiling lines for any lateral drift. Any drift detected is then corrected by laterally moving the left and right planting heads accordingly. This correction feature makes it possible to plant on the three separate subsoiling lines simultaneously while at the same time minimizing lateral drift of planting positions.

It takes approximately 4 sec depending on the planting pitch setting to drive to the next planting positions while measuring the distance traveled.

The vehicle travel data is obtained in the form of changing satellite positioning data. While this is not direct measurement and measurement accuracy often fluctuates, the current method is the second-best alternative as the bulldozer-based tractor is not equipped with a system to measure travel distance.

Normally, soil on subsoiling lines is fertilized and it is said that seedlings planted more than 30 cm away from subsoiling lines do not receive the benefit of fertilizer. With the planter, seedlings are planted generally within +/-15 cm of subsoiling lines (**Fig. 6** and **Fig. 7**) and that, according to the users, in effect presents no issues and is acceptable.

Needless to say, subsoiling line accuracy (parallelism) is an important factor for inter-row spacing accuracy.

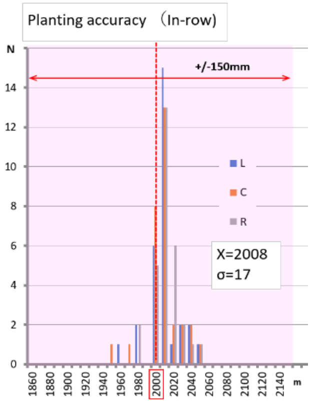

Fig. 6 Planting position accuracy (Example of in-row pitch)

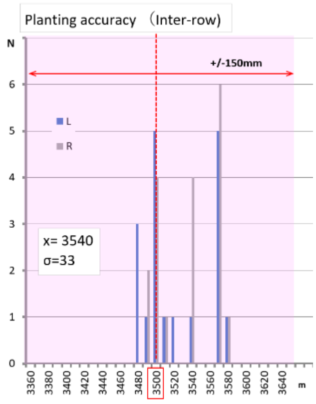

Fig. 7 Planting position accuracy (Example of inter-row spacing)

3.2.3 Irrigation tanker trailer and irrigation

As mentioned earlier, irrigation is not only needed for the growth of seedlings but also an important method to improve the survival rate of planted seedlings by removing voids around the root and thus enhancing further rooting.

This process is also performed with the widely-employed manual planting by planting workers stomping and compacting the soil. The stomping quality, however, is not uniform, and the planting quality achieved by the planter is rated higher than the manual operation.

As described above, irrigation cannot be separated from other processes. The amount of water each seedling is irrigated with, according to interviews with user companies, varies widely from one company to another, ranging from 0.6 L to 5 L depending on the site's climate and soil conditions, which season planting is conducted and other reasons. Consequently, the following irrigation arrangement has been employed. The idea of mounting a water tank of sufficient capacity on the tractor was dropped. The tractor is equipped with only the watering control valve while each user company prepares a trailer carrying a water tank that suits their own operation requirements. The tractor is equipped with a tow hitch to pull the trailer and the hydraulics to drive the water distribution pump (**Fig. 8**).

Fig. 8 Examples of a tanker trailer

Irrigation water is sourced from nearby rivers and lakes and normally large tanker trucks are used to transport water from those sources. The quality of water from those sources varies widely. Procured water is sometimes contaminated with sand gravel and trash. Therefore, slurry resistance is one of the criteria used when selecting related components for the water transport lines.

3.2.4 Refilling seedlings during planting operation

Each magazine on a planting head is loaded with 196 seedlings. If a planting cycle takes 12 sec to complete, the magazine becomes empty in about 40 min of uninterrupted operation. If the in-row planting pitch is set to 2 m, which is a typically-used pitch, the magazine becomes empty after advancing 392 m while planting and the system triggers a “no seedlings” alert, causing the machine to stop.

In Brazil, planting fields are huge and rows are typically 500 to 700 m long and can sometimes be over 1 km. Therefore, running out of seedlings in the middle of a field is a possibility.

To address the issue, the irrigation tanker trailer is equipped with a rack to carry replenishment seedlings. The planter’s one-man operation concept should not require any worker other than the operator to attend to the refilling of seedlings, which is a task performed by the operator. With the systems currently used other than the planter, seedlings are refilled manually into a magazine, which typically has around 50 small chambers to hold the seedlings. Meanwhile, each planting head on the planter carries 196 seedlings and the number of seedlings carried on the three planting heads totals as many as 598, making refilling apparently a time-consuming task.

The first option that was considered to address this issue was to increase the capacity of the magazine. However, the magazine’s capacity can only be increased to a certain extent. At the same time, increasing the capacity, frustratingly, still presents a related issue, i.e. refilling takes longer to complete.

At the end of deliberations, a through-hole-type “refill box” was employed as the solution.

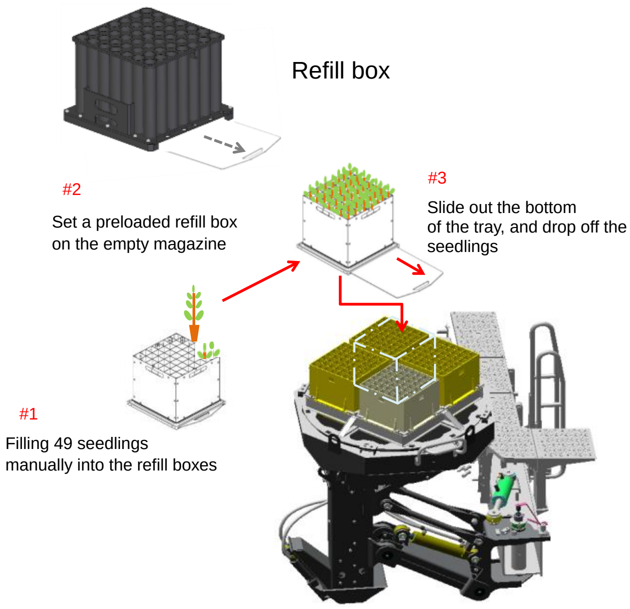

Fig. 9 Refill box and refilling sequence

The refill box has 49 small chambers to hold as many seedlings that are arranged in the identical layout to the magazine on the planter. The smartest feature of the refill box is the bottom of the box that can be slid out to drop the seedling into the magazine.

To enhance its portability for the operator, the refill box is made of resin to reduce the weight. A refill box fully preloaded with seedlings weighs less than 12 kg.

At the yard, a sufficient number of refill boxes are loaded with seedlings and then loaded onto the tanker trailer. When the magazines become empty in the field, the refill boxes are placed above the magazines and, by sliding out the bottom plates, the seedlings, all 49 of them, are instantly refilled into the magazines. While a total of 12 preloaded refill boxes are needed to refill all of the magazines, the method should offer a substantial reduction in the time taken for refilling even by just one person (**Fig. 9** and **Fig. 10**).

Fig. 10 Using refill boxes to refill seedlings

Assuming the entire refilling is completed in 25 min, carrying refill boxes for three refilling sessions (i.e. 36 boxes) should enable 4 h (half-day) uninterrupted one-man planting operation. In this case, the operator's half-day work volume can be translated into 2352 planted seedlings. When this is compared with the current labor-intensive, manual planting, in which normally around 10 persons work as a team, forming a row and planting seedlings one by one, the operator's work volume is equivalent to that of around five people (as of 2016).

User companies appear to have the intention to operate planters around the clock to maximize efficiency, experimentally mobilizing planters at night as well.

If the amount of initial irrigation per seedling is 3 L, the total irrigation water that needs to be carried for a half-day operation is about 7 kL, which is nearly the limit for the tanker trailer in both size and weight that is towed on rough terrain in the field. Therefore, a half-day planting operation with 7 kL of irrigation water and 36 refill boxes on the tanker trailer should serve as a model operating mode.

Ideally, all rows in the field should be around 800 m long, which will have just used up the seedlings and water when the planter returns to a point 10 m away from the initial start point after driving down the first row, turning around and driving back down the second row. This enables reloading the planter and tanker trailer with new seedlings and water at a convenient place for the next round-trip planting session. This may be demanding too much in the way of field improvement.

3.2.5 Seedlings for the automatic planter

Besides the above, field operation evaluation tests conducted by user companies have shed light on the quality of seedlings.

With the planter, seedlings in the magazines on the planting heads fall by their own weight and become planted. During the fall, the roots of the seedling function as a guide as well as a weight and therefore they need to be dense and hard enough to fulfill those functions. It has been found that seedlings with low-density or soft roots often became stuck in the head and failed to be planted successfully, a serious issue.

Also, seedlings with too much foliage can have high resistance when falling through the feeder tube. There are still other quality issues. All those issues mentioned above indicate that seedlings for the planter need to be more uniform in quality than those for manual planting.

To address the quality issues of seedlings for the planter, advice was sought from the São Paulo State University (Universidade Estadual Paulista) in São Paulo, Brazil, while attempts were made to standardize seedlings. In the course of those initiatives, it became clear that the use of paper pots for the roots of the seedling is highly effective in preventing stuck seedlings, which will be recommended to the users.

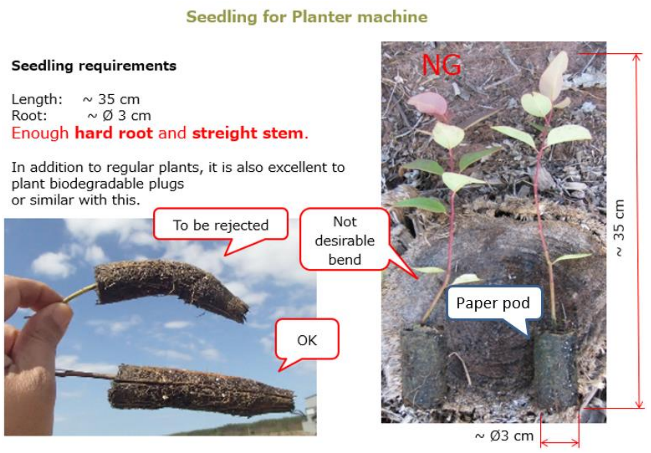

Fig. 11 Quality of seedlings

4. Conclusion

The planter was developed and brought to a successful launch with generous support from companies in the papermaking industry in Brazil who share common goals. Behind the united front is labor shortage they all apparently feel pressured to resolve urgently. With the launch of the planter, users now face the need more than ever to review the conventional afforestation operation, as the issues related to seedlings have clearly shown, with respect to the possible introduction of the planter. The planter has already proven its performance clearly in efficiency and cost. It is now user companies' turn to decide on whether to update the current field operation to introduce the planter.

Any hesitancy will only leave them behind the times. The planter has prompted the afforestation industry in Brazil to squarely face environmental and manual labor issues, and in the end will have a bright future.

Fig. 12 D61EM-23 debuting at a launch event

Introduction of the authors

Hirokazu Asaka
Joined Komatsu Ltd. in 1983.
Vehicle Development Center 3,
Development Division

Shinichi Yonezawa
Joined Komatsu Ltd. in 2008.
Vehicle Development Center 3,
Development Division

[A comment from the authors]

Meeting people of different nationalities, different languages, different products handled, different company sizes, different corporate cultures...everything, and developing a product with them. It has been a challenging and rewarding endeavor, the likes of which we have never experienced. Looking back, the discussions and drinking sessions at every afforestation site across Brazil that we visited for investigation and prototype machine testing are now irreplaceable resources.

Again, we sincerely thank everyone we worked with there.