# Forestry Department

Food and Agriculture Organization of the United Nations

## International Poplar Commission Thematic Papers

### FIELD HANDBOOK - *POPLAR HARVESTING*


Stefano Verani, Giulio Sperandio, Rodolfo Picchio,
Raffaele Spinelli, Gianni Picchi


October 2008


Forest Resources Development Service
Forest Management Division
Forestry Department

Working Paper IPC/8
FAO, Rome

## Disclaimer

This Field Handbook "Poplar Harvesting" does not reflect any official position of FAO but aims to expose the most common working techniques and the future trends in poplar plantations, resulting in practical guidelines for developing efficient, cost wise and secure harvesting systems.



Comments and feedback are welcome.

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# Foreword

Poplars (*Populus spp.*) play a key role in fast wood plantations of temperate climates. According to the data collected by FAO during the 22$^{th}$ Session of the International Poplar Commission (IPC) in 2004, about 7 millions hectares of plantations are managed all over the world and 56% of this area, about 3.8 millions hectares, are planted for wood production while the rest has mainly environmental purposes. For some countries, poplars result to be one of the main sources of high quality timber. Five countries reported annual removals of more than 1 million m$^3$ of poplar wood from planted forests, namely Turkey, China, France, Italy and India (in this last country all the production is obtained by agroforestry systems). Furthermore most countries reporting at the IPC declare an increase of plantations for the period 2000-2004. This success is due to the excellent results of poplar breeding leading to fast-growing and disease-resistant *Populus* hybrids. Thanks to the impressive flexibility of poplars, those trees provide wood for the most different uses ranging form pulp, plywood, reconstituted wood panels and engineered lumber, but also matches, furniture, and fuelwood. This last use implies new growing techniques as poplar is managed as short rotation forestry for renewable energy, resembling its cultivation to an industrial agricultural crop.

Poplar plantations are still minor contributors of world wood market, but their importance in temperate areas is rapidly increasing as poplar is foreseen to be a strategic resource of wood products for many countries. This implies a great effort to implement newer and more efficient clones, optimize the cultivation technique and reduce the cost of logging activity. This last set of operations may range from a total manual system to a heavily mechanized work according to different countries, final assortments, market trends and economics balance. In any case, it is essential to organize an efficient harvesting system, providing the optimal partition of available assortments with the lowest cost possible and working in proper security conditions. The present handbook aims to expose the most common working techniques and the future trends in poplar plantations, resulting in practical guidelines for developing efficient, cost wise and secure harvesting systems.

# The operation

In any poplar logging operation, the working system usually adopted is the Short Wood System, meaning nevertheless assortments with a length of about 2 metres (Photo 1). The main operations executed are: felling, processing (delimbing, cutting to size) and loading of the material. Generally the operations of bunching and extraction are not necessary and the processing of the trees and the loading of the material for subsequent transport to factories take place on the felling site: only when the vehicle cannot enter the clearing (access road of a reduced size or particularly wet land due to excessive rain) or due to specific conditions of the yard layout, the material is extracted to a log yard where it is loaded.

The extraction of whole trees, with or without branches, can also be carried out, with consequent processing of commercial logs at the landing (Photo 2). In relation to the level of mechanization used for the execution of the various operations, three types of operation can be identified: traditional, advanced and fully mechanized. The first is characterized by a low use of mechanization: chainsaw for felling and processing, use of agricultural tractors, partially modified for forestry use, with the possibility of fitting equipment brought (winch or rear bar for extraction, hydraulic knuckle-boom loader for the handling and loading of material). The second type is characterized by a high use of mechanization, it foresees the use of equipment that can carry out various operations, for example a feller-buncher that carries out the felling and the bunching and alignment of trees. The third uses an even more superior mechanization with combined machines, for example a harvester with feller-buncher-delimber-cross cutter which can perform all the operations necessary for producing the final assortment (felling, delimbing and cross cutting). In yards with these last two types of logging, very often the use of forwarders and skidders is also foreseen for the extraction and loading of material as well as the use of chippers for the chipping of top ends and branchwood. In practice the working systems mentioned above, which refer to the classification described by Hippoliti, can undergo alterations due to the use of different vehicles within the production process: a classical example is the use of a loader fitted with hydraulic grapples, for handling the material, in the traditional system, which can be described as advanced traditional (Photo 3).

Photo 1. Poplar veneer logs.

Photo 2. The extraction of whole trees, without branches, for the cutting to size at the landing.

Photo 3. Loader fitted with hydraulic grapples, for handling the material.

## Felling and processing in traditional logging

By felling one means the operation which, through the execution of one or more cuts at the base of a tree, determines its felling.

By processing one means the operation which includes phases necessary (delimbing and cutting to size) to obtain, from the tree felled, the wood assortment required.

## *Semi-mechanical felling – work execution*

Since manual felling was abandoned in the early seventies the machine most universally employed for this operation is the chainsaw (Photo 4).

It is composed of a two-stroke internal-combustion engine which makes up its body, connected to a centrifugal clutch that moves a sprocket wheel to which the chain with cutting links is hooked which, running along a grooved bar, is the actual cutting tool. The engine is single-cylinder, fed by a mixture of petrol and oil at 2-5%. A separate tank contains oil which, thanks to a pump, is released between the grooved bar and the serrated chain to reduce friction. The chainsaws are classified based on engine power, bar length and weight (Table 1). Every chainsaw therefore, based on its classification, has to be suitable for the operation to be performed.


Photo 4. Two medium chainsaw models suitable for use in poplar plantations.

Table 1. Chainsaws classification.

| Type | Displacement [$cm^3$] | Power [kW] | Guide bar length [cm] | Weight [kg] |
|---|---|---|---|---|
| Light | 20-50 | 1,2-2,5 | 20-35 | 2,5-6 |
| Medium | 40-70 | 2,5-4 | 35-50 | 5-8 |
| Heavy | > 70 | > 4 | > 50 | 8-16 |

The rules to follow in the felling of a poplar plantation with a chainsaw are those typically applicable to any tree. Excluding the possibility of carrying out felling with one single cut in that in a mature poplar plantation the stems definitely have a base diameter of more than 20 cm, one has to proceed by making a notch that directs the fall of the tree and then by performing a second cut in the opposed side (back cut) that releases the tree and causes its fall.

By producing the “notch”, the operator removes a wedge from the stem in the direction chosen for the fall of the tree. It is produced with two cuts, one obliquely and the other horizontally; in order for the notch to work effectively, the two cuts have to meet perfectly without overlapping, forming an angle no smaller than 40-45°. The depth of the horizontal cut has to fall between 1/4 and 1/3 of the diameter of the tree in the cutting zone (Figure 1). While making the horizontal cut and after finishing the opening of the undercut, the operator checks that the border joining the oblique cut and the horizontal cut is perpendicular to the direction of fall. After completing the undercut, the back cut is made, horizontally from the opposite side to the direction of the fall of the tree. It has to be made above the horizontal cut of the undercut. This difference must not be less than 1/10 of the diameter at the butt of the tree. The back cut does not meet the oblique cut of the undercut but limits a zone in which the fibres remain intact and can guide the fall of the tree. This zone, called “hinge”, has to be equal to at least 1/10 of the diameter at the butt of the tree and as a rule it is delimited by two parallel edges. The absence of the hinge, due to an incorrect execution of the back cut, can have consequences ranging from the chainsaw getting jammed in the wood (the cut-off tree sits on the stump) to the uncontrolled fall of the tree itself as it has no restraint. To avoid splitting of the stem, making the basal part unusable, which is of greater commercial value, the undercut has to be positioned as close as possible to the ground.

Felling is normally carried out by one person; in special cases, with trees leaning in the opposite direction to their fall, another person is needed for inserting aluminium or plastic wedges in the back cut in order to avoid the tree to “sits” on the bar of the chainsaw. The wedges are pushed into the back cut with a sledgehammer or the eye of a hatchet, and cause the tree to tilt, starting its fall to the ground in the chosen direction (Photo 5).

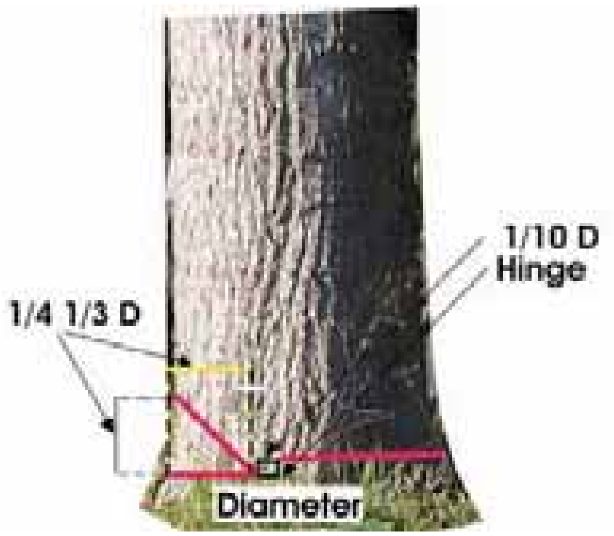


Figure 1. Correct execution of the felling operation (D = diameter).

Photo 5. Insertion of the wedge with a hoe during the back cut.

A survey within the plantation, before starting work, will be necessary to identify the direction of fall of the trees in order to make the subsequent operation of extraction (if necessary) or loading of the material as easy as possible. Felling has to take place in rows so as to obtain a regular alignment of felled trees on the ground.

In a logical sequence of use, the number of rows to fell depends on the area of the landing, on the load capacity of the vehicle available (lorry or articulated lorry) and on the distance from the user factory. Journey times have to be calculated minimizing the waiting times for the haulier at the yard.

## *Semi-mechanical processing – work execution*

By processing of the material, one means the set of phases of transformation of a tree into semi-finished assortments with characteristics corresponding to a particular use at the end. In other words, processing is preparation of the material at the source, according to prearranged commercial categories.

The main phases of processing the material, starting with the tree, are its delimbing and subsequent cutting to size. Earlier in the process of these two operations there is almost always an "inspection" of the stems, carried out by professionals or by staff from the industry who collect the material, which certify their suitability for transformation in the final assortment.

### *Delimbing*

Delimbing consists in the removal of the branches with a cut as close as possible to the stem, avoiding leaving stumps. The instrument used is the chainsaw which has to be lighter and more compact with respect to the one used in felling. In bigger trees it is generally carried out by starting from the outside of the canopy moving in a spiral towards the inside, as in a series of concentric circles, starting on one side of the stem and finishing on the other, paying attention to the cut of the branches on which the tree rests, to avoid it moving unrestrained once this support is taken away.

For bigger branches it is necessary to make the cut first on the pressed side and then on the outstretched side to avoid the bar of the chainsaw getting jammed in the wood (Figure 2). Branchwood with diameters of 3-4 cm or less is gathered in big piles to then be burnt or crushed using a clearing saw with hammers. Bigger branches on the other hand are sectioned in general and assembled into stacks.

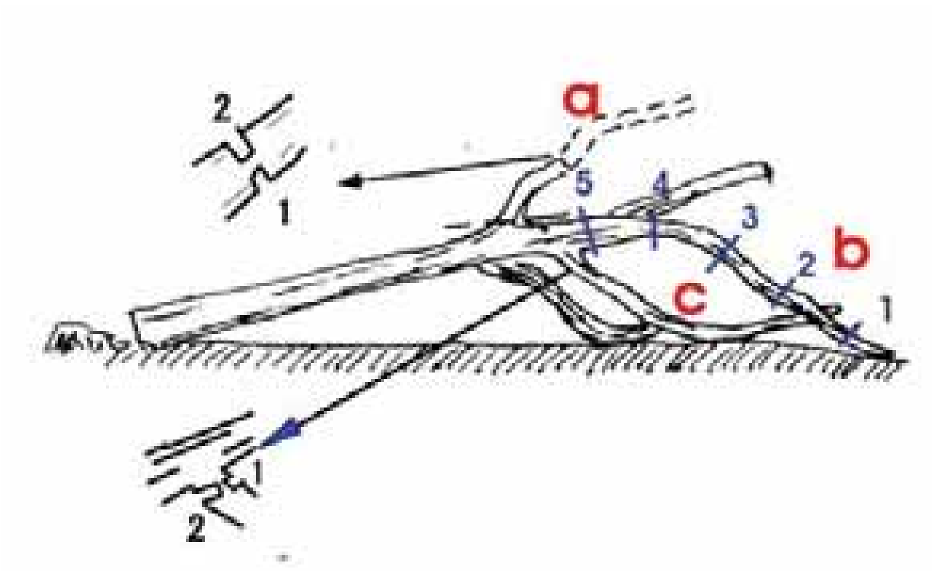


Figure 2. Correct method for delimbing hardwood trees.

### *Cutting to size*

This consists in cross-cutting the stem into pieces of a set length, based on customer requirements and final use (rotary cut veneer, sawing, paper mill or panels). For small stems there are not any particular problems, and the same can also be said for bigger stems, when they are perfectly supported all along their length on the ground, as it generally happens during poplar logging operations (flat and even terrain). In these cases a single cut is made perpendicularly to the longitudinal axis of the stem that covers it along the whole diameter. With medium to large stems not wholly resting on the ground, raised at one end and acting as lever, or that bend because they rest on two supports, two bulges in the ground or a small ditch, a different procedure needs to be followed.

It is enough to identify within the areas to be sectioned the part where the wood fibres are compressed and to start work just next to this, entering the stem at about a 1/3 of its diameter, going on to the extended part until it meets the previous cut (Figure 3). In a stem or in a part of it that sticks out like a shelf it is easy to identify the compressed part in the lower zone. On the contrary, in a stem that rests on two protruding supports or bends in a small hollow, the compressed part is at the top.

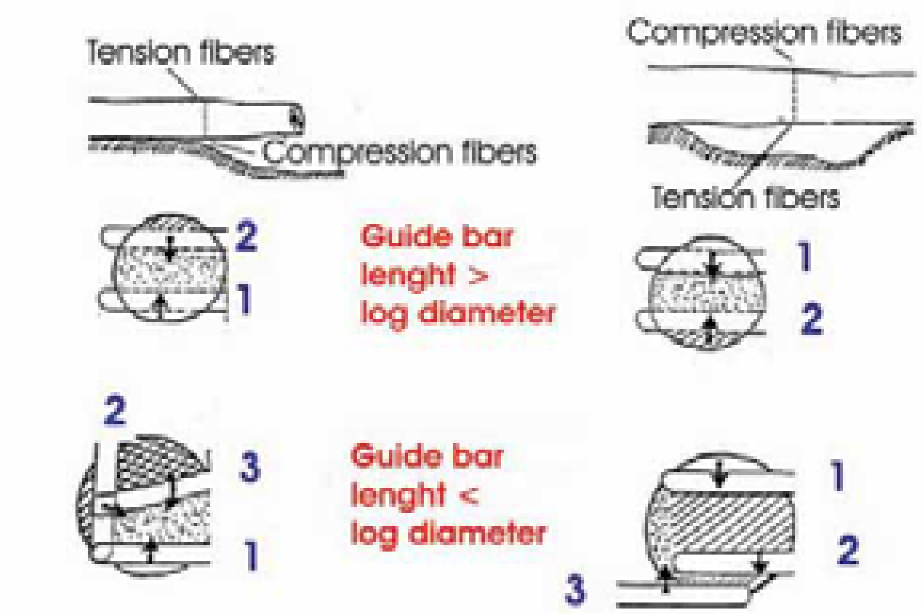


Figure 3. Correct method for the cutting to size of stems.

If on the contrary cutting to size is carried out in the extended part, there could be splitting of the timber, sources of danger or waste, while in the compressed part the bar of the chainsaw would almost certainly get jammed. The two operations previously mentioned are generally carried out on the same plant by two people: one who sections the stem into logs starting from the base, and another who, starting from the top of the tree, carries out delimbing and cutting to size at the same time. Both have to always work at safety distance.

## Prevention and safety

The execution of felling and processing operations of a poplar plantation foresees, on the part of operators, a quite stressful working pace, also because, for this type of employment, "incentive pay" is still a widely practised form of pay today, with the consequent increase in the risk of accidents. The main form of prevention to adopt is that of carrying out the work perfectly. In carrying out felling with the chainsaw it must be kept in mind that there is an obligation to wear all the gear for individual protection provided by the employer and compulsory by law (Photo 6).

Photo 6. Chainsaw operator while he makes an undercut, equipped with suitable gear for individual protection.

The work of a chainsaw operator, in particular, has in fact a series of repercussions on health that often make themselves felt in time, due to not respecting simple rules of prevention. For this purpose, safety trousers must be worn (the legs are the most exposed part of the body at risk for those using a chainsaw), boots with steel toecaps and nonslip soles, gloves to limit as much as possible the vibrations induced by the chainsaw and not to have the hands exposed to contact with branches and any cutting instruments. Last but not least, in order of importance is the helmet with face mask and headphones. Its structure protects the head from the possible fall of material from above (the fall of parts of branches in mature poplar plantations is quite frequent) while the face mask, consisting in a non-reflecting metallic net tied at the sides of the helmet itself, protects from chips that rise up while the chainsaw is being used. The headphones limit the noise of the chainsaw motor and consequently moderate damage to the auditory system.

Another useful forethought should be given to not wearing clothing articles with protruding and/or hanging elements (for example a scarp). In short, one has to avoid anything that can get caught in the chain of the chainsaw while moving, causing uncontrolled and often tragic events. As far as working with the chainsaw is concerned, it is necessary to pay attention to avoiding contact between the chainsaw and the wood coming about with the tip of the bar, to avoid the risk of kickback with the subsequent loss of control of the machine. Another useful piece of advice is to insert the chain break (the safety catch placed at the front on the upper handle, which on activation, blocks the chain), during brief movements with the machine started up. It would also be advisable, once the direction has been chosen for the fall of a tree, to check that felling doesn’t occur on obstacles such as rocks, stumps or simple depressions in the ground, which, even if small, can act as points of support (lever) and leading the falling stem to kick up at the back end with the possibility of causing harm to the operator. Make sure that around those felling there are not other operators performing different tasks. Even with the foresight of the construction firms and with the care of the operator in acting in the best possible way, this job remains one of the most tiring; the right times for intervals and stopping work therefore become necessary, in order not to tire the body too much.

## Felling and processing in advanced and fully mechanized logging

In advanced and fully mechanized logging, felling is carried out with the aid of machines. The operator, from inside the vehicle cab, handles commands to approach the tree and to position the cutting instrument to knock it down.

### *The felling head*

The felling head is the basic unit that makes it possible to carry out mechanical felling. It is composed of a grapple with three or four metal arms that are used to hold the tree during and after felling (buncher-structure) and of a proper cutting instrument placed at the base, that can be a clipper, a disc (Photo 7) or a bar hinged on one side with a cutting chain, such as that of the chainsaw. This kind is certainly the one most used in felling given that it has big cutting range (about 80 cm).

A felling head as described can be set at the end of an articulated hydraulic arm and fed by the hydraulic circuit of the arm itself, driven by machines with a power of no less than 80 kW. In general, this kind of equipment can be found on excavators or suitably modified loaders. Rarely are agricultural tractors heavily modified to obtain a result that is nevertheless inferior, especially as manageable hydraulic power and as weight distribution. The head feller with chain bar is generally also equipped with instruments for the delimbing and cutting to size of the tree (photo 8).

Photo 7. Felling by disc head on an excavator, in the advanced mechanization.

### *Mechanical felling – work execution*

Though having ample space to operate after considering the distance of the poplar plantation (5-7 m between rows and 5-7 m along the rows), it is still useful to plan the work before starting.

The operator who prepares itself to use the machine will have to get information about the place where he will be operating; it is essential to know the limits of the work area, the access routes to the land, identify the presence of ditches or canals, electrical lines or telephone cables, areas of the land with low carrying capacity (particularly during fairly rainy periods) and of anything that can slow down or cause damage during work.

Photo 8. Two models of felling heads and processors. The cutting element is a grooved bar along which a cutting chain runs.

Later, once the area has been analysed, the direction of fall of the trees needs to be identified and has to be functional for subsequent loading or extraction. A good working method is to operate alternatively on two rows at a time. Once the machine enters between the two rows, felling is carried out once on the right and once on the left, and the felled trees are aligned in the direction of the machine as it moves along (Figure 4). This reduces the tie for the felling operation and at the same time a track is left for the transit of vehicles that will load the prepared material or extract the whole tree with or without branches.

Proper felling with the felling head is carried out by positioning it so that the stem is at the centre of the head, positioned as low as possible. The grapple arms close and cutting begins (Figures 5, parts 1, 2 and 3).

The trees can be pushed towards the felling direction during the cut by raising them slightly with the arm of the crane before starting to cut, so as to contribute to making it easier for the cutting element to move (Figure 5, part 3).

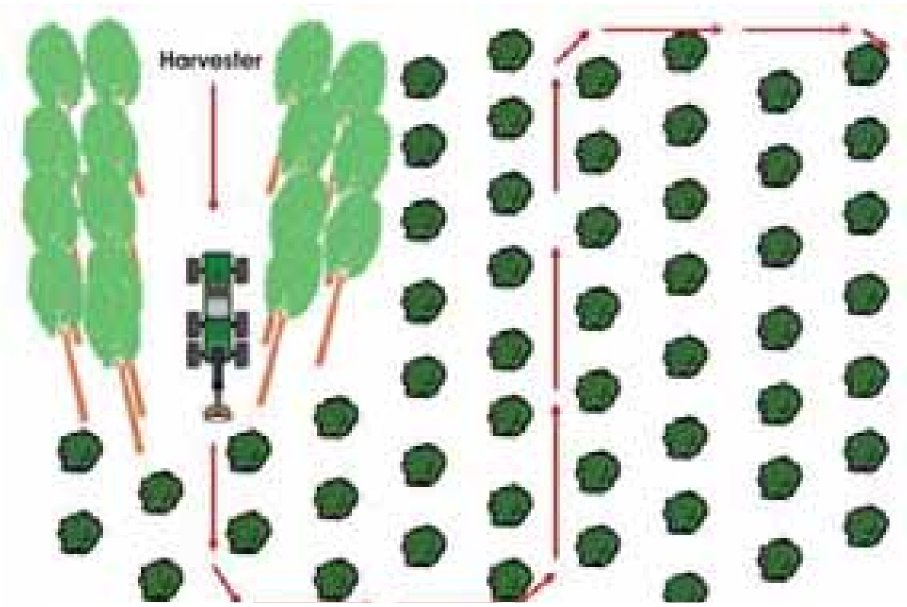


Figure 4. Rational operating diagram of using advanced mechanization in poplar logging.

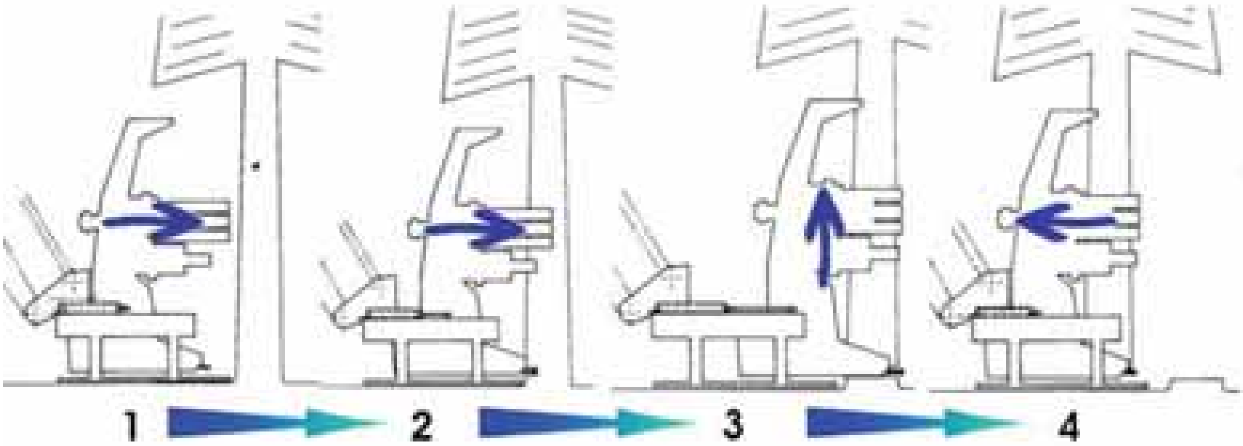


Figure 5. Sequential diagram of felling with felling head: the arrows indicate the movement of the head.

As soon as cutting takes place, the tree can be raised (Figure 5, part 4) and then felled and aligned (Photo 9).

Photo 9. Felling with a harvester.

Photo 10. Processing with chainsaw. The use of individual protection is often disregarded.

Delimbing and the eventual cutting to size will be carried out, as with the traditional method using a chainsaw being wise to begin on the opposite side to that where felling of the following rows is being executed (Photo 10).

### *Felling and mechanical processing – work execution*

Felling, delimbing and cutting to size are carried out with combined feller-delimber-cross cutting (harvester) heads that can be mounted onto more or less specialized engine units and together they constitute the harvester. These are high-tech machines composed of an engine unit with an articulated chassis with 4 or 6 driving wheels and for working in poplar plantations they are almost always tyred and provided with a crane of which at one end a harvester head is mounted that can fell and process the tree. From the revolving cab, through a detachable or articulated hydraulic arm, one can operate the harvester head which performs all the functions previously explained. Delimbing is carried out by four or more knives that are generally the same jaws of the grapple that hooks the tree. Two wheels or pulling tracks, rubber or metal, controlled by the operator, grip the tree and allow it to run against the knives. Cutting to size to the desired measure is possible in that a small pinion on the head, while the stem moves, is pressed to the stem and acts as a measuring instrument, thanks to electronic systems equipping these machines. The electronic information recorded can be multiplied and in general they are managed using an actual computer on board provided with the appropriate software (Photo 11). On some models it is possible to mount a chain bar also in the upper part of the head (Photo 12). This is activated by the operator when there are big branches on the tree that cannot be removed with knives or excessive time is required to remove them. Making a cut near their bifurcation saves time and does not waste material.

Photo 11. Computer screen on board with which the most modern harvesters are equipped.

Photo 12. Feller head processor equipped with double bar for cutting to size.

Machines of this kind are of a considerable size and have very high power - about 130 kW - and can also weigh 25 t. To be activated, the heads require a greater hydraulic power of 200 l/min and their weight goes from 1 to 2.5 t.

Once felling has been carried out, the tree is made to rotate and placed in front and perpendicular to the machine (Photo 13). Thanks to pulling wheels mounted on the head of the harvester, the tree is moved so that the branches meet the knives and are removed by them. In successive order a cut is made and makes the log of previously programmed length fall (Photos 13 and 14). The assortments produced, on the felling site, or at the landing if extraction of the whole tree has been carried out (Photo 15), are normally arranged in the pathway. The software on board, as well as programming the length of the logs, can provide, at the end of the ay, the number of various assortments produced.

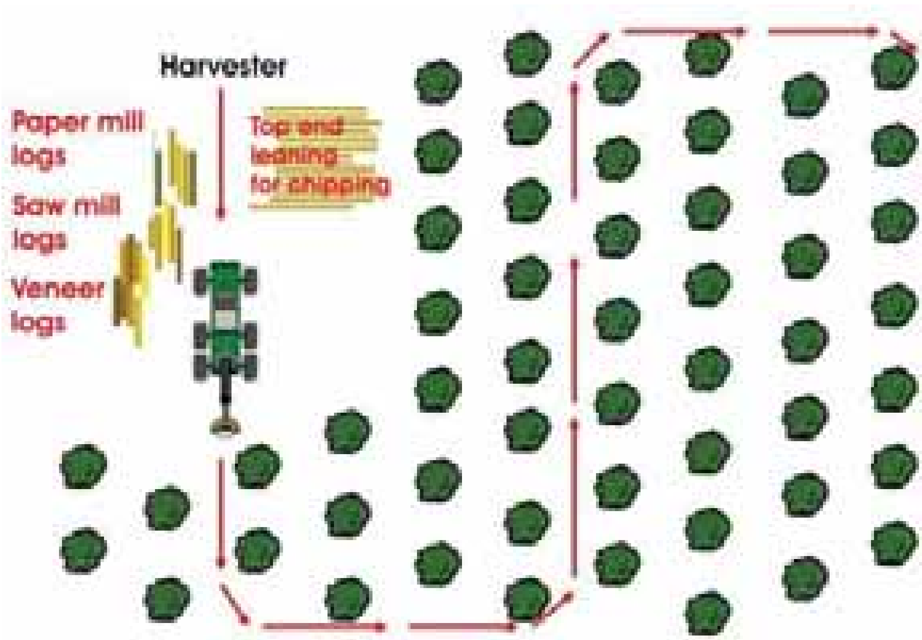


Figure 6. Rational operational scheme of using full mechanization in poplar logging.

A useful trick is to delimb and cut the stem to size keeping the trees as close as possible to the ground, or still better, with the top end leaning on the ground in order to reduce tension on the wood and strain on the head and arm of the machine.

Photo 13. Positioning of the tree for processing.

Photo 14. Harvester during processing of the tree.

Good work management can be as illustrated (Figure 6) and described below. The harvester can operate in four rows, starting to cut in the central lane (between rows 2 and 3). As it goes forward, the material processed is stacked between the first and second rows (material for rotary cutting) and between the second and third rows (material for sawmills and paper mills). The tops will be stacked between the third and fourth rows. Once the first four rows are logged, the work can continue with the machine positioned contrary to the preceding direction, on the adjoining four rows entering between the 6th and 7th and the material and branchwood will be stacked to mirror the first four rows cut. The top ends are therefore stacked in the first, second, sixth and seventh rows while the top ends in the third, fourth and fifth rows.

Photo 15. Processing at the landing of trees extracted whole.

## Prevention and safety

An operator using a vehicle equipped with a felling head or a harvester head comes up against minor dangers seeing that he works inside the cab often also equipped with comfortable facilities such as an ergonomic seat and sound-proof and air-conditioned environment. Attention in this case has to be diverted to the exterior, and in particular to other operators present in the area who absolutely must not work in an area equivalent to at least twice the range of action of the hydraulic arm. In some cases, in fact, it is almost impossible for an operator with a chainsaw in action and an operator on the harvester to be able to hear each other (fig. 7).

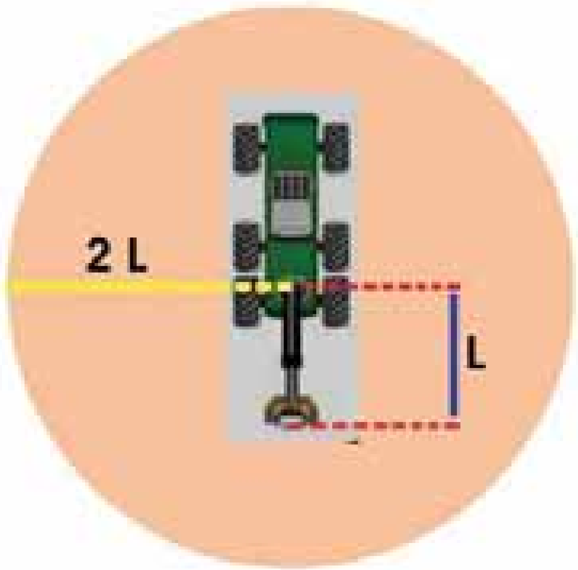


Figure 7. The orange area shows the danger area corresponding to the range of action (L) of the hydraulic arm.

Photo 16. The material, already processed is often loaded directly on site by the vehicle which will then take it to the logging industry.

## Extraction and material loading

Generally extraction is not counted among the working operations of poplar logging, in that the material, already processed, is loaded directly on site by the vehicle that will then take it to the logging industry (Photo 16). When a lorry or articulated lorry cannot enter the clearing, the already processed material or the whole trees, whether delimbed or not, are extracted as far as the landing where they will then be processed and loaded for delivery to the logging industry. Depending on the working system, traditional, advanced or fully mechanized, adopted on the site the vehicles employed for this operation are different.

### *Extraction in traditional logging*

Traditional logging by definition foresees the use of multifunctional machines that can, if necessary, be equipped with tools brought to perform different operations. A classic example is a tractor fitted with a winch or trailer to extract whole trees or processed material or a hydraulic knuckle-boom loader to move and load material.

***The tractor***

The tyred agricultural tractor, if necessary with modifications for forestry use, is the vehicle most used in traditional logging for the extraction of wood. It can be equipped at the back with a winch or trailer with hydraulic knuckle-boom loader. Traction has to be on the 4 wheels to guarantee reliability and very good performance. As far as power is concerned, a machine of 50-70 kW guarantees a satisfactory job. High top speed is not essential but useful, especially if moving also on asphalt roads. A powershift system makes it possible to shift gear under load. Though not essential in work on grounds with a low slope, it is useful for a smooth change and the possibility of not disengaging the clutch. Furthermore, it can be equipped with a reversing gear which makes it possible to work by reversing direction at a speed of as much as 40 km/h.

What is crucial, on the other hand, especially if using powered-axle trailers, is a synchromesh power take-off to have gear change rates in proportion to those of the wheels. The blocking of the differential gear, in conditions of different grip, avoids one wheel stopping while the other continues to accelerate making progress of the vehicle improbable. Every tractor is fitted with an hydraulic system necessary to activate the lifting apparatus and several operating machines. The working of the most common forestry equipment requires an hydraulic system with a maximum capacity of at least 35 l/min, capable of exerting a pressure of 150 kg/ $cm^2$. If, for example, the tractor has to activate a crane for the loading of stems, the supply of greater capacity and pressure allows the work to be accelerated.

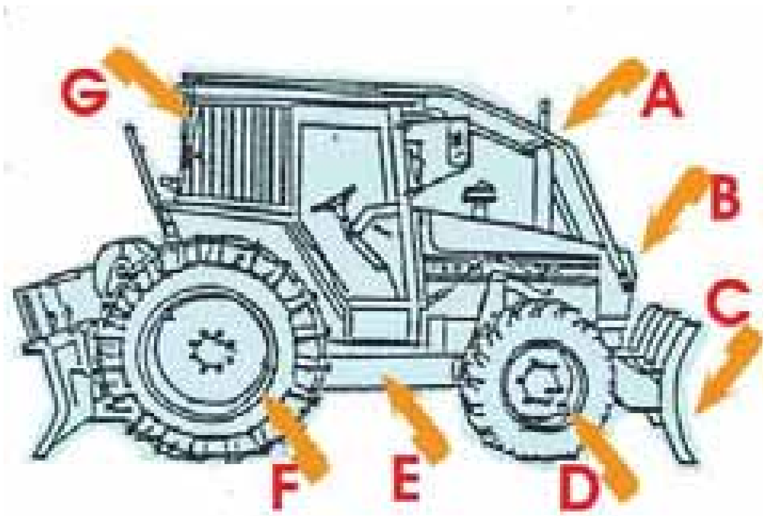


Figure 8. Agricultural tractor in forestry version.

The tractor has to be equipped with an hydraulic lift with a capacity of at least 2500 kg. The braking system has to work on all axles, and the steering be servo-assisted with a wide steering range to make operating easier. The connecting element for towed operating machines is a hitch fitted with a rigid fork with a removable pivot, while for carried and semi-carried operators it is formed by a three-way servo-assisted system of connecting and blocking the tools (three-point hitch). Among the main modifications to be made so that extraction work can be carried out as safely as possible with less time wasted and therefore increased productivity, the following should be remembered: protection for the side and back windows of the cabin (Figure 8 G), protection chassis for the cabin (Figure 8 A), a front ballast (Figure 8 C) to prevent rearing of the vehicle (it can even be a small shovel or hydraulic grapples) or in any event, loss of stability while driving; the most resistant tyres need to be chosen (higher number of plies) and with protection for the valve (Figure 8 D); steel reinforcements placed on the rims (Figure 8 F); protection such as sheets placed ventrally and laterally to the engine and radiator (Figure 8 B and E).

### *The forestry winch*

The forestry winch is an operating machine and can be mobile or fixed (Photo 17). In the case of mobile winches, they are attached to the tractor using a three-point connection and are made to function by its own power take-off. Fixed winches, on the other hand, can also be activated directly through the tractor's hydraulic circuit.

Photo 17. On the left a mobile forestry winch; on the right a fixed mobile winch.

Structurally, in its most simplified version, a forest winch is composed of a metal structure on which a drum and transmission are restrained, which in practice can appear complex and offer different combinations. In most cases the transmission of the motion is mechanical, thanks to a cardan shaft connected to the tractor's power take-off which transmits motion to a multiplier/ reducer set applied to the drum on which a clutch and brake act in order to control its movement. Mobile winches are most used, they are mounted on the hydraulic lift in a few minutes and are much more versatile than those riveted to the tractor. As well as the metal structure containing the elements for transmitting and braking motion, in the winch we can find a wire net for protection, a plate below, integrated with the rest of the structure with the triple function of anchoring, when it is lowered, of hoisting the head of the stems when it is raised using the hydraulic lift and of protecting the tractor against uncontrolled movements of the stems themselves during skidding.

Another important provision with which forest winches are fitted is the fairlead. This is a pulley hinged like a flat at the top of the metal structure, which the rope passes through, completed by a sort of perforated rope guide, horizontally pivoted, and also hinged on the sides of the pulley itself. The fairlead reduces wear and tear of the rope and makes its winding around the drum smooth and it also facilitates its direction, both when winding free and when pulled back with the stems hooked. Another distinctive feature of the winch is the number of drums. As well as those with one drum, there are those with two drums making it possible to bunch and extract a higher number of stems. They obviously have double ropes and fairleads (Photo 18).

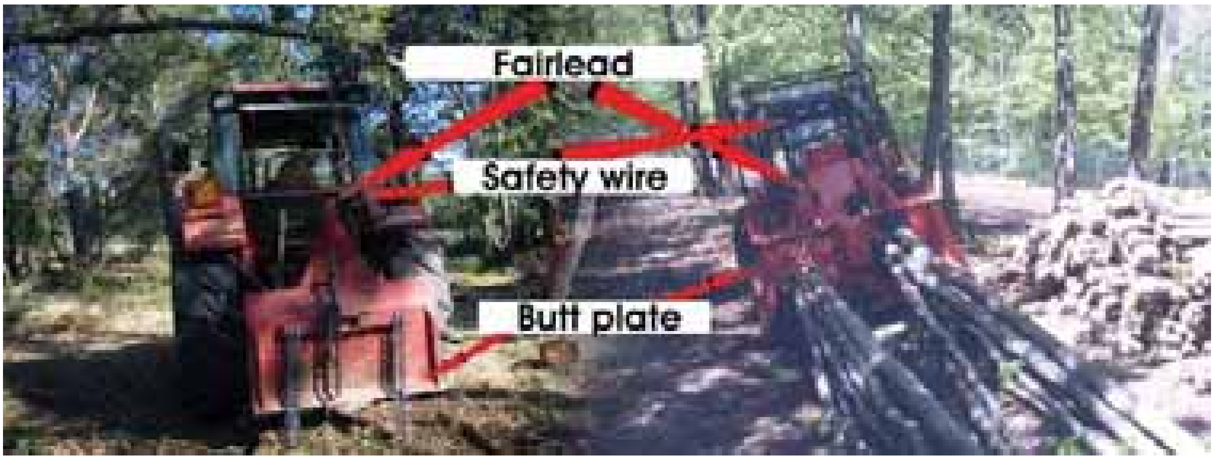


Photo 18. On the left a forest winch with one drum and on the right with two drums; both forest winches are of mobile or carried type.

Another parameter to be considered when choosing one of these vehicles is the maximum developable force of traction. This is a very important measure because it sets the field of application of the winch itself and determines its limits. There are different models with different forces of traction, which range from about 20 kN to just over 100 kN, with an average value of 60 kN. An average winch of this kind should have one or two drums, each able to hold at least 80-100 m of rope with a diameter of 10-12 mm with a mass of about 500 kg. It is preferable to use ropes with 114 strands; it is not important whether the core is steel or hemp. For the skidding of material from the final cutting of the poplar plantation, ropes with a 10-12 mm thickness are sufficient, having a breaking load close to 8 000 kg. The rope has to be supplied with chokers, making it possible to extract more trees in a single trip.

**Work execution**

Carrying out the work is quite simple. The tractor has to be positioned with the rear axle in the direction of the butt of the trees to be extracted, so the winch is lowered making the plate rest on the ground to make the position of the vehicle more stable (Photo 19 A). At this point, by taking the last hook, the operator unreels the rope until he hooks the furthest tree of those planned to be withdrawn. The other trees are hooked to the rope of the winch using the chokers running along it (Photo 19 B); these hooks are formed by a part that slides along the rope and by another perforated part with a forged section so as to be able to house, by inserting it perfectly, the link of a chain or the lead seal of a choker. Other trees to be extracted will have been previously hooked with the choker cables or chains.


Photo 19. Skidding operation for winching with a forest winch with one drum of the mobile or carried type.

Only after finishing the hook-up operation is a signal given and the tractor driver acts on the clutch lever to make the drum roll up again and pull the rope back with its relative load until the butt of the stems comes into contact with the plate on the winch (Photo 19 C and D). Then the plate is lifted from the ground and skidding begins, ending at the landing.

***The trailer***

With the trailer, skidding is carried out of the material already cut to size and assorted. If possible the trailer has to be of a forest type and therefore fitted with one or two powered axles, a strong chassis to resist stress during transport and systems that increase its manoeuvrability (Photo 20).

Photo 20. On the left equalizer axle system with hydraulic traction; on the right hydraulic system for steering and levelling the trailer axles.

It has to have a low centre of gravity, powered axle and wheels with wide tyres (Photo 21). Compared to the farm tractor, the basic structure of a forest trailer is common to the different models available on the market, the chassis is formed by steel axles, connected to the tractor by a drawbar with a hook with revolving eye and it rests on an axle with two or more powered wheels or directly on the wheel hubs in the case of trailers with hydraulic traction. Some heavy trailers have a double axle or twin wheels. Where there is a loading platform it is useful if this can be hinged on three sides to facilitate unloading of the material. In choosing a tractor, a rule that is simple to apply recommends 10 kW of power in the tractor per ton of the capacity of the trailer. The tractor has to have traction on its four wheels and synchronized power take-off. The trailer has to be combined with a hydraulic knuckle-boom loader for loading and unloading material.

Table 2. Classification of forest trailers.

| Type | Max load (kg) |
|---|---|
| Light | 3500-5000 |
| Medium | 5000-7000 |
| Heavy | 7000-14000 |

The loaders can be mounted directly onto the tractor or forest trailer and are formed by a base on which the hydraulic arm is mounted, generally divided into two articulated blocks, of which the second has a removable arm. They are also fitted with stabilizers, in the lower part, essential during loading. Everything is activated by the tractor's own hydraulic system or by an independent one, in this case operation is guaranteed by the pump driven by the tractor's power take-off.

Photo 21. Forest trailers with hydraulic knuckle-boom loader.

## Work execution

The operator places himself parallel to the start of the pathway of the logs, so that he can load as easily as possible and carry out the least number of movements with the loader (Photo 22). With the stabilizers lowered, he brings the grapple above the logs, then by rotating the arm and if necessary extending it, opens the grapple and begins to hook them.

Photo 22. Log extraction with tractor equipped with trailer.

The logs need to be hooked in an area corresponding to about half their length, or nevertheless in such a way as not to unbalance the load. Once the grapple is closed and the logs are grasped, the material is loaded onto the trailer. If the material is quite long, it is better to grasp it at one end, place it on the loading platform and, moving the grapple towards the centre, finish the load with a second operation. Loading has to be carried out in such a way as not to leave any free space on the loading platform.

## *Prevention and safety*

Even if the poplar plantation certainly cannot be compared to a wood (almost no ground roughness, generally slight slopes), a tractor working in it has to be provided with a series of modifications and devices guaranteeing as much protection for the machine as for the operator manoeuvring it. Furthermore, other modifications will serve to make movement of the machine safer, especially if burdened with the weight of another vehicle attached like, for example, a winch. Winches always have to be oiled and never deprived of the protection nets with which they are equipped by their manufacturers. It is important to keep up maintenance, and check rope wear and joint strength, in order to avoid breakages which involve the risk of the broken rope to lashes on the operators and of the uncontrolled load to roll on them.

During bunching of the stems, when the tractor is not moving, the plate of the winch has to be lowered to the ground, in order to be used as anchor. The ropes of the winch must always be handled wearing gloves to avoid injury and cuts due to possible fraying. The mechanical part of the winch must absolutely not be touched when it is in motion or when the power take off is running; the same goes for the cardan shaft and it is essential that it be used always wearing protective headphones and chains that limit their movement.
Clothing too should be as appropriate as possible for the job and close-fitting in order to avoid parts that may get caught by the moving elements.

The manual handling of the stems on the ground has to be done only with a sappie or a peavy to avoid injury, strains, muscle sprains and lumbar pain. Using an hydraulic knuckle-boom leader generally causes damage not so much to an operator as to those helping to arrange the load. It is therefore necessary to make sure that while the crane is moving there are no people beneath the moving loads so that, if they fall, or move uncontrollably, there is no source of danger or damage. The hydraulic arm should have safety valves that keep the flow of oil blocked in case there is a loss of pressure, thereby avoiding an immediate and dangerous loosening of the structure. Before activating the hydraulic arm the stabilizers have always to be positioned on the ground.

All entries to the cabs of the tractor and the hydraulic knuckle-boom loaders have to be fitted with nonslip steps to avoid falls. Every vehicle must be provided with a first-aid kit and an extinguisher.

## *Extraction in advanced and fully mechanized logging.*

In these systems of logging, the vehicles used in extraction are high technology, with high-power motorization and guarantee excellent work productivity. The main ones are the forwarder, an articulated tractor designed to carry the load on a bunk (Photo 23), and the skidder, also an articulated tractor but designed for dragging the load on the ground by means of a grapple or a winch fitted to the rear end (respectively grapple skidder and cable skidder) (Photo 24).

**The forwarder**

The machine is made up of two main parts: a front train where the cab and motor are situated; and a rear train that hosts the loading platform and the crane, with an average reach of 7 m.

Photo 23. Bearing articulated tractors or forwarders.

Photo 24. Articulated forest tractor fitted with a grapple (grapple skidder).

The front and rear trains are connected by a flexible articulated joint. The machine has two powered axles that allow 4, 6, or 8 wheels to be mounted. They can have a capacity of between 8 and 12 t and are equipped with engines with power between 80 and 110 kW. The length can vary from 8 to 10 m. Mass ranges between 9 and 13 t. The cab has a reversible driver's seat that is electronically adjustable depending on the operator's weight and height, with wide visibility and an internal air-conditioning. The functions of the vehicle are controlled by an on-board computer making it possible to manage the vehicle's operative parameters: the load transported can be displayed and recorded, the distances covered and the number of trips per hour, or relating to the whole working day.

The loading and extraction of the material with a forwarder follow the same working procedure for extraction using a tractor with trailer and hydraulic knuckle-boom loader. The difference in using this vehicle can be found in the fact that it is easier to operate and to use.

## Work execution

In general, logs that have already been assorted are extracted. If organization of the yard requires it, it is nevertheless possible, considering the length of the vehicle, to extract whole lopped stems and carry out cutting to size at the landing. The operator, utilizing the reversibility of the driving position, proceeds in reverse gear and reaches the loading area by positioning the machine at the side of the assorted material, stops the vehicle, places himself at the controls of the hydraulic knuckle-boom leader with grapple and beings loading (Photo 25). With every “haul” logs are taken more or less according to their diameter making the most of the opening of the loading grapple which generally covers an average surface of 0,35 $m^2$. Once there is no more space available on the loading platform, the hydraulic arm rests on the stems, if the crane is mounted on the rear axle or on the facility arranged at the front if it is mounted on the forecarriage, in order to secure it during transport. The operator therefore reverses his driving position by 180° and, in forward gear, begins extraction towards the landing where the material already cut to size is loaded onto an articulated lorry (Photo 26), or unloaded, if there are whole lopped stems, and cut to size into commercial assortments.

Photo 25. Extraction with forwarder, operative phase of loading material.

Photo 26. Loading on articulated lorry with forwarder.

Photo 27. Skidder with open grapple.

*The skidder*

This is a tractor with high-power motorization, 60-90 kW, with central articulated connection ensuring very good manoeuvrability of the vehicle. At the back an hydraulic grapple can be mounted, driven by one or two jacks, assembled on the tractor’s hydraulic lift, that ensure both horizontal and vertical movement by the grapple and therefore a lower number of operations in hooking the material (Photo 27). Alternatively or in some cases together with the grapple there is a winch with one or two drums. Fifty percent and more of the machine weight are distributed at the front to avoid rearing of the machine during skidding. The engine is completely protected by a steel plate, just as the lights and wheel valves are protected. All wheels have the same diameter with no difference between front and rear axle to ensure good grip and mount forest tyres. At the front the vehicle is equipped with a bulldozing shovel that can be used when approaching several trees. The mass of the average skidder can vary from 6 000 to 8 000 kg. The speed they can reach is considerable: about 30 km/h.

Photo 28. Extraction of whole trees with a skidder.

Figure 9. Tractor equipped with a clam bunk.

## Work execution

With a tractor with grapple, whole trees are extracted, generally with branches (Photo 28). Compared to extraction using a winch it is the machine that approaches the material, hooks it and extracts it directly, while working with the winch the machine is stationary while the rope is pulled back. In other words approach and hooking with the grapple are almost simultaneous and bunching (winching) does not take place before actual extraction. After reaching the area with felled trees, the driver operates, approaches in reverse gear and with the open grapple hooks the tree. Once the tree is hooked he operates and takes position over another tree, opens the grapple, lets the tree, previously hooked, fall and closes the grapple again, thus taking the two trees. Repeating the same operation, a good driver can hook 4-5 trees and thus take the most advantage of the loading surface of the grapple, which can reach as much as 1 $m^2$. The material is then unloaded at the landing where delimbing and cutting to size are carried out with a harvester. There are also tractors which mount inverted grapples (clam bunks) to catch the load end once this has been placed on them by a loader.

## Prevention and safety

The operator operating the above-mentioned vehicles, working inside the comfortable cabs (air-conditioned and sound-proofed) does not need any particular safety means. His attention, as in the case of using combined machines, has to be turned to the exterior making sure that within the range of action of movements and operations there are not other people at work.

## Chipping

Chipping is the operation that makes is possible to reduce the woody material, in this case tops and branches, into even-sized particles called chips (Photo 29). Chips are a less valuable assortment and the average market price paid by manufacturers is low. In recent years, nevertheless, the growing use of alternative energy sources rather than fossil ones and the consequent creation of power stations or small works to produce thermal energy has varied its use, previously it was only for producing panels of reconstituted chips, and has increased its demand. The production of such an assortment also makes is possible to recover on average 20-30% of biomass that would otherwise be a residue of logging and therefore ground or burned on the clearing.

Photo 29. Heap of chips at the landing.

### *The chipper*

The chipper is a machine which, by means of a cutting instrument, reduces tops, branches or whole trees into small chips. It can be fitted with a self-contained engine or utilize the power provided by a tractor. Depending on the cutting instrument there are three types of machines: drum, disc and end less (Photo 30).

In the first type, the chipping element is composed of a cylinder, of a diameter varying from 40 cm to 100 cm, which rotates on its own axle and on which knives are assembled tangentially. In the second type, the cutting element is composed of a big flywheel on which 2 to 4 knives are mounted in a radial position. The flywheel has a minimum diameter of 80 cm. In the third type, the cutting element is made up of a tangent screw rotating on a horizontal axle. The material can be fed from above or from the front by means of a mouth in the form of a truncated pyramid on which, laterally, there are pulling rollers. The product is generally ejected through a gooseneck. To function they require very high power, up to 400 kW, and can be mounted on specific tractors and therefore independent in movement (Photo 31).


Photo 30. Three different types of chippers based on cutting element.

## Work execution

The chipping operation within a poplar logging yard can take place, depending on the vehicle available, basically in two ways: directly on the field or at the landing. In the first case, the chipper, which has to be independent in movement, is positioned along the row of tops to be ground and blows the material directly into an articulated lorry, or body placed parallel to it (Photo 32). This is the system that ensures the least maintenance. In fact, not being extracted the material is not "polluted" and the knives last longer. On average with one set of new knives 100 to 300 t of chips can be produced, and this quantity can be considerably reduced is the wood is contaminated with soil during extraction. If an automatic chipper is not available, the material has to be extracted as far as the landing here it is then chipped. The arrival of material at the machine has to be programmed so as to avoid the chipper being left not running due to lack of first matter. The chipper nevertheless has to always take place inside the articulated lorry: chipping on the ground or inside a trailer to then load the chips again onto an articulated lorry is to be avoided, if possible.

Photo 31. Big power chipper mounted on a forwarder.

Photo 32. Chipper mounted on a forwarder working parallel to a tractor with trailer to transport the chips.

## General considerations on working methods

The working methods previously described, in a phase of general economic considerations also, were analyzed in more detail and were represented with four types of logging: traditional (T), traditional-advanced (TA), advanced (A) and fully mechanized (S).

Adopting one of the working methods described above essentially depends on the degree of mechanization adopted and therefore on the financial investment that companies are able to sustain, and consequently on the volume of work that can be carried out annually. Tables 3, 4 and 5 quote the machines used in the different operations for the different types of logging taken on, the range of average gross productivity of work attainable, divided according to individual operations and to the whole yard and the average capital needed to take on the four types. It should be highlighted that every type of logging is characterized by a greater or lesser degree of mechanization while the operations performed by the machines used do not follow a coded sequence but depend on the logistics and organization given to every single yard. For example, in fully mechanized logging the harvester which should carry out in continuous succession the felling and processing of trees, can first carry out felling and then processing in the log yard of whole trees extracted with a skidder, or process trees previously cut down and aligned with a feller-buncher.

Table 3. Operations performed and main machines used depending on the type of logging adopted.

| *Type of logging* | *Felling* | *Alignment Bunching* | *Processing* | *Extraction* | *Loading* | *Chipping* |
|---|---|---|---|---|---|---|
| Traditional (T) | Chainsaw | | Chainsaw | Farming tractor with winch (whole trees) with trailer (logs) | With grapple of farming tractor or trailer | |
| Traditional Advanced (TA) | Chainsaw | Excavator with grapple | Chainsaw | Farming tractor with winch (whole trees) with trailer (logs) | Excavator with grapple | |
| Advanced (A) | (Feller - buncher) | (Feller - buncher) | Chainsaw | Farming tractor with winch (whole trees) with trailer (logs) | Excavator with grapple | |
| Fully mechanized (S) | (Harvester) | | (Harvester) | Forwarder, Skidder | Forwarder | Chipper on a tractor moving over the clearing |

Table 4: Range of average gross productivity of work that may be found in various operations of poplar logging according to type of logging adopted (t $h^{-1}$ $man^{-1}$).

| Working systems | Felling | | Processing | | Extraction | | Loading | | Chipping | | Logging | | With chipping | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Traditional (T) | 15 | 18 | 2 | 3 | 12 | 14 | 5 | 6 | - | - | 1,18 | 1,59 | - | - |
| Traditional advanced (TA) | 25 | 35 | 2,5 | 3,5 | 7 | 9 | 7 | 9 | - | - | 1,38 | 1,86 | - | - |
| Advanced (A) | 35 | 40 | 6 | 6,5 | 5 | 8 | 5 | 8 | 12 | 14 | 1,68 | 2,33 | 1,47 | 2,00 |
| Fully mechanized (S) | 40 | 50 | 12 | 16 | 20 | 26 | 8 | 10 | 15 | 18 | 3,53 | 4,53 | 2,86 | 3,62 |

Table 5: Indicative level of investment in capital machines, in relation to the type of logging adopted (Euro).

| Traditional (T) | Traditional Advanced (TA) | Advanced (A) | Fully mechanized (S) |
|---|---|---|---|
| 80-100.000 | 170-190.000 | 350-380.000 | 800-1.000.000 |

At the moment the working method most used is the traditional one, very often with variations that foresee the use of a machine for handling the material whole or cut to size (traditional advanced) that can considerably increase the productivity of the entire yard. The adoption of advanced and fully mechanized working methods, using felling or harvester heads and of sophisticated vehicles for extraction, the forwarder in particular, and of chippers, has nevertheless spread in recent years. Clearly to the advantages induced by these working methods; higher productivity compared to traditional systems, complete logging of all the crop with the chipping of tops and branchwood and therefore facilitation in restoring the land, the high financial investment to be met is countered and the consequent amortization that can be guaranteed only in relation to a greater surface area processed annually that, however, has to be centralized as much as possible in order to limit the costs of moving the machines. Unfortunately this last requirement is very often not fulfilled due to the excessive distribution of poplar areas. It should also be highlighted that to use these machines highly specialized, specifically trained staff have to be employed. For example, too much pressure given to the knives of a harvester head can cause excessive removal of bark thereby making the assortments no longer marketable or reducing their value considerably.

# Root extraction

After harvesting and extracting poplar trees, the agricultural land should be restored for further cultivation by removing the root systems. This operation requires specialized machinery in order to reduce costs, being the simpler solution the use of a propeller-crusher applied to a farm tractor. The machine destroys the taproot and secondary roots, mixing residues and soil. At present this procedure is the most common, but the roots of harvested trees may represent an interesting source of wood biomass, and their recovery deserves special attention for the following reasons: first, the stump-root system is a substantial portion of the tree mass; second, root wood often has higher heating value than stem wood, and may prove to be a better fuel; third, the removal of the root system in tree plantations, considered as a service rendered to the landowner, is anyway accomplished. Therefore, harvesting tree roots does not require the payment of a concession, and may carry additional revenues in terms of landowner payments.

## *Root extraction background*

First experiences in root extraction date to early 1900 (Reinhold, 1951), but a real interest in industrialized systems for root recovery arises in the 1970s when the Scandinavian boom of pulp manufacturing justified special efforts to find new sources of wood raw materials. Pine and spruce root systems were extracted using modified excavators, equipped with the *Pallari* grapple: a special attachment designed to uproot and split flat stumps (Figures 10 and 11). This was successfully tested in Denmark, France and Sweden.

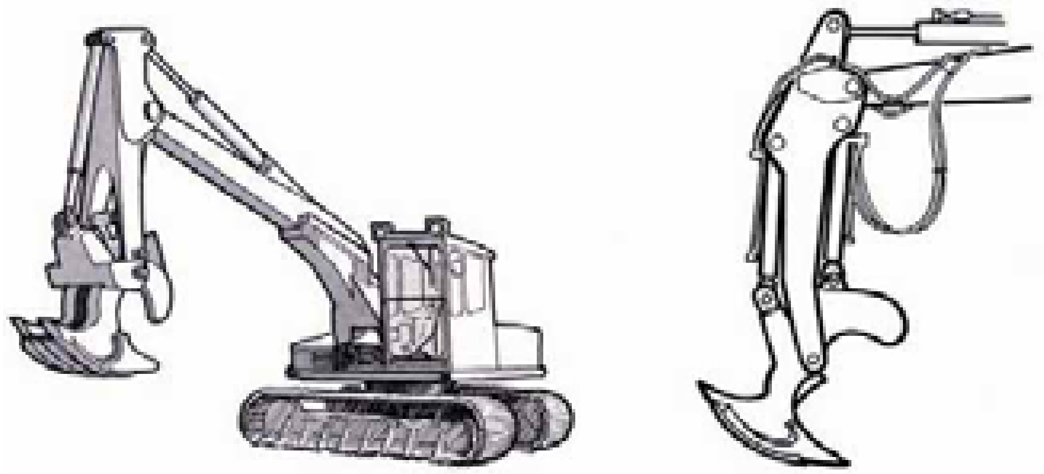

Figure 10. The *Pallari* grapple mounted on an excavator and a profile detail of the attachment.

Root cleaning was achieved by shaking the roots just after extraction and leaving the extracted root systems outdoors, so that the rain would wash out any soil still clinging to the wood.

Figure 11. Root extraction system based on *Pallari* grapple; roots are leaved in the field outdoors for a few months to allow the rain to wash soil out.

By now Finnish researchers are leading the revival of root wood harvesting, made possible by a renewed interest in biomass fuels. This same trend may involve Central-Southern Europe poplar plantations having a great potential for biomass recovery, due to the abundance of the residue, the ease of access and the industrial character of management. Nevertheless, compared to spruce, poplar trees have deep taproots that a *Pallari*-type unit cannot handle very well, requiring a specifically designed harvest system.

## *Poplar root extraction*

The first “poplar specific” machine was designed in 1960 by an Italian manufacturer and it is basically the same concept still in use. The implement is an auger designed to fit the rear end of a farm tractor and to receive power through the power take-off. The auger is hollow inside, and large enough to contain the taproot of a mature poplar tree (Photo 33). The tractor moves to the stump, lowers the auger over it and drives the cylinder into the ground to the depth of approximately 150 cm. Then the auger is raised with a soil "carrot" inside it, containing the taproot. An ejection ram pushes the "carrot" out of the pipe, dropping it to the ground. The auger is completed by a pair of propeller blades welded to the pipe terminal crown. These blades would crush the remaining side roots so that they would not hinder subsequent soil preparation.

Photo 33. The auger type extractor is basically a cylinder large enough to contain the taproot of a mature poplar

The auger-type extractors have been widely used in Italy and abroad, especially in Hungary and in the Balkans, being ideal for trees with a strong taproot (poplar, pine etc.). On the other hand, the core-sampler system produces dirty "carrots" that need cleaning. Active on-site cleaning allows reducing storage time and transportation cost, and it is performed with chain-flail cleaners: these are mounted on a wheeled chassis and towed by a loader or a farm tractor (Photos 34 and 35).

Photo 34. A forestry loader may tow and power the chain-flail cleaner while maintaining its mobility and productivity performances.

Photo 35. A common farm tractor may operate the cleaner, but it requires an additional pump to operate it together with the crane.

As an alternative the chassis may be mounted directly on the loader resulting in an improved mobility on the field (Figure 12 and Photos 36, 38 and 39). The two flail axles are powered by independent hydraulic motors, connected to the pump of the carrier. The loader moves along the rows of extracted roots, picks up the "carrots" one by one and dips each one a few seconds between the rotating flails. The clean roots are thrown 5-6 m away, to form small heaps. Gathering clean roots in heaps facilitates loading and transport. Clean roots are loaded directly onto 3-axle trucks driven into the field, using the same loader that cleaned them. If the soil is wet, farm tractors with 3-axle trailers are used instead of trucks.

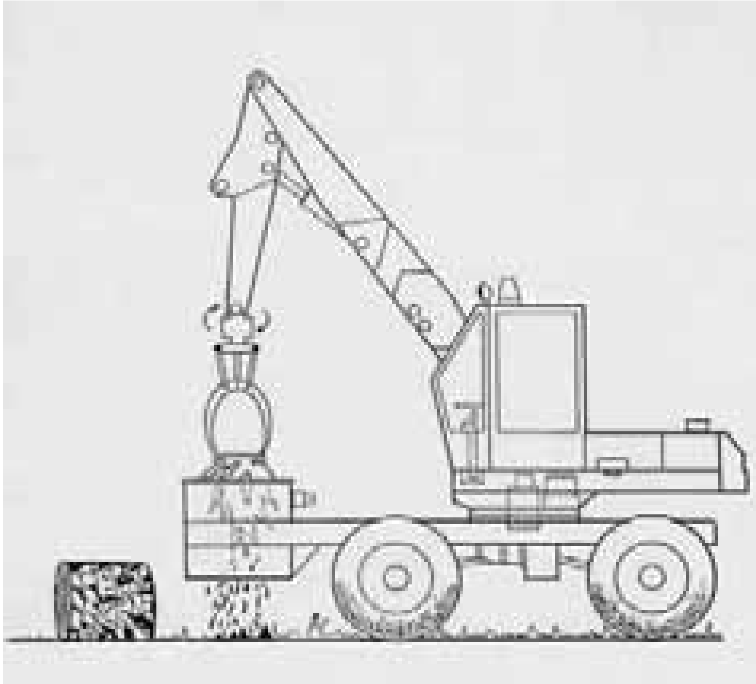

Figure 12. As an alternative the cleaner can be mounted directly on the chassis of the loader, resulting in a more compact and agile unit.

Photo 36. After cleaning the roots are gathered in heaps in order to facilitate the following loading operations.

With these machines, Italian contractors have developed recovery systems that are both efficient and cheap. Extraction and cleaning units are usually based on general-purpose prime movers, easily available on the market. Under favorable conditions these units can achieve a very high productivity. In principle, all operations involve three teams: the extraction team, the cleaning-loading team and the transportation team. They generally work separately and assemble only during loading: when a transportation unit arrives on site, the loader attached to the chain-flail stops cleaning and comes to load it. Occasionally, the extraction unit is also called in for towing the transportation vehicle through difficult terrain. This generally happens when the transportation vehicle is a standard road truck.

Extractors may be mounted on farm tractors (Photo 37) or dedicated prime movers, each coming in a number of versions. In general, when using farm tractors as extraction units those should be modern machines, with a power of at least 100 kW. Ideally, the tractor should be fitted with integrated electro-hydraulic controls and auxiliary pump. The first facilitating the movements during work and the second accelerating the digging phase. Such a machine can reach a gross productivity of 150 stumps per hour, twice as much as the lighter models and 50% more than an equally powerful tractor without improved controls. The higher operating costs of these machines are widely offset by increased productivity. Lighter machines are cheap to operate, but they are too slow and they are good for part-time business only.

Photo 37. A farm tractor mounted auger extractor at work on a poplar plantation.

Cleaning is done with chain-flail trailers, attached to a farm tractor or to a wheel loader. While the hydraulic system of farm tractors is not powerful enough for driving both the chain-flail and the loader mounted behind the tractor cab, requiring an additional pump, the chain-flails powered by wheeled loaders are directly connected to the hydraulic system of their prime movers. Furthermore with these machines the cleaner may be carried instead of towed, resulting in a more compact unit much more maneuverable, fast and agile in cleaning and loading operations. As a result self-propelled forestry loaders perform best: they can clean 170 stumps per hour, and load 400 filling a 10-ton truck in 15 minutes (net productive time) – twice as many as a loader-equipped farm tractor unit can. Loading speed is particularly important, since long loading times are not paid by the loader only, but also by the transportation unit and by any other unit eventually assisting them. Farm-tractor units are less maneuverable than self-propelled loaders, and their crane is not as quick, obtaining a maximum output of 250 stumps per hour. Besides, the power available for the cleaner is limited, which results in a longer cleaning time. As a rule of thumb, cleaning takes longer when increasing the clay component of soils and this for two reasons: first because the clay tends to stick to the root surface more than the sand does, and second because roots grown in clay soils are shallower and more branchy than those grown in sandy soils, so that more flailing is required to achieve thorough cleaning.

Transport vehicles were either 3-axle 10-ton trucks or farm tractors with a 3-axle 10-ton trailer. Transport is best performed by trucks, which are faster than standard farm tractors and can cover the same distance in less time, both empty and loaded (Photo 38). In addition, standard farm tractors are not much cheaper: transport is at least 35% more expensive when using a standard farm tractor rather than a truck, and in some cases it can cost twice as much. Transportation is indeed a bottleneck, limiting the productivity of the whole operation: recourse to high-speed farm tractors (Photo 39) may prove an effective solution, as these machines offer good cross-country mobility and high road speed (about 80 km/h).

Photo 38. Common truck and trailers can enter directly into the field when the soil is dry, the loader can quickly fill these units reducing their expensive waiting time.

Photo 39. High speed tractors with 3 axes trailers may provide a good compromise between cross-country mobility and road speed.

The average recovered fresh taproot weight 58 kg with a moisture content of 42.3 % (wet base), resulting in 33 kg oven dried biomass. The average cut yielded 18 tonnes of fresh biomass of root wood per hectare corresponding to about 10 oven-dry tonnes. In Italy, root extraction is still regarded as a service rendered to the landowners, willing to pay between 200 and 300 €/ha for getting their fields cleaned. For an average yield of 10 t (oven dry)/ha, such a payment represents an integration to the harvesting cost of 20 to 30 €/t (oven dry), which is quite substantial and explains the survival of low-efficiency operations. However, if the biomass market will take off, competition among recovery operators is likely to reduce landowner fees, and therefore optimized harvesting methods will be required: certainly, the extraction productivity recorded today is much higher than that reported for older versions of the same technology, which extracted between 30 and 60 stumps per hour. Comparison with the Scandinavian extraction system is more difficult, because the stands, stumps and operational methods are radically different. For the mainstream *Pallari* method, Hakkila and Mäkelä reported a daily productivity of 10 and 20 $m^3$ per 8-hour day. These figures included extraction, splitting/cleaning and moving to a collection site. Poplar root recovery, summing extraction, cleaning and loading time and applying a wood density of 850 $kg/m^3$ to fresh poplar result in a daily productivity of poplar root recovery between 15 and over 35 $m^3$ per 8-hour day. The better result is certainly related to the easier working conditions offered by poplar plantations in agricultural land.

## New growing techniques: poplars for biomass and fibre

The fast growing aptitude of poplars led to develop new kind of plantations as a response to the growing market demand of mass commodities such as chips for bioenergy or paper industry. These plantations aim to maximize the productivity per hectare, with less or no requirements in terms of timber quality, and are grown with a technique known as Short Rotation Forestry (SRF). The concept of SRF implies the cultivation of fast growing tree species on agricultural land at extremely high density of plantation; the use of intensive tending techniques, and particularly a high grade of mechanization in every phase; the repetition of harvest at 1-3 year intervals (up to 8 for fibre production), and the regeneration of the crop as a coppice with sprouts arising from a permanent stool. Since the introduction of the concept of “grassland forestry” in the late ‘60s this practice has been under study in many countries with the aim of maximizing the biomass production. The efforts dedicated to this research forwarded this technique from the theoretical stage to an actual fiber production system. At present, commercial SRC plantations are established in Sweden and the United Kingdom with willow, and in Italy with poplar. On good sites, specifically selected clones grown as SRC can yield up to 16-20 odt/ha year (oven dry tons/hectare), which is a definite progress over the 13-15 odt/ha/year levels reported in the past. Several crop systems are adopted, differing in rotation length and – consequently – in planting density:

- <u>very short rotation</u> system: is harvested at 1-year intervals and adopts a planting density exceeding 10,000 cuttings/ha. Cuttings are planted in twin-rows, with a spacing of 1.8-2.8 m between twin-rows, 70-80 cm between the rows forming a pair and 40-50 cm along the rows. Stem size at harvest reaches 2-3 cm (cut level), with peaks of 6-8 cm.

- short rotation system: is harvested at 2-3-year intervals: cuttings are planted in single rows, with a spacing of 3 m between the rows and 0.5-0.6 m along the rows. This results in a stool density of 6-7,000 units/ha. Stem size at harvest reaches 10-12 cm at cut level.

- longer rotations can be adopted with the medium rotation system; these plantations, called “fibre farms”, mainly produce pulp wood for paper industry. Trees exceed the size of 15-20 cm at cut level and harvesting can be performed with standard forest machinery. Coppice regeneration is less common for these plantations.

## *Harvesting Poplar Short Rotation Coppice*

"Grassland" type SRC compares either to conventional forestry or to common agriculture: the crop is a completely new one, posing completely new problems. Being a key point of SRC management, the question of how to harvest these new crops was raised already 15 years ago. In fact the only market product of these plantations is fuel chips, a mass commodity which must bear a relatively low unit price to be competitive. Therefore, the economic margins of the business are somewhat constrained and harvesting system and transport, representing over 70% of the total costs, should be as efficient and cheap as possible.

Manual systems, conventional forestry equipment and unmodified agricultural machinery were all tried, but the experiments generally met with little success. Fortunately, much progress has been made since then, thanks to many projects which investigated a number of alternative solutions. The most impressive result of these efforts is the production of a number of SRC harvesters, able to cope with a variety of different conditions. In this handbook, we propose a classification of SRC harvesting equipment, based on the harvester's functions, providing synthetic information that allows framing the operational scenarios connected to any given harvester.

SRC harvesting consists of four main operations: cutting, collection, extraction and comminution. The main functional difference between harvester types is the number and the type of operations that they can perform. In order of growing integration, we find the following functional types:

1) *Cut-only harvester*. The harvester cuts the stems, laying them in windrows or heaps. Cut stems are then collected by a separate unit, which delivers them to a chipper (Photo 40). As an alternative, one can use a chipforwarder to collect, chip and extract in one pass.

Photo 40. A simple harvester, based on a circular saw, cuts the trees and pushes them by the side. Following a tractor with a special front end loader piles them up to the field headland for stocking or chipping.

2) *Cut-and-bundle harvester*. The harvester cuts the stems and collects them in bundles, which are dropped on the field, like hay bales (Photo 41). They are later collected by a separate unit, most often a conventional forwarder or a farm tractor with forestry trailer.

Photo 41. Trailer mounted harvester unloading the bale along the road.

3) *Cut-and-extract harvester*. The harvester cuts the stems, collecting and loading them over a deck of some sort (Photo 42). It then takes its load to the field edge or to any suitable landing. Chipping is the only operation delegated to a separate unit.

Photo 42. This prototype of crawler harvester collects the whole stems and loads them on a back deck.

4) *Cut-and-chip harvester*. The harvester cuts, collects and comminutes the crop, delivering the chip at the field edge. In alternative, the extraction can be delegated to chip shuttles, to keep the harvester going (Photo 43). Chip shuttling is used preferably when the extraction distance is large.

Photo 43. Modified forage harvester working on a 3-year old poplar plantation.

## Systems in use

Even if all the four functional types are actually represented by some existing machines, cut-and-chip is by far the most common type and within it the forager system is the prevalent method for harvesting very-short rotation and short-rotation SRC. It is based on a modified forage harvester, whose standard header is replaced with a special SRC header as shown in Photo 44. The harvester is assisted by 2 to 4 tractor-trailer units, which receive the chips and move them to a landing. The number of tractors depends on the productivity of the harvester and the distance of the field to the collection point. In a properly organized work the harvester, the most expensive machine of the system, never stops for lack of empty trailers.

Photo 44. Dedicated header for SRF harvesting.

As a typical work scheme, the tractor-trailer travels by the side of the harvester which is blowing the chips perpendicularly to its moving direction (Photo 45). A second tractor may be following at short distance in order to quickly replace the filled one. When the row is over both harvester and tractor-trailer turn on the header and enter a new row and corridor. Turning is easier when moving to a row placed at a certain distance (20-40 m), so that harvesting will proceed from the sides of the plot. This system requires a free corridor by the side of the trees row to harvest but farmers are not prone to leave frequent strips of unused land, resulting in plantations with no "entrance". Thus, at the beginning of the work, it is necessary to "open" the field: the harvester enters a row closely followed by a tractor-trailer unit (Photo 46). The chip is blown over the cabin of the tractor into the trailer. At the header the couple turns and opens a second corridor at a distance of a few rows (5-15). Once the two corridors are ready, harvesting can follow in the more efficient "side by side" scheme.

Photo 45. The tractor moves by the side of the harvester, when the trailer is full it unloads the chips at the landing while the forager fills a second tractor

Photo 46. Tractor and trailer following the forager while "opening" the field.

Forager system has a very high productivity: ranging from 10 to over 40 green tonnes/scheduled machine hour (gt/SMH), with an average value of 25-30 gt/SMH. The corresponding harvesting cost varies between 15 and 30 Euro/tonne, including delivery to an intermediate storage site in the vicinities. Top performance is obtained only when several factors concur, and namely: good terrain conditions, adequate machine choice, high crop density and appropriate row spacing. A forager is a heavy machine that cannot traffic wet or sloping soils, and should only be applied to flat and solid terrain. Furthermore, modified foragers cannot harvest stems that are too big and too close: cut stems have to be placed horizontally to enter the chopper, and if they are too long and too near to each other, they often get entangled with the uncut stems ahead, jamming into the header. This problem does not occur with small stems, which are shorter and more flexible, so that their tops bend and the butts can be fed horizontally to the chopper. Therefore, effective harvesting of large-size stems requires an accordingly large spacing, so that the tops of cut stems can sneak between the standing crop ahead and the stems can be laid horizontal. Similarly, row distance must follow strict rules, because the forager-based harvesting system is quite rigid with respect to crop spacing. Most SRC headers have been built for harvesting twin rows placed 75-80 cm apart: any significant variation in row spacing makes harvesting difficult or even impossible. The distance between twin rows must also be adequate for machine traffic, generally from 2.4 to 2.8 m. These same headers can also harvest single-row plantations, by working slightly offset to the row alignment, but in this case row spacing must be 3 m: typically these plantations are managed on two-year-rotations and produce larger stems.

Tractors and trailer unit take the biomass to the collection point, which may be a paved area at the farm centre or any area close to the fields and accessible by truck. Chips are quickly unloaded on the ground, forming a heap, and generally are transferred to the plant within a short time. Trucks loading operation is completely independent of the harvesting system and is best achieved with a hydraulic loader – either a knuckle-boom loader or a front-end loader (Photo 47). The operation is very quick but requires that some of the chips are left on site, as trying to scrape the last few chips from the ground may result in contamination with soil and stones.

Photo 47. Truck loading with front-end loader.

An alternative is the use of trailers with piggyback containers. The tractors unload the full container and take an empty one at the collection site. Trucks unload the containers emptied at the plant and load the full ones, resulting in a unique system strictly linked (Photo 48). In this case trucks should be able to return the empty containers approximately within the time the harvester requires for filling them, otherwise the whole system would stop. The availability of a large number of containers may play a buffer role, but this solution implies high investments and a very large landing.

Photo 48. Container based logistics.

## *Practical aspects*

The success of harvesting is determined when establishing the crop, as machine performance largely depends on crop conditions. Ideal fields are rectangular, with wide headlands and cross-roads 150 m apart. Side-slope must be avoided (Figure 13). Wet soils should be drained, using open-air ditches running parallel to the rows. Rows must be regular and their spacing must be set according to the harvester one expects to use. In brief, one should take the same care as is taken when establishing conventional agricultural crops. In fact, most of the limits of SRC harvesting are imposed by the support fleet of converted farming equipment. The choice is between careful field planning and using a dedicated support fleet, but the latter option is much more expensive.

When establishing their SRC crops, farmers should consider the following guidelines, if they want to harvest their fields successfully. This does not mean that other configurations cannot be harvested, but only that these might restrict harvesting productivity and/or increase damage levels in the remaining stand.

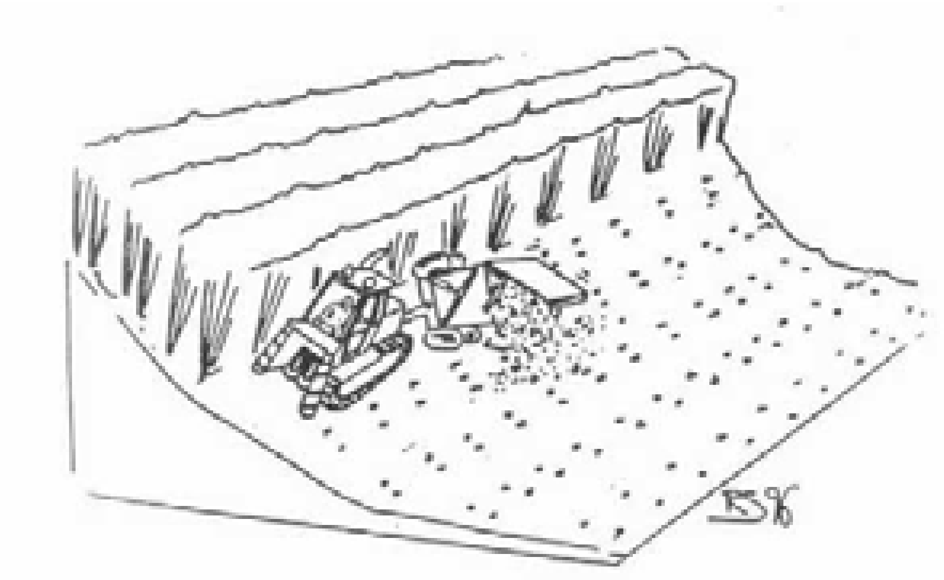

Figure 13. Side slope should be avoided when establishing SRC plantations.

**Site selection**

It is a fact that SRC is seen as a way to utilize marginal land. However, if one thinks to turn biomass production into an economical activity, then one has to avoid extreme conditions or has to find ways to mitigate them. Excessive soil moisture is the most common single factor of marginality for those fields destined to host willow plantations. Most SRF harvesters cannot negotiate very wet terrain (Figure 14). Harvesting on wet ground can be done only with deeply frozen soil. The alternative is laying down a drainage system, to reduce soil moisture and allow both machine access and fast tree-growth. It is strongly advisable to use open-air ditches parallel to the rows, in order to reduce drain crossing to the required minimum. Underground drain pipes within the plantation are soon made ineffective by root growth and should be placed under the headlands and the cross-roads, to connect the ditches and complete the drainage network (Figure 15).

Figure 14. Wet terrain is a limit to harvest, being a constrain for the harvester but even more for the tractor and trailer unit.

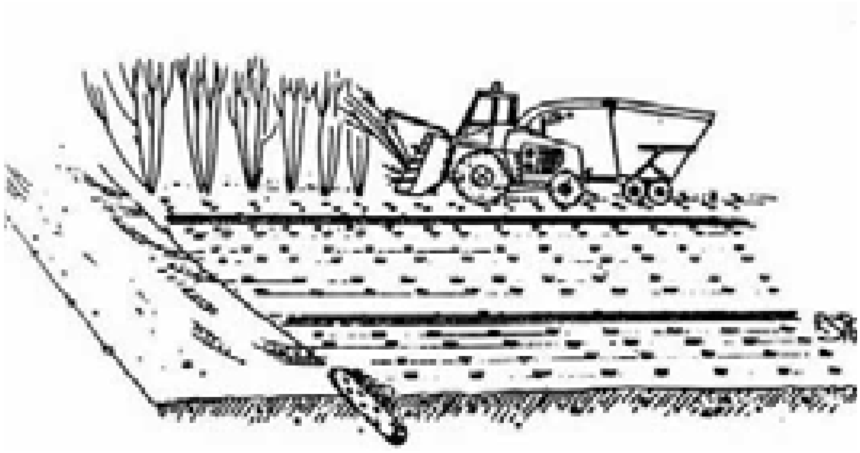

Figure 15. An efficient drainage system can increase the number of "harvestable days" during the wintertime.

## Field lay-out

Most often, field shape follows terrain patterns or farm-boundaries. One can hardly change these constraining factors. However, efforts should be made to lay-out the fields in the most rational way. The theoretical field is rectangular in shape, with cross-roads 150 m apart. These cross roads allow chip shuttle units to break out of the row and drive to the landing (Figure 16). Cross-roads take some area out of production, but they prevent unnecessary in-field traffic. Both the headlands and the cross-roads should be covered with vegetation, i.e. grass. The cross-roads should be wide enough (6-8 m) to allow the shuttle tractor and trailer to exit and enter the field without damaging the last stools of the rows.

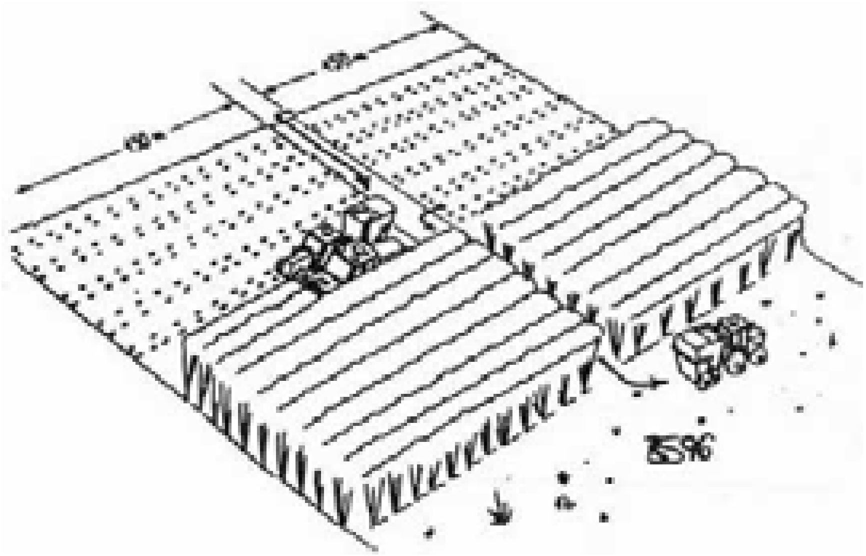

Figure 16. The ideal field layout with frequent cross roads.

**Headlands**

Adequate headlands must be provided. Insufficient turning space is the most frequent reason for poor harvesting performance: it imposes complicated maneuvering, which results in soil rutting and decreased productivity (Figure 17). Shuttle traffic will cross the area, and the harvester will turn here. For traffic only, a width of 8 m is sufficient, but if the area is used for storage of the product or re-loading into containers, then a larger space is required. If the product is stored at the headland, one will consider the storage time and the eventual passage needs of other users or of the same user for other tasks.

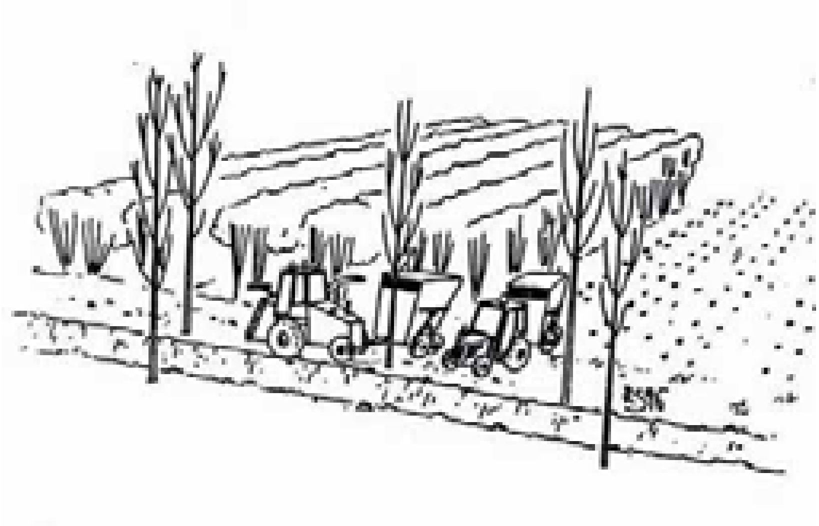

Figure 17. The headland has to be large enough to allow turning of the harvester and the less agile tractor and trailer

## Row length and spacing

Short rows should be avoided. They impose an intolerable increase of turning time, and a comparative reduction of productive time (Figure 18). Sometimes, rows are so short that turning would take longer than reversing to the starting position. Rational row length varies between 100 and 150 m. Given the average yield of SRC crops, most harvesters can complete a load within this distance. When planting longer fields, cross-roads should be laid out with an interval of 150 m (see above).

The rows should form a right angle to the headlands and the cross-roads, in order to allow the machines to enter the row from both directions, so as to facilitate harvesting up and down the rows. If the field is skewed with respect to the headland, rows should bend over the last 10 or 20 m to enter the headland at a right angle (Figure 19). Row spacing is crucial to machine productivity. Even if most harvesters can technically handle both situations, using a double-row harvester on single rows means curtailing its productivity. Therefore, at the time of establishment, one should already gather information on the type of harvester which is likely to be available in a 3-4 years time.

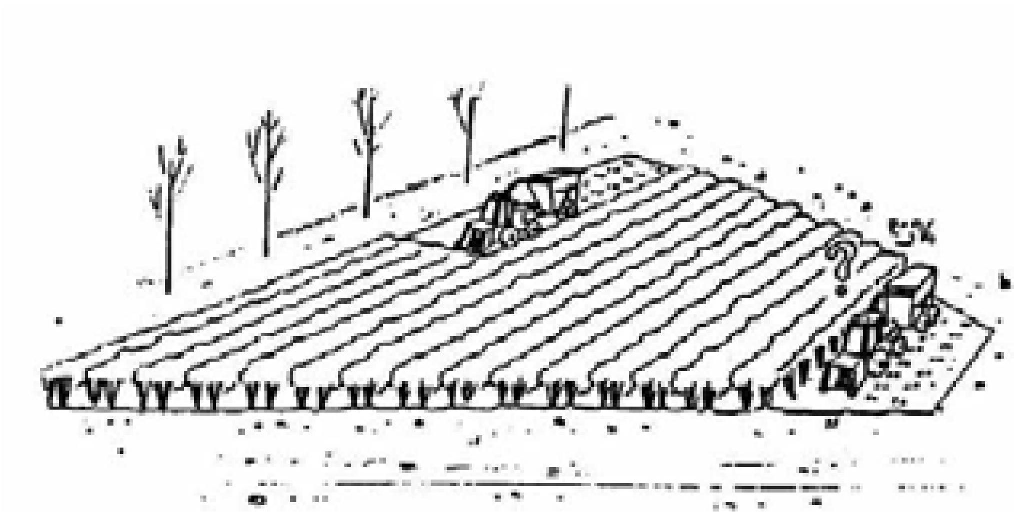

Figure 18. Short rows reduce harvester productivity demanding more time for turning.

Very short rotations require a short spacing along the rows, in the order of 45-80 cm. Of course, much depends on tree development. If the stems are expected to reach a considerable height before harvesting, then spacing must be increased - especially if they are harvested with a cut-and-chip machine. Most such machines need to lay the tree horizontal after cutting, in order to feed it to the comminuting device. If trees are taller than 5-6 m and/or thick and branchy, a narrow spacing increases the risk of them getting stuck to the trees ahead, still to be cut resulting in machine blockage.

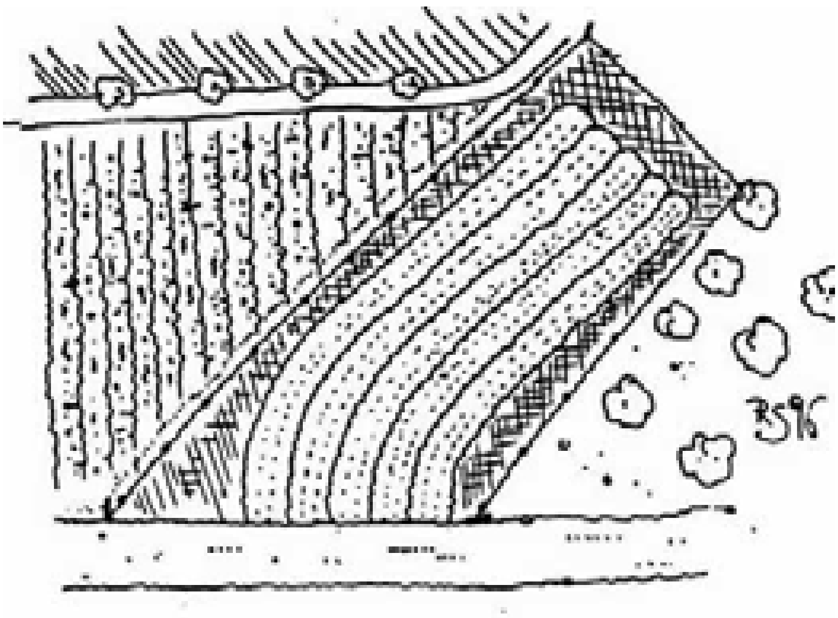


Figure 19. The tree rows should bend to enter the road/headland perpendicularly

## Harvesting of "Fiber Farms"

"Fiber farms" fill the gap between Short Rotation Coppice grown for energy production and traditional poplar plantations geared to yield a mix of wood products. Fiber farms are specifically designed to produce quality fiber for pulp and board manufacturing. For this reason, trees are planted thicker than in traditional timber plantations, and thinner than in the new SRC stands. Similarly, the rotation is intermediate between the 2-3 and the 10-14 years. Fiber farms are often established with poplar and are harvested at 5-8 years intervals according to the mean annual increment and the target assortments. Poles or cuttings are planted in single rows, with a spacing of 3 m between the rows and 2 – 2.5 m along the rows (1,300-1,700 trees/ha). Stem diameter at harvest can reach 15 cm at breast height. Regeneration is generally based on the planting of new trees after terminating the old stools, generally using a newer clone. This system is applied mainly in the Americas where such plantations are grown for producing fiber, eventually in association with a mix of secondary products, such as and energy biomass. Fiber farms are particularly popular in the Columbia Basin (NE Oregon and Washington – USA), where some large wood industries have established over 10,000 ha of cottonwood Fiber Farms. Similar solutions are increasingly applied in other countries, such as Italy, where an increasing share of the new short-rotation poplar plantations are being designed for medium rotation. Very often, these crops are grown for multiple purposes, and biomass production is only one of the goals growers aim at achieving.

This crop is easy to harvest, as it offers the advantages of flat terrain, even stand structure and total crop removal on clearcut blocks: that opens a whole range of harvesting options to explore and develop. Standard forest technology can be adapted to the harvesting of Fiber Farms. Of course, stem size is small compared to the capacity of standard forest machinery, so that specific solutions must be adopted. In the US, where plantations cover great continuous areas, harvesting efficiency is improved by multiple trees handling solutions (bunching); in Italy, where plantations have small area and are scattered over the landscape, light and highly movable units are recommended. Generally speaking, an oversized harvesting system is a great advantage for farmers: in fact, when the harvest age is reached they can decide either to harvest or not according to market conditions. If price is low the plantation will act as a growing stock and can be harvested with a delay of few years. Harvesting productivity will only improve with an increment of tree size. On the contrary, SRC growers are forced to harvest at the established age or the modified foragers will be unable to handle the larger trees.

## *Harvesting systems in North America*

In US plantations, where most of the current experience has been obtained so far, two main harvesting systems are used:

Peripheral Landing System. This system hinges around individual landings obtained at the edge of each harvest block (each farm consisting of a number of different harvest blocks). It has been in use since the very beginning of harvesting in these plantations and it is still extremely popular today, due to its simplicity. Trees are felled and bunched with an excavator-based shear that treats four-row swaths (Photos 49 and 50). Bunches are then collected by a heavy front-end loader (Photo 51) and forwarded to a delimber-debarker-chipper (DDC) parked at the roadside, on the field's edge (Photo 52). The front-end loader reaches 300 m from the chippers: when forwarding distance exceeds this value the chipper is relocated. Clean chips are blown directly into 15-16 m long chip vans. A second, smaller front-end loader works around the DDC, removing and piling debris. Due to its simplicity and inherent efficiency, this system constitutes the baseline of any comparison.

Photo 49. As an alternative to the excavator, a dedicated prime mover can be used. The shown model harvests the trees and collects them in the rear clam bunk.

Photo 50. When the load is complete the feller moves by the side and leaves the bunch of trees ready for forwarding.

Photo 51. A powerful front-end loader transports the bunch of whole trees to the landing.

Photo 52. At the landing the mobile Delimber-Debarker-Chipper loads directly the trailers.

Central Landing System. This system is totally different and hinges around one single landing, placed at the very center of the farm. This central yard is equipped with semi-permanent structures that should help reduce losses, simplify transportation and make handling easier. This system is considered preferable when longer rotations are harvested, as the centralized landing can be best equipped for separating multiple assortments.

Trees are felled and bunched with a high-speed disc saw mounted on an dedicated prime mover (Photo 53). The choice of a circular saw instead of a shear depends on the need to avoid compression damage to the butt logs that may debase timber assortments. On the contrary, shears cause compression damage and are only suitable when no timber is produced (shorter rotation). A large forwarder picks up the trees and loads them on a shop-made trailer, connected to the forwarder frame by a fifth-wheel assembly. When full, the trailer is hauled by the forwarder to roadside and transferred to a reconditioned truck for transportation to the central yard (Photos 54 and 55). The total distance covered is around 200 m for the forwarder and over 5 km for the truck. At the central yard, trees are unloaded with a log stacker and piled. Larger trees are separated during forwarding and loaded on designated trailers. These are also unloaded with the log stacker, but are taken to a processor for the separation of timber. Hence, the landing will contain three separate stacks: one for the sawlogs obtained with the processor, one for the tops resulting from the processing and one for the smaller trees, from which no timber can be obtained. From here, a medium-size front-end loader moves the smaller trees and the tops to the DDC and collects the flail debris. The DDC blows the chips into a pair of hoppers, containing approximately 1.5 chip van loads each. When trucks arrive, they are loaded via conveyer belts from the hoppers. The hoppers act as buffers and minimize interactive delays between the chipper and trucks: this approach has proven successful elsewhere under similar conditions. In addition, loading from the hoppers is much faster than directly from the chipper, which results in shorter turn times and may allow downsizing the truck fleet. Finally, trucks do not need to leave the paved road to reach the chipper, since the processing yard is located on the main road to the plantation. This reduces travel times, fuel consumption and trucks wear.

Photo 53. At the roadside the full trailers are transferred to trucks for road transportation to the central landing.

Photo 54. For this use simple reconditioned trucks are an excellent choice.

Both systems can produce in excess of 400 green tonnes per day and return delivered cost varying from $15-30 per green tonne. Transportation is a major item: depending on distance, it may represent 30-70% of total delivered cost. The central yard option is more complex and has a 20% higher stump-to-truck cost, but this is more than offset by substantial savings on transportation, and by the higher profit of better value recovery.

Photo 55. Felling is done with high speed disk saw mounted on a dedicated prime mover. In this case it also tows the trailer for whole trees.

Both systems generate a considerable amount of debris, approximately three loads for every 10 loads of clean chips. The debris is generally refined with a tub grinder and used as hog fuel or compost. The management of debris constitutes a critical point and is one of the key reasons why cut-to-length harvesting is not popular on fiber farms: if CTL harvesters would be used in the field, scattered debris should be then collected and removed before replanting. On the contrary, whole-tree harvesting allows removing all the material in one pass.

## *Other experiences*

In few other countries medium rotation poplar plantations and harvesting systems are still in a test stage. Normally, trees are felled and bunched with a machine and then either chipped in the stand or forwarded to the field edge and chipped there. In the former case, the chipper moves through the stand and the chips are blown into tractor-and-trailer units for transporting to a collection site, where they are loaded on trucks. In the latter, tree bunches are forwarded to the roadside with a grapple skidder or a front-end loader, and once there, they are chipped with a heavy chipper that directly fills the trucks parked by its side.

In recent years, Italian operators have tested a few alternative harvesting methods, all based on in-stand chipping.

<u>Whole-tree harvesting</u>. Felling is performed with a mini feller-buncher, obtained by equipping a skid-steer loader with a high-speed circular saw and buncher arms (Photo 56). Such machine can cut and bunch two trees per cycle, laying six rows of trees on a single wind-row. Windrowed trees are then fed to a terrain chipper by a self-propelled loader. Chips are blown into silage trailers and forwarded to a landing for loading onto chipvans. This system is efficient and cheap. A particular advantage is the use of low-investment, highly-mobile units. A light truck can quickly load the skid-steer loader and the saw, covering in short time many small plantations scattered over the landscape. Self-propelled loaders are road-legal and can cover short distances on their own wheels. The high relocation cost of bigger machines can easily exceed the profit of harvesting small plots.

Photo 56. A mini feller buncher can handle up to two whole trees per work cycle.

CTL harvesting. This system relies on an excavator-base harvester that can efficiently fell the trees and separate logs from tops (Photo 57). Logs are then forwarded to the roadside with tractor-trailer units, while tops are chipped in the stand as in the previous system. The advantage of CTL harvesting consists of allowing the separate sale of logs as quality product (either biomass or fiber), which can obtain a better price. Furthermore, logs are easier to store than chips, and can be used to build fuel storages.

Photo 57. An excavator based harvester can harvest and process the trees accumulating tops and logs in different heaps or rows.

Current experience indicates a total delivered cost between 19 and 21 €/green ton, leaving some profit margins. There is still much room for improvement, and in the future we may expect better results. In particular, one needs to explore the benefits of roadside chipping and the potential of integrated production, strategies that the US experience showed to be capable of good profit margins.

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