Original scientific paper

Survival Test of RFID UHF Tags in Timber Harvesting Operations

Gianni Picchi, Martin Kühmaier, Juan de Dios Diaz Marques

Abstract

Traceability of wood products is more and more relying on high technology systems. Among them the Radio-Frequency IDentification with Ultra High Frequency (RFID UHF) tags are probably the most flexible and promising tools. Several studies address their use in timber logistics, but the possibility to mark standing trees and maintain intact the information along a whole-tree extraction system is still not explored. Under this perspective one of the main challenges is the capacity of UHF RFID tags to survive the harsh conditions of timber harvesting. Different tag models and different placement positions on the tree may lead to diverse ratio of tags arriving intact up to the landing. Particularly extracting operations may play a major role in damaging or removing the tags from the trees. In the present study, two tag models and two fixing modalities were compared during three commercial hauling and one transport operation in mountain conditions. Over a total of 239 tracked tags, just 5 were lost, proving a good reliability for this traceability system. This preliminary result will serve for addressing the electronic tree/log marking method in the frame of the project SLOPE, co-funded by the EC.

Keywords: RFID UHF, tree marking, hauling, survival test, cable yarder

1. Introduction

In the near future, the productivity and profitability of forest timber supply chains are expected to increase rapidly by implementing the tools and methods of precision forestry (Holopainen et al. 2014). This trend is also expected in mountain forestry, where forest operations are mainly based on cable yarding systems, but the relatively low degree of mechanization of these systems represents a potential constraint to the application of high precision technologies (Cavalli 2012). This specific challenge is addressed by the project SLOPE, co-funded by the EC, with the goal to set up an integrated and innovative timber supply chain in mountain areas. In the planned work flow, different digital data sources, such as aerial sensors and terrestrial laser scanners (LiDAR), are used for the acquisition of georeferenced 3D data on the standing trees. This is elaborated with dedicated software returning the optimal tree bucking suggestions (Dassot et al. 2011, Murphy 2008), which are used by the processor for maximizing the value of the extracted timber according to the market demand. The transmission of such data requires a traceability system that relates the digital information generated for the single standing tree to the actual item being harvested and transmits this data to the forest machines, making available in real time the bucking instructions for each tree. The same traceability architecture can be used to assign an ID to each log produced and link this to all the available information (measures, quality). For this purpose several solutions have been used for actual marking of trees and logs in forest operations or timber logistics, such as color marking, barcodes, QR codes and Radio-Frequency IDentification technology (RFID) (Tzoulis and Andreopoulou 2013). The latter has a wide range of applications in the field of logistics, livestock and warehouse management among others (Ferrer et al. 2010, Zhu et al. 2012) and seems to be the most promising tool for supply chain management, particularly for the capacity to be red at considerable distances: Ultra High Frequency (UHF) RFID, operating at a frequency of 868 MHz, can be detected at distances of over 10 m in optimal conditions. According to the EPC standard, RFID tags have an internal memory that allows a content of 96 bits (EPC Class 1), included in a string of 14 characters, providing a unique ID to each tag. Such information can be used for automatically tagging an item (log or tree) in a database.

In forestry applications, RFID technology has been mostly tested for control and optimization of timber logistics (Korten and Kaul 2008). Another application area is the traceability of timber throughout the whole supply chain, where the use of RFID for log marking may increase the degree of automation of the log inventory, reduce the need for repeated measurements of the timber and increase the overall efficiency, with evident economic benefits (Hakli et al. 2010). Nevertheless, the potential of electronic marking of trees may be extended beyond the traceability of goods, which could be coupled with other contents aiming at the optimization of the forest operations.

The tests performed so far with UHF RFID tags in timber logistics prove that this technology is reliable, and that, in the appropriate conditions, tags may be read even at relatively long distances (2–4 meters). Kaul (2010) tested the performance of several RFID tag models both in bulk reading (e.g. a full truckload of tagged logs) and single items identification. With the appropriate selection of RFID tag model and reader/antenna layout, bulk reading can return 92% of read rates at mill gate entrance, while single log identification in optimal conditions (e.g. at the belt conveyor of the sawmill) provided 100% of read rate.

Björk (2011) claims that an economic benefit can be detected along the supply chain even with partial tagging of the whole load of logs, which still allows for a certain degree of traceability of the loads. This would also make less critical the impact of a low automated read rate and/or a low physical survival rate. Nevertheless, the full potential of RFID marking, particularly when used for transmitting instructions, can be expressed only if the reliability of the system is high. This is related to the read rate, but mainly to the capacity of RFID tags to survive all along the production process maintaining intact its operational capacity. In this sense, forest operations are a very challenging environment. In the case of cable yarding operations, the frequent shocks, frictions and impacts of the extracted material against ground, standing or felled trees and piled timber make it reasonable to expect that part of the applied RFID tags could be lost or destroyed in the phases of bunching, extraction and landing of the marked whole trees and the subsequent logistics operations of logs.

Fig. 1 depicts the application planned, where UHF RFID tags are first placed at breast height on standing trees by the forester during the marking phase (1). Only trees to be felled are marked and related to the digital forest database previously generated by LiDAR technology. The chainsaw operator in charge of felling the test site will be equipped with a light RFID reader connected via Bluetooth to the service smartphone (always carried for security reasons) and before felling the tree will read the tag on it (2). This will allow him to relate the felled tree, and the corresponding ID, to a new tag, to be placed on the cross section surface (the butt of the felled tree). This position is considered as optimal for the designed supply chain, in fact it is more protected against friction during skidding operations than the tangential surface (on the bark) and leads to an optimal reading angle (perpendicular) with antennas placed on the cable yarder carriage and on the processor head. By reading the RFID tag of the tree, this latter machine will gather in real time the cutting instructions from the digital forest database (3), guaranteeing a precise and fast bucking operation, and maximizing the value of timber assortments. Finally, the processor designed in the frame of the project will apply a new UHF RFID tag to each log produced (4), linking the ID to a new database featuring the measured dimensions (diameters and length) and the commercial quality class assessed with dedicated sensors (Sandak 2015). Timber would now be ready to make part of a dedicated management system, where the application of RFID tags may lead to cost reductions estimated in the range of 70% compared to the current systems of industrial wood procurement (Björk et al. 2011).

The actual capacity of UHF RFID tags to endure these conditions is still unexplored, particularly for the phases of concentration and hauling of trees in the forest. The aim of this study was to evaluate the performance of two tag models and two fixing options thorough the timber supply chain in steep terrain during cable yarding and logistic operations. The study also aimed at identifying the most critical stand or operational parameters that could have an influence on the survival rate of the applied tags (e.g. diameter or length of the extracted piece; distance of concentration; etc.) and possible mitigation actions for reducing its negative impact on the reliability of information flow and traceability system.

2. Material and Methods

2.1 RFID tags used

The basic structure of RFID tags is the transponder, a metallic element built in different shapes, according to the purpose and the manufacturer, and the integrated circuit. These elements are fixed on a simple

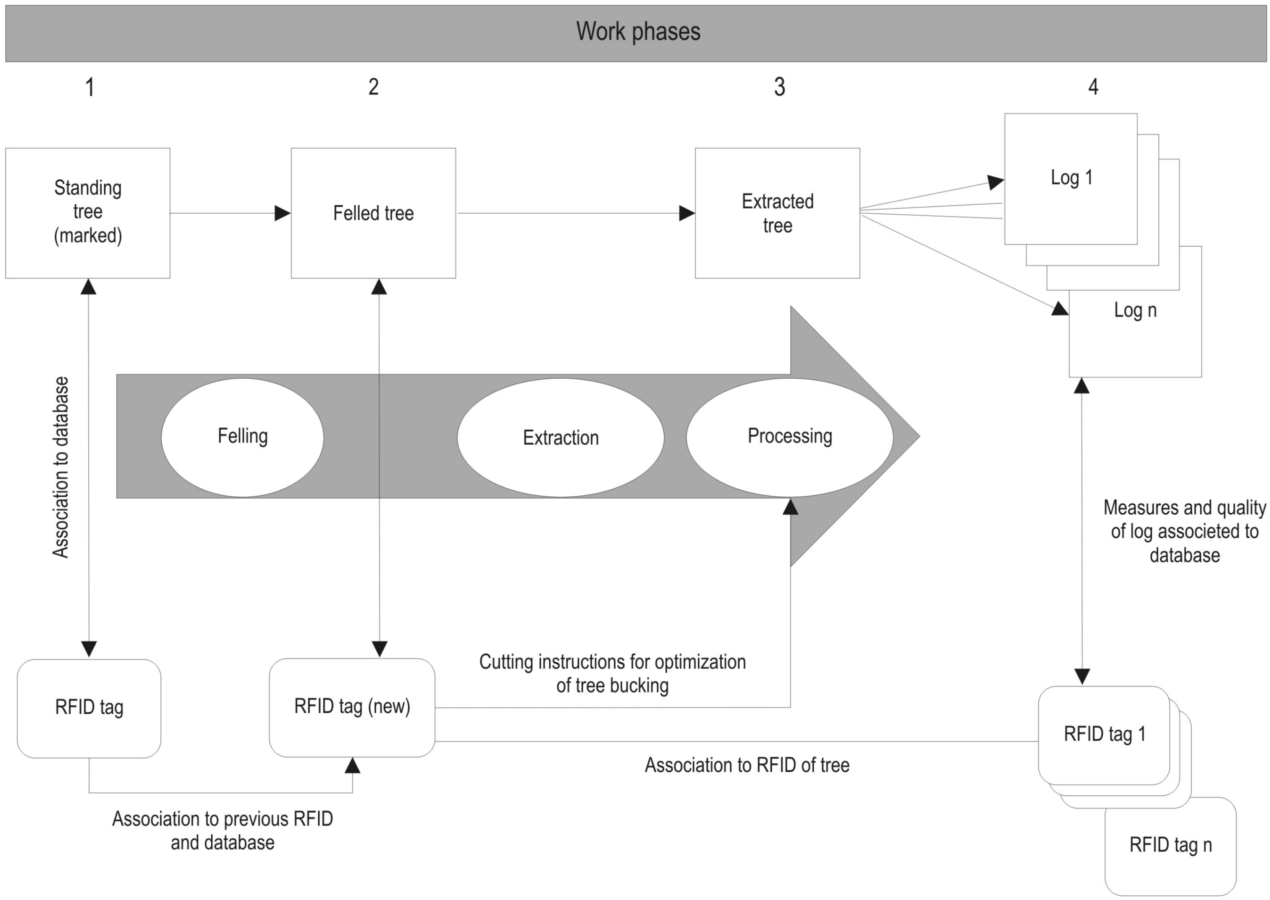

Fig. 1 Schematic representation of the timber supply chain process with RFID tag based transmission of information

plastic tape structure (possibly with one adhesive surface for application), or protected and supported with different type of cases, according to the final application. Clearly, the complexity of the final RFID structure is reflected in the size and the unitary cost.

In a previous screening phase, a large number of commercial UHF RFID tag models had been compared in order to identify the most suitable types for the specific purposes of the project, and in general for tree and log marking. A selection of 10 tag models had been tested in standing tree and marking operations, gathering the opinions and suggestions of expert professionals. Finally, two models were selected for the actual survival test over the whole production process (Table 1):

⇒ Wintag Flexytag UHF D7040S. This tag model was selected because it was considered particularly suitable for the forest environment. In fact it was originally designed for laundry uses, with a waterproof polyurethane cover (IP68) designed for maintaining the operative capacity at temperatures ranging from –40°C to 80°C as well as resistant to UV, acids and salt solutions. This tag model was available just in a limited number (n.=31), thus it was only used in a part of the survival tests;

⇒ Smartrac Shortdipole Monza 5. A logistic dedicated model with long reading range. This is a very simple tag model basically constituted by the transponder and the relative die cut applied in plastic colored stickers provided in reels. In

Table 1 Main characteristics of the RFID tags tested

RFID tag model	Trasponder size, mm	Overall size, including plastic cover, mm	Reading range in laboratory conditions with high power readers (2 W), m	Average unitary weight, g
Wintag Flexytag UHF D7040S	47x13	64x45	2–3	4.9
Smartrac Shortdipole Monza 5	93x11	120x25	10	1.1

order to make it suitable for the purposes of timber traceability this model was modified by applying a PET EVA plastic cover with thermal treatment (110 °C).

The selected UHF RFID tags are designed for being manually fixed on the trees or logs by means of a common mechanical stapler deploying 6 mm long aluminum staples. This system was chosen for its simplicity, cost effectiveness and the negligible effect of the aluminum staples in case of impact with the sharp tools at the sawmill. Furthermore, the selected tags have very low unitary weight, an important aspect considering that at the sawmill the tags are discarded together with the external parts of the log, which enters the stream of industrial residual wood. This raw material is commonly used for pulp or energy production, and in both cases the share of impurities (plastic and metal of the tags) should be reduced to a minimum if this system is to be accepted by end users.

The second treatment was the method of RFID tag fixing on the logs:

⇒ A double stapling was regarded as the standard solution, being theoretically more reliable, given the double grip of the staples on the wood and the tags and the total adherence of the tag on the log surface, reducing the risk of being caught and ripped by branches and slash;

⇒ Single stapling was compared because it presents two potential advantages:

  ✓ stapling the tag on a single spot, instead of two, simplifies greatly the application of the RFID tag on the log, particularly when this is automation system for tag placing on a prototype timber processor head,

  ✓ apparently the preliminary tests conducted in more controlled conditions (timber yard) suggest that, by not adhering completely to the wood surface, the tag becomes more readable because the antenna results are less exposed to the loss due to the dielectric constant of wood (Ghahfarokhi et al. 2011). In this sense, it should be taken into consideration that, by adopting this solution, it will not be possible to fully control the reading angle in the following automatic operations, thus a circular antenna and direction insensitive transponders are to be used if this solution is preferred.

The combination of RFID tag model and fixing system resulted in three treatments: Wintag RFID tag with double stapling (DW), Shortdipole RFID tag with double stapling (DS) and single stapling (SS). Due to the limited number of Wintag RFIDs available, these were not tested with the single staple (Fig. 2–3).

Fig. 2 Marking method with Wintag RFID and double stapling (DW)

Fig. 3 Marking method with Shortdipole RFID and single stapling (SS), note the uplifted position

Electronic reading was performed by means of a hand held UHF RFID reader CAEN qID 1240 with in-built double perpendicular antennas. The reader was interfaced via Bluetooth to a mobile phone, returning the ID of identified tags, and the average number of tags red per second. Power settings were adjusted to low level (140 mW) for avoiding the risk of multiple tags return signal. In case of difficult access to the log pile, it could be set to maximum power (500 mW), allowing in the better cases a reading distance of about 80–60 cm in operative environment. The same reader was used in laboratory for testing the tags to be used prior to the field study.

In the forest, the trees and logs were measured and marked before extraction. A progressive number was assigned to each tree and log painted with forest spray

Table 2 Parameters collected in the forest prior and during cable yarder operations

Measured parameters	Description
Tree/log parameters	
Maximum diameter, cm	Tags were applied at the butt of the felled tree or at the main diameter side of logs and the corresponding diameter measured. If this was not accessible, measurement and tag application were performed on the minor diameter side
Length, m	Measured or estimated
Species, descriptor	The tree species were noted
Type of section descriptor	Log (processed) Top (with branches) Whole tree
Load parameters	
Choker position descriptor	Top of the tree or minor diameter of the log/tree section Butt of the tree or main diameter of the log/tree section
Hauling distance, m	Distance travelled by the carriage loaded
Concentration distance, m	Distance from the original position to the vertical of the carriage
Type of load descriptor	Single item per load Multiple item per load (two or more trees, sections or logs)
Electronic marking parameters	
Tag type descriptor	DW, Flexytag fixed with two staples DS, Shortdipole fixed with two staples SS, Shortdipole fixed with one staple

color and a RFID tag was applied. Tag model and application type was varied randomly. During extraction, a further set of parameters were recorded, describing each single load (Table 2). Notes were taken for any particular event, such as impact of the tagged area against standing trees or friction with slash and ground.

Such descriptive and numerical parameters were considered as the most representative for a following factorial analysis of the results.

2.2 Cable yarder extraction

The capacity to endure the operations of lateral yarding and extraction of RFID tags was tested in three commercial cable yarding operations in the Italian Apennines (Table 3). In a properly planned and conducted cable crane extraction, the trees are felled in a direction almost opposite to the position of the cable line, with an angle facilitating the extraction of trees. In this layout, the operator fixes the tree or the tree sections by applying the chokers to the butt of the plant. This position reduces the effort for the cable crane to concentrate by skidding or partial skidding the tree close to the line, where it is finally lifted and transported along the corridor. This work condition minimizes the damage to the remaining trees (Marchi et al. 2014) and, given the reduced impacts, should also be the less dangerous for the RFID tags survival.

All the hauling operations studied were performed in conifer dominated stands, but differed for a number of details, among which the dominant was related to species. In all cases the conditions were particularly challenging compared to a common operation, and a high number of factors affecting the reliability of the tagging system could be evaluated, while in case of high rate of survival, the robustness of the system could have been confirmed:

Site 1: was a mixed forest dominated by fir (*Abies alba* Mill.) with occasional Austrian Pine (*Pinus nigra* Arnold) and broadleaves (beech, chestnut, maple, cherry). The silvicultural work was partially an emergency operation due to storm damage on an already planned selective cut, with the dominant layer of conifers (broadleaves were processed and extracted only in case of damage). Most of the trees were felled over two months before the extraction operations, which were postponed for weather conditions (snow). The terrain presented a regular profile and slope. All the activities were performed by a crew

Table 3 Main characteristics of the cable yarding lines studied during the tests

	Site 1	Site 2	Site 3
Area	Firenzuola (Firenze)	Montepiano (Prato)	Firenzuola (Firenze)
Altitude above sea level, m	953	843	1079
Coordinates of the cable yarder tower	N44 06.719 E11 16.721	N44 05.830 E11 09.572	N44 08.887 E11 19.353
Average slope, %	35–45	30–40	40–50
Average mainline height, m	12	6-8	14
Direction of extraction	Uphill	Uphill	Downhill
Average extraction distance, m	185	235	215
Average concentration length, m	12.3	15.4	12.6
Average log/tree diameter, cm	41	37	42
Minimum log/tree diameter, cm	27	22	20
Maximum log/tree diameter, cm	56	57	80

Fig. 4 Landing of cable yarder with limited operational size. In such conditions post extraction handling may cause further impacts on the tagged surfaces

experienced in forest harvesting and cable yarder extraction (also operating in site 3).

The unloading area was limited, posing a further challenge to tag survival, since the probability of collision among trees unloaded or handled and the piled timber is higher (Fig. 4). This also led to a more complicate control of RFID tags survival with the handheld reader. For this reason, it was not possible to check electronically all of the trees, even if the tag and the tree number was visible. In these cases, the presence of the tag, the apparent condition (damaged or not) and the relative tree number were recorded. Clearly, this issue would not occur if forest machines equipped with RFID readers will be used, since each tree would be grabbed and read individually.

Fig. 5 Cable yarder concentration in a storm damaged forest is very challenging for the survival of tags due to the abundance of debris, deadwood and uprooted stumps, which could rip or damage the transponder (the white arrow indicates the position of the RFID tag on the log)

Site 2: was a pine dominated site (*Pinus nigra* Arnold) of a final regeneration cut for facilitating the natural renovation of broadleaves. Very few standards were left, reducing the interference with the concentration of trees. This area was not affected by storm damage. The terrain profile had an unfavorable convex slope, which led to a low average height of the skyline in spite of the three intermediate supports installed. The crew was composed of professional chainsaw operators, but inexperienced in the use of cable yarders for timber extraction. For this reason, most of the loads were skidded for almost 50% of the distance, with logs completely lying on the ground, in conditions very similar to winch extraction. In several occasions, the butt of the tree impacted against standing trees, protruding stones, already processed logs and the abundant slash left on the ground.

Site 3: The site was dominated by fir (*Abies alba* Mill.) with occasional beech. The whole area had been affected by a wind storm, which damaged over 50% of the original standing trees (completely uprooted to partially damaged by the fall of other trees), and the forestry activity can be described as an emergency intervention. Terrain profile was quite irregular, with two changes of convexity/concavity over stretches. In such conditions, trees were hooked to the chokers either at the butt or the top, according to their position and the easiest solution for untangling trunks and crowns. This made the lateral yarding quite difficult, with frequent scratching against standing and lying trees (Fig. 5). For the same reason, the specific work conditions of this forest operation were considered as challenging for the survival of tags, which were exposed to additional frictions and shocks compared to a properly planned extraction.

2.3 Intermediate Transport of logs by tractor

In timber logistics, the most critical conditions for the survival of RFID tags are expected to occur during log handling, mainly represented by loading and unloading operations. The endurance of tags to these activities was observed in a single commercial operation at the previously mentioned site 1, where timber was transported from the landing area of the cable yarder to an intermediate storage area over a distance of approximately 300 meters on a steep downhill forest road. The tractor towed a small single axe forest trailer, with tilting unloading system, which was loaded at the cable yarder landing by the processor in grapple mode. Before loading, the dimensions of each log were measured by the crew, involving additional handling.

On the timber piled at the landing, RFID tags were applied on the log side facing the road, while loading

Fig. 6 Unloading was performed by tilting the trailer against already piled logs, causing further impacts potentially lethal for the tags

on the trailer was made in order to optimize and make stable the load, thus the tagged sides were randomly distributed in front and on the back of the trailer. At the storage area, logs were unloaded by tilting the trailer and sliding the load against the timber piles. Also in this case, the work conditions were particularly challenging for the survival of tags (Fig. 6).

In this test, only DS and SS tagging systems were used. Not all of the logs in the pile were marked, either because below the diameter of 24 cm, set as minimum threshold, or because not safely accessible.

Logs with a diameter lower than 24 cm were not considered for the study (not tagged) but counted on the load since their presence could be one of the factors influencing the survival of tags on the marked logs. In the study, 7 round trips of the tractor followed, transporting a total of 198 logs, of which 86 carried a UHF RFID tag.

3. Results

3.1 Extraction operations

The general performance of RFID tags along the extraction process of trees or logs was positive (Table 4). Overall 5 RIFD tags were lost during the extraction of 153 marked items, resulting in a mortality of 3.3%. None of the tags arrived at the landing had been made inoperative, even when the whole of the hosting crosscut area presented evidences of shocks, abrasion or impacts. In some cases, the tag was not visible for the adherence of mud or soil on the crosscut section, but still it was possible to detect it with the dedicated reader. A partial removal was observed for 2 DS tags, i.e. one of the stapling areas was ripped, while the other still kept the tag more or less firmly. In any case, these tags were successfully read at the landing, and thus accounted within the survived. Given these proofs of resistance, the 6 RFID tags that could be checked only visually by the operator, and presented no signs of damage, were added to the total of success-

Table 4 Results of the reading test at landing (cable yarding) and at the storage area (tractor transport)

Cable yarding	RFID tag type	Marked	Electronic/visual control			Just visual control[1]	
			Operative	Removed	Destroyed	Not damaged	Not visible
Site 1	SS	19	16	0	0	3	–
	DS	23	20	0	0	3	–
Site 2	DW	16	16	0	0	–	–
	SS	19	19	0	0	–	–
	DS	18	18	0	0	–	–
Site 3	DW	15	14	1	0	–	–
	SS	23	21	2	0	–	–
	DS	20	18	2	0	–	–
TOTAL		153	142	5	0	6	–
Tractor transport	SS	44	32	0	0	8	4
	DS	42	31	0	0	8	3
TOTAL		86	63	0	0	16	7

fully landed tags. It should be emphasized here that in the work system envisaged, each RFID tag will be read automatically by the processor when grabbing single trees, thus averting the case of tags out of reach. In any case, even if the tags out of reach for manual reading are excluded from the analysis, the mortality rate increases just to 4.3%.

Due to the very low number of lost tags, it is not possible to perform a statistical analysis of the results against the recorded parameters. On the other hand, this is per se a result, proving the high reliability of the system.

3.2 Transport of logs

The results for the transport test have to be considered as preliminary for the relatively reduced number of logs. Nevertheless, due to particularly harsh conditions, the results can be regarded as particularly encouraging. In fact, over the fully verified tags (visually and electronically), none had suffered damage or was removed. A part of the tags was visible under the pile, but not reachable by means of the RFID reader. Two tags had visibly suffered an impact during unloading. Electronic check (by means of the RFID reader) was possible just for one of these (single stapling), which resulted unharmed and perfectly operating. It is thus reasonable to add the tags (visually identified) among the survived tags, since during all of the trials the event of a tag still attached but made inoperative by shocks never occurred, and it can be considered as extremely unlikely in tags that do not even show sign of impacts or scratches. In any case, even considering this last tag as destroyed, the overall survival rate would be above 98%.

4. Discussion

4.1 Extraction operations

Considering the factors evaluated and the direct observations of the operators, it is possible to identify the main cause of tag removal: the position of choker with respect to the crosscut section, where the RFID tag is applied. Of the 5 missing tags, 4 were placed on the side opposite to the choker position. Furthermore, all of the missing tags were lost in site 3, the most affected by storm damage. This forced the operators to set the chokers at the most accessible position, rather than the most appropriate for the cable yarding extraction itself. As a result, over 31% of logs/trees were hooked from the top or minor diameter end, opposite to the RFID tag position. However, this factor alone cannot explain the tag removal since in sites 1 and 2 the hooking position opposite to tag placing occurred in 19 and 17% of cases, respectively. When the tags are lost, the choker setting position appears to combine with other factors, the main being the specific layout of the cable line. In fact, the extraction in Site 3 was performed in downhill direction, and the combination of skyline height and terrain profile caused the hanging trees/logs to brush violently and repeatedly against the ground with the crosscut surface hosting the RFID tags. This happened mostly at the landing, but also occurred in other spots, according to the length of the extracted trees/logs. This combination of factors (loads hooked from the minor diameter or the crown and a convex unloading area) can be regarded as quite unusual and particularly unfavorable to RFID survival. Nevertheless, the survival rate for this specific site was still above 90%, confirming the reliability of the tag marking system.

The RFID tag model and the method of application seem to have no influence on the final survival rate. In fact 2, 2 and 1 were lost, respectively, of the types DW, SS and DS. In this scenario, the method SS, representing the simplest UHF RFID tags and the fastest application system, should be preferred.

4.2 Transport of logs

The test suggests that no difference can be found in single or double stapling fixing of the tags, thus the first should be preferred. This result is particularly encouraging for the development of an automated RFID tag application system to be installed on the timber processor. In fact, the possibility to fix the tag with just a single staple simplifies greatly the design of the machine.

By observing the operations, the loading phase does not appear to be a dangerous operation for the tag survival in the specific tested position, even if accidents, such as impact against other logs or the trailer posts, do occasionally happen. On the contrary, in the given case unloading seems to be a particularly challenging operation, since logs are landed by tilting the trailer, thus sliding down the timber, which potentially hits the ground with the radial face or the pile of logs previously unloaded.

It is important to note that all along the logistics of logs, the position of the tagged extreme cannot be certain. The RFID tag is necessarily applied to one extreme of the log: during loading and unloading operations this extreme can be positioned on the loading cage of the trailer/forwarder/truck and on the pile in a casual position. As a result, the tags will be partly facing one side of the arrangement and partly the opposite side. This issue shall be taken into account when designing the following traceability systems for automatic detection of UHF RFID tags in the load, and particularly when planning the position of fixed antennas for bulk reading.

5. Conclusions

The results of the test are very positive. The overall survival rate of RFID tags in forest operations and timber logistics was close to 98%. Considering just the cable yarding operations, the survival rate decreased slightly to almost 97%. In the single cable yarding operation, where RFID tag casualties were recorded, the survival rate was 91%, while 100% of tags successfully arrived at the landing in the other two sites observed.

Tractor transportation and timber piling led to no detectable damage or losses to the RFID tags, nevertheless, due to the limits of the manual RFID reading system used for this test, 28% of the tags could be verified just visually, or the tagged area could not be found at all in the piled timber, leaving a degree of uncertainty. This would not happen in the fully mechanized reading system under development, since each tag would be automatically red during extraction and processing of the trees.

The study confirms that large RFID tag models, with longer read range, can be used without incurring a higher risk of information loss. Furthermore, a single stapling position is enough to assure a stable grip on the crosscut surface, simplifying the tagging operations in forest (manual) and in the subsequent automated processes.

It can be conclude that simple RFID tags fixed on the trees with common aluminum staples can be regarded as a reliable tool for tracing or transmitting information all along the extraction process of timber from the forest to the landing and from there to the end user. This system provides a powerful and relatively inexpensive device for control and optimization of forest operations and timber logistics and its applications should be further tested in different work conditions and extraction systems.

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Authors' address:

Gianni Picchi, PhD.*
e-mail: picchi@ivalsa.cnr.it
CNR-IVALSA
via Madonna del Piano 10
50019 Sesto Fiorentino
ITALY

Martin Kühmaier, PhD.*
e-mail: martin.kuehmaier@boku.ac.at
University of Natural Resources and Life Sciences, Vienna
Department of Forest and Soil Sciences
Institute of Forest Engineering
Peter Jordan Strasse 82
1190 Vienna
AUSTRIA

Juan de Dios Díaz Marqués, PhD.*
e-mail: juan.diaz@itene.com
ITENE - Instituto Tecnológico del Embalaje, Transporte y Logística
Area: Advanced Intelligent Systems
C/ Albert Einstein, 1
46980 Paterna, Valencia
SPAIN

* Corresponding author

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