

Verification of RFID System Usability in Silage Bale Life Cycle Management

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Abstract: Digitalization has nowadays raised interest in variable applications of farming. Increase of knowledge level, by means of unique identification, automation and control, farmers gain relevant business profit. This research is focused on the utilization of passive radio frequency identification (RFID) technology in silage bale application, both manual and automated level. Challenges arise due to silage conservation, varying environmental and seasonal conditions, different identification environments and RFID operation principle. Further maximum communication signal strength is limited by telecommunication standard regulations (e.g., ETSI). The applicability of RFID technology with different commercial passive transponders is measured manually in a silage bale of 160 cm in diameter, covering 360 degrees around the bale. In addition, automated field tests are conducted in a real environment, where the data collection system is appended to a tractor and RFID reader antenna in a baler. Manual measurements are conducted as identification distance (meters) and transponder population (number of tags), while automated measurements are based on the number of successfully identified silage bales. Based on the manual measurement results, the most suitable tags for the automated field measurements were chosen, and the applicability to silage bale identification was verified. Field tests showed 100% success, with 151/151 uniquely identified silage bales. Achieved results prove that passive RFID operates well enough in silage bale identification, further enabling the development of digitalization of silage bale life cycle.

Key words: Digibale, silage bale life-cycle management, radio frequency identification, digitalization of silage bale, unique identification.

1. Introduction

Digitalization and Internet of Things (IoT) have gained interest across all commercial sectors. Many potential applications have been introduced, but in most cases, commercial side and practical benefits have forgotten. This paper focuses on digitalization of silage bale life cycle, having its origins in business needs. Digitalization has foundations in unique identification, where passive radio frequency identification (RFID) technology was chosen as a potential identification methodology due to its wireless and non-line of sight operation principle. By integrating existing technologies and an application

software in a new fashion, a new concept and implementation of automated unique identification and tracking of silage bales, bale bookkeeping and open marketplace are created to modernize silage bale farming sector.

The first phase of this research project is to choose and verify unique identifiers, i.e., transponders for silage bale identification throughout bales' life cycle and define most appropriate system arrangements in a baler. This paper introduces the principles and results achieved in that research: first RFID operation principle in application is described, then passive transponders' performance is evaluated in stationary conditions, and finally automated field tests are described, evaluated and analyzed against the application needs.

Corresponding author: Katariina Penttilä, Ph.D., research fields: metrology, RFID, ecological technology, energy efficiency.

1.1 Silage Bales

In Finland, silage bales are conserved from fall until up to springtime, even to next fall sometimes. They are wrapped with bale net and further multiple plastic layers. Most of silage bales are stored in stacks on the edge of field or near cowshed without any special tag identification. Spray paint may be used for identifying the bales. These markings may be elapsd during the storage period, by making it impossible to track and identify bales, and combine them to the typically used manual bookkeeping. Bales are subjected to variable weather conditions as warm sunshine, cold, rain, snow and frost, repeating multiple times during storage. Further, birds or rodents can cause holes to plastic layers of silage bales. Therefore, the bale identifiers, now RFID transponders must be placed inside the bale wrappings. However, as silage bale conservation is based on lactic acid fermentation, with pH around four and dry matter variation between 20% and 45% [1], the challenge of radio wave propagation in such environment arises.

Typical silage bale size varies between 1,300 mm

and 1,600 mm in diameter. They are handled with pallet trucks in random orientation. Therefore, the ultimate target would be in achieving identification coverage of 360 degrees around the bale. This paper introduces the first steps to achieve this, by reviewing and analyzing passive RFID tag measurements in the silage bale application.

1.2 Digibale Concept

Digibale concept is a concept enabling unique bale identification, collecting microclimate information, analyzing bale related data, managing bale storages, and also selling and buying silage bales in open application platform. Fig. 1 presents the work packages (WPs) of Digibale project, launched for implementing the concept [2]. The following describes WPs shortly:

WP1: Background data collection, benchmarking and foundations

- to collect information about the life-cycle management of bales' lifecycle;
- seek information on which parameters are important for the target audience;

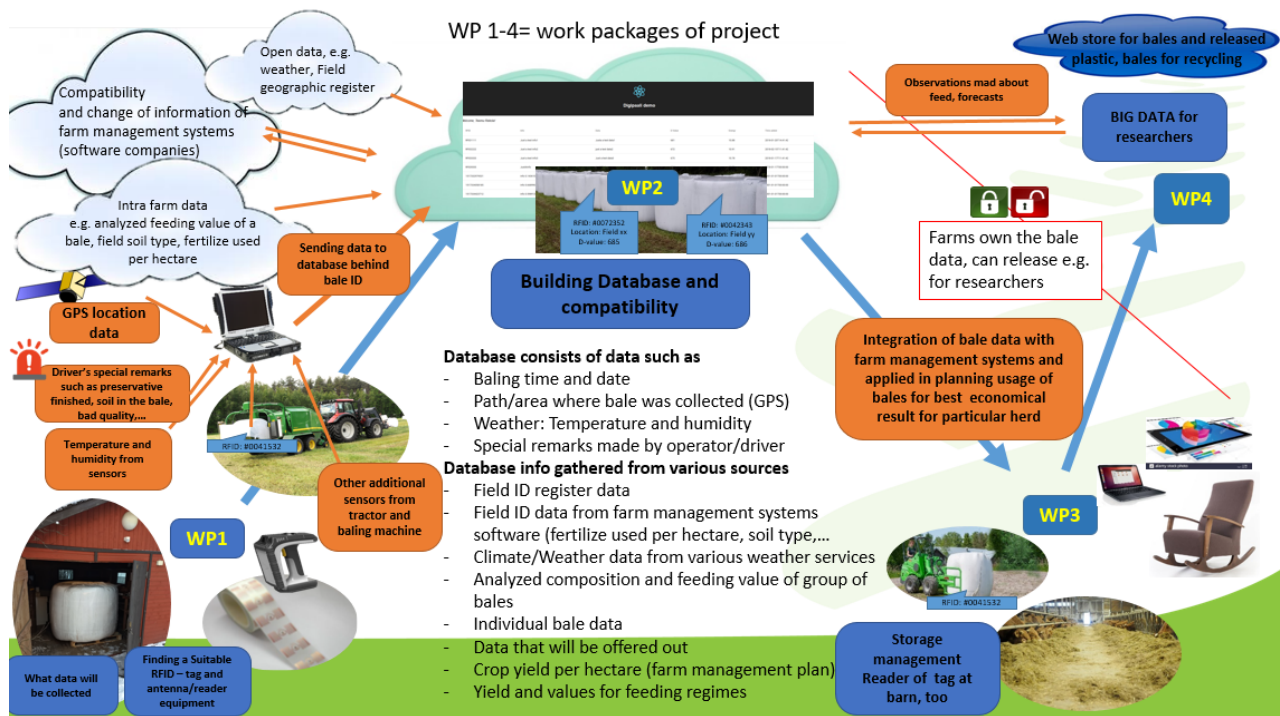


Fig. 1 Schema of Digibale concept [2].

- hardware and network connections: microclimate measurements, RFID reader and tags, database connection, supply in baler machine;

- initial acceptance testing.

WP2: Building database and compatibility

- develop the unique marking of bales;
- collect and export the status and location data to the database;

- field testing with baler machine.

WP3: Collection and use of data

- collect, analyze and combine binary identification, location and measurement data for internal and external;

- data sources;

- user interfaces for different purposes.

WP4: Business and service design

- web store;

- own data for farmers;

- big data for researchers.

This paper focuses on WP1, primarily RFID performance measurements.

1.3 Principle of RFID Technology

RFID technology is an identification technology that uses radio waves for communication. Typical operational frequencies are 865-868 MHz in Europe and 13.56 MHz globally [3]. The first one is based on electromagnetic waves, enabling long-range identification, while the latter is based on magnetic coupling, and operates only in near field. Some commonly known RFID applications are key cards, passports, library anti-theft systems, near field payment and metro tickets.

The operation principle of passive RFID is based on backscattering technology [4-6]. Passive technology means that the transponders do not have any kind of internal power source, but it harvests its operational energy from the reader's transmission signal [7, 8]. RFID reader, with external or integrated antenna, is connected to backend system and operates as master towards transponders. Based on application needs,

reader sends identifier polling request to its surroundings. Regional institutes, such as European Telecommunication Standards Institute (ETSI) limit the maximum allowed transmitted power level. Depending on the radiation pattern of the antenna, the reader's request will spread either a narrower or a wider area, while the total amount of radiated power shall be under specified limit. If any transponder exists inside the range, the reader transmission signal will first wake the tag up, then give the identifier reading command and finally send some unmodulated signal, which the transponder will modulate and reflect backwards [9-11]. The transponder modulation, which is fully passive, is based on switch connection inside transponder microchip. The modulation is on-off type amplitude modulation [7]. Communication principle is introduced in Fig. 2.

While magnetic coupling enables identification ranges up to around 1 m, ultra-high frequency (UHF) RFID at around 866.5 MHz enables identification distances up to around 10 m [12, 13]. These distances are maximum free air distances, meaning, that between the reader antenna and the transponder, there is only free air, without any obstacles. All absorbing materials, such as concrete wall structures, attenuate the radio signal and diminish the identification distance. In addition, the material, where the transponder is attached to, influences to the achievable identification distance. All absorbing or reflecting base materials will attenuate the communicating signal, and therefore diminish the identification distance. Absorption means that the material itself absorbs radio waves causing diminishing the maximum peak intensity [14, 15]. Reflecting occurs when the radio wave is reflected from the base surface, and then eloped away [16-19]. As in the application at hand, the transponder base has strong humidity level and large humidity variation, being between 20%-45% [1], the wrapped silage bale becomes conductive, sharing both absorbing and reflecting properties. Large humidity value leads to high conductivity [14, 15], further

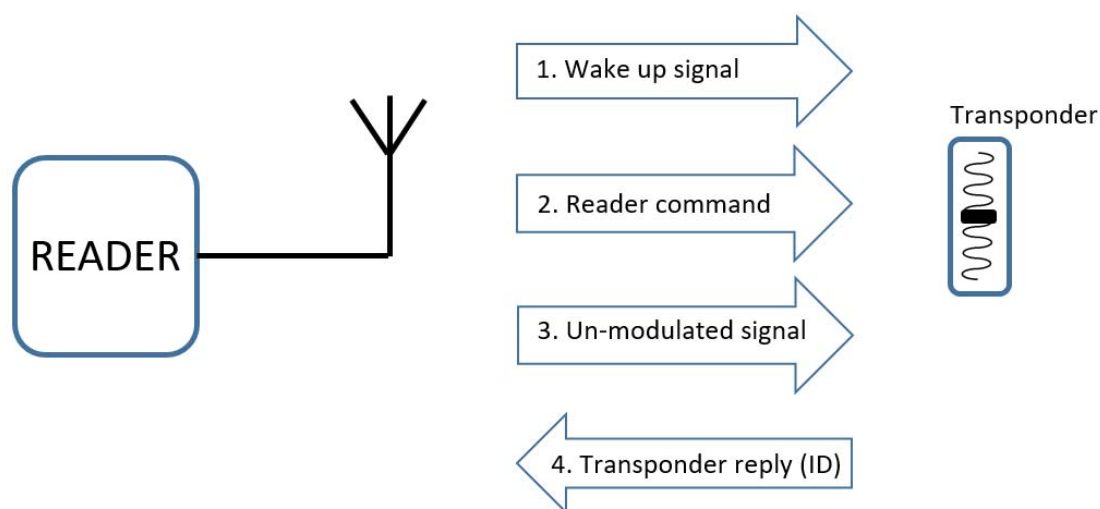


Fig. 2 Radio frequency identification (RFID) reader-transponder communication principle.

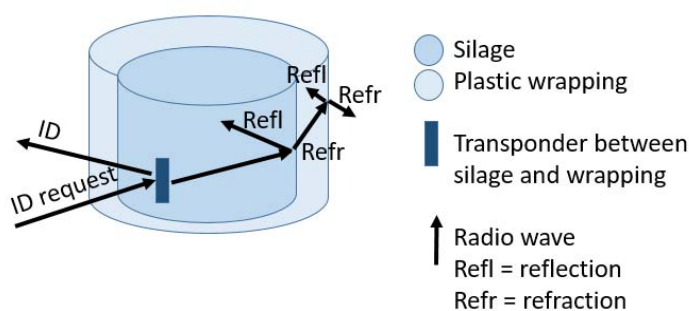


Fig. 3 Illustration of reflection and refraction principles in silage bale application.

causing strong wave propagation in the bale, which diminish the amount of radio wave reaching the transponder, and therefore diminishing the identification distance. The radio wave propagated inside the silage bale will quickly reach the edge of the bale, and then will partially reflect back to the bale, and partially refract to the plastic wrapping and further outside air. In addition, part of the radio wave will propagate as a surface wave along the silage and further causing improved identification performance at a certain angle, which are not perpendicular to the reader antenna, but at a slight angle compared to that. Fig. 3 presents reflection and refraction phenomena in silage bale application. To conclude, radio frequency

identification in silage bale application requires that transponder has strong ability to harvest and backscatter radio waves in challenging environment [20-23].

2. Materials and Methods

This paper examines the performance of passive RFID in silage bale application. In order to conduct required measurements, this chapter introduces and arguments chosen technologies and methodology.

2.1 Initial Tests and Test Results

Initial tests were taken to find out the best performing passive transponder. Totally four

potential transponder types with different microchips were tested and measured in terms of free air reading distance. Tests were taken in laboratory conditions. Then the best performing transponders were chosen for application measurements. Fig. 4 introduces the pictures of each tested transponder types. The choices of these transponders were based on manufacturer and retailer's recommendations.

The initial transponder test results are presented in Table 1. Results show that the Dogbone 425-1 shows best performance, and therefore it was selected for application measurements.

2.2 RFID Components

Radio frequency identification components were chosen based on performance criteria and integration to the baler application. Based on initial tests, Dogbone 425-1 transponders were chosen for first silage bale measurements. This transponder is presented in bottom left, in Fig. 4. In final application, three different readers are chosen to enable various different identification positions in

the Digibale application concept. For both initial test and the first bale measurements, Speedway UHF RFID reader was used consistently.

2.3 Manual Measurements: Methodology

Application measurements were taken outside, with real silage bale, as shown in Fig. 5a. Small holes were cut on the bale wrapping, and the chosen transponders were placed under the plastic wrapping. Before measurements, the cuttings were sealed with high quality tape to confirm that microclimate inside the silage bale wrapping remains as close as possible to the original. Cutting the bale is introduced in Fig. 5b. Totally eight transponders, shown in Fig. 6, were placed inside bale wrapping with even steps, to fulfilling the 360 degrees around the bale. Fig. 7 shows the measurement arrangement, and directions of wave propagation between transponder and reader antenna. The positions 4, 5 and 6 in Fig. 7 (numbered positions in the figure) are located in a way that the radio wave will propagate through the silage bale, which causes multiple reflection and refraction points presented in Fig. 3 [24-26].

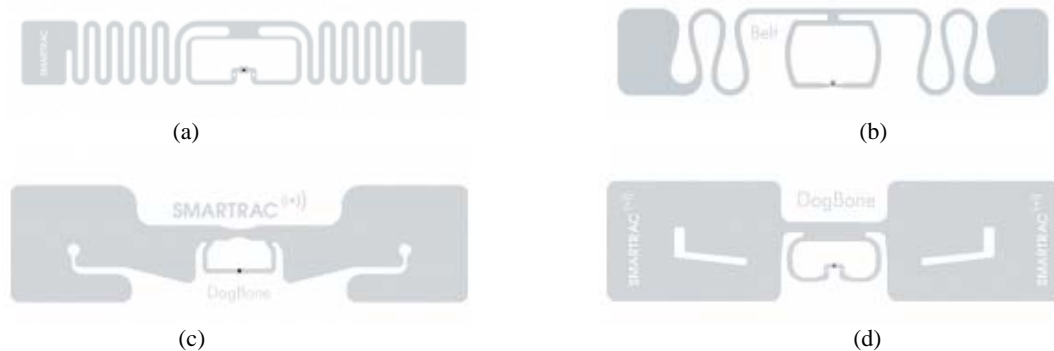


Fig. 4 Belt 387-1 (a), Belt 285-3 (b), Dogbone 425-1 (c) and Dogbone 391-2 (d).

Table 1 Transponder free air test results.

Transponder type	Free air reading distance in laboratory conditions in 0 degree angle towards the reader antenna, m	Free air reading distance in laboratory conditions in 90 degrees angle towards the reader antenna, m	Microchip type	Transponder size, mm × mm
Belt 387-1	2.6	3.0	G2IL	70 × 10
Belt 285-3	2.5	2.6	Monza 6	70 × 14
Dogbone 425-1	6.8	7.2	Monza R6	94 × 24
Dogbone 391-2	6.4	4.6	Ucode7	94 × 24



Fig. 5 Silage bale: (a) test bale (left); (b) bale cut (right).

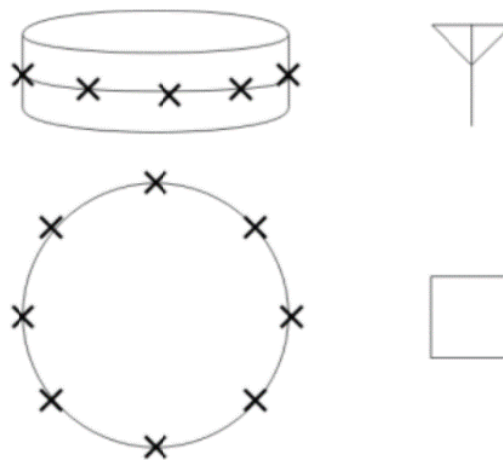


Fig. 6 Schematic view of transponder placements in bale (top: side view; bottom: top view).

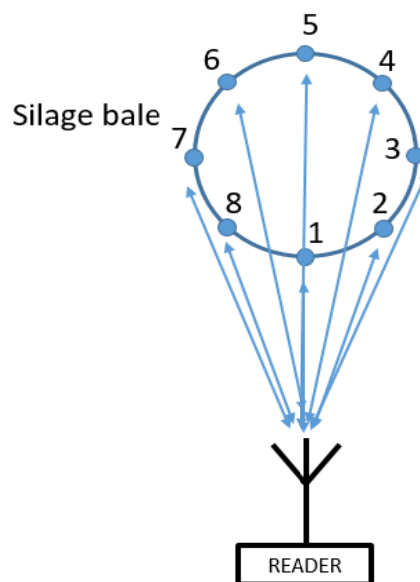


Fig. 7 Measurement arrangement, top view.

The identification distance was measured by moving the reader further from the bale, until the transponder inside the wrapping was no longer backscattering its identification code to the reader.

2.4 Automated Field Tests: Methodology

After manual measurements were finished successfully, the identification and measuring system were integrated to tractor and baler. The reader

(Sampo S2 by Nordic ID) and other hardware were placed in IP classed box in the rear of the tractor, as Fig. 8 shows. The system were powered by tractor, so separate battery was not needed. RFID antenna cable was led via tractor-baler axle to the baler, until the antenna, which was placed on a baler's support beam, as shown in Fig. 9. As antenna cable is rather fragile coaxial cable, it will not tolerate strong bending. Cable was attached tractor-baler other cabling, mounted

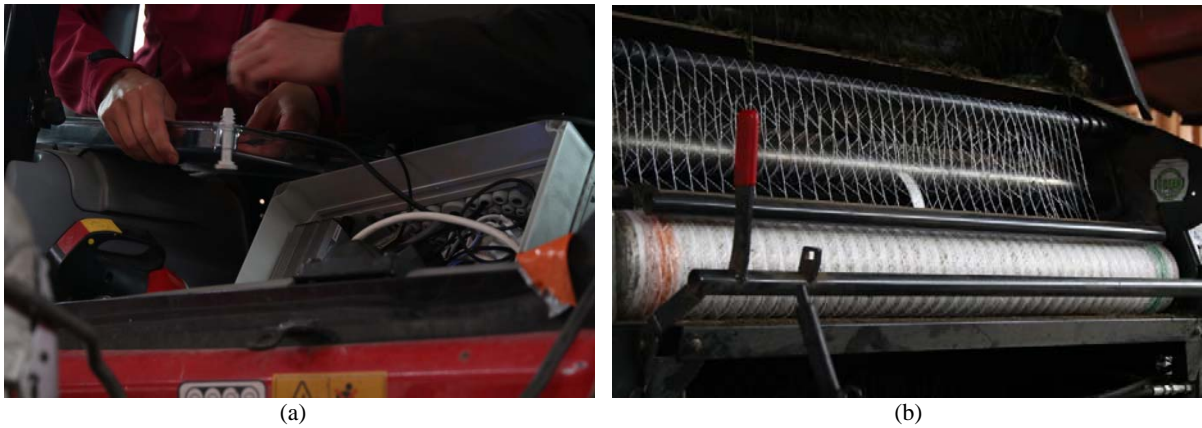


Fig. 8 Reader setup in the rear of the tractor (a) and silage bale net with passive RFID tags (b).



Fig. 9 Silage bale net with integrated RFID transponder (front), and reader antenna in back (white box).

further in baler side structure, and finally attached again to the baler's pillar structure. For field tests, normal bale net was replaced with a modified net, where the RFID transponders were fixed on every 10 m with plastic film with strong adhesive.

Aside of unique bale identification, the aim is to collect silage bale specific temperature and relative humidity data, and also harvesting location. Next step will be adding the last seen location also in the database, which enables that all bales are visible all the time, throughout their lifecycle. This arrangement requires that farmers have multiple RFID readers in different working phases: in baling process, in logistics and in cow houses. Every step is conducted in close co-operation with a group of farmers, i.e., innovation group of EIP-Agri Digibale project and transparently to farmer's community and stakeholders.

3. Results and Discussion

This section introduces and analyses measurement results for both manual verification and automated field tests.

3.1 Manual Measurements

Manual measurements are the basis of proofing the system operation. By conducting basic performance verification, operation in real baler machine can be estimated, and any nonfunctioning doubts can be verified, and further overcome.

The results for Dogbone transponder measurements are presented in Table 2. When the reader is facing the transponder (position 1 in Fig. 7), or being in small

angle against it (positions 2 and 8), the transponders are identified with sufficient distance. On the other hand, at positions 3 and 7, the transponder edge is facing the reader antenna, and the transponder antenna is not facing the transmitted wave. Therefore, transponder identification is not achieved with any distance. In positions 4, 5 and 6, the transmitted wave should propagate through the silage bale, which causes too much reflections and refractions, so that the electromagnetic wave elopes to its surroundings, and further attenuates in a way that the harvested wave does not give sufficient amount of energy to the transponder microchip to wake up and recognize the reader request.

3.2 Automated Field Tests

The results of automated RFID transponder field tests are presented in Figs. 10 and 11. These results are based on three test runs, where all the transponders were identified successfully. Fig. 10 gives a general map in the area of farmers' fields. The left corner of the figure shows, that totally 151 silage bales have been identified. Fig. 11 shows more closer look to the application software, and shows detailed location, and transponder related information on the left side of the map. Green circles in the map presents successfully identified transponders, while red dots are intentionally marked as fault ones. Nevertheless, this operation was manually tested to demonstrate farmer's possibility to add faulty mark to system in any problematic case, such as birds or rodents causing holes to bale's plastic layers.

Table 2 Manual measurement results in silage bale.

Transponder position in bale according to Fig. 7	Simultaneous identification of multiple transponders, OK/NOK	Maximum transponder identification distance, mm
1	OK	3,800
2	OK	1,700
3	NOK	0
4	NOK	0
5	NOK	0
6	NOK	0
7	NOK	0
8	OK	3,600

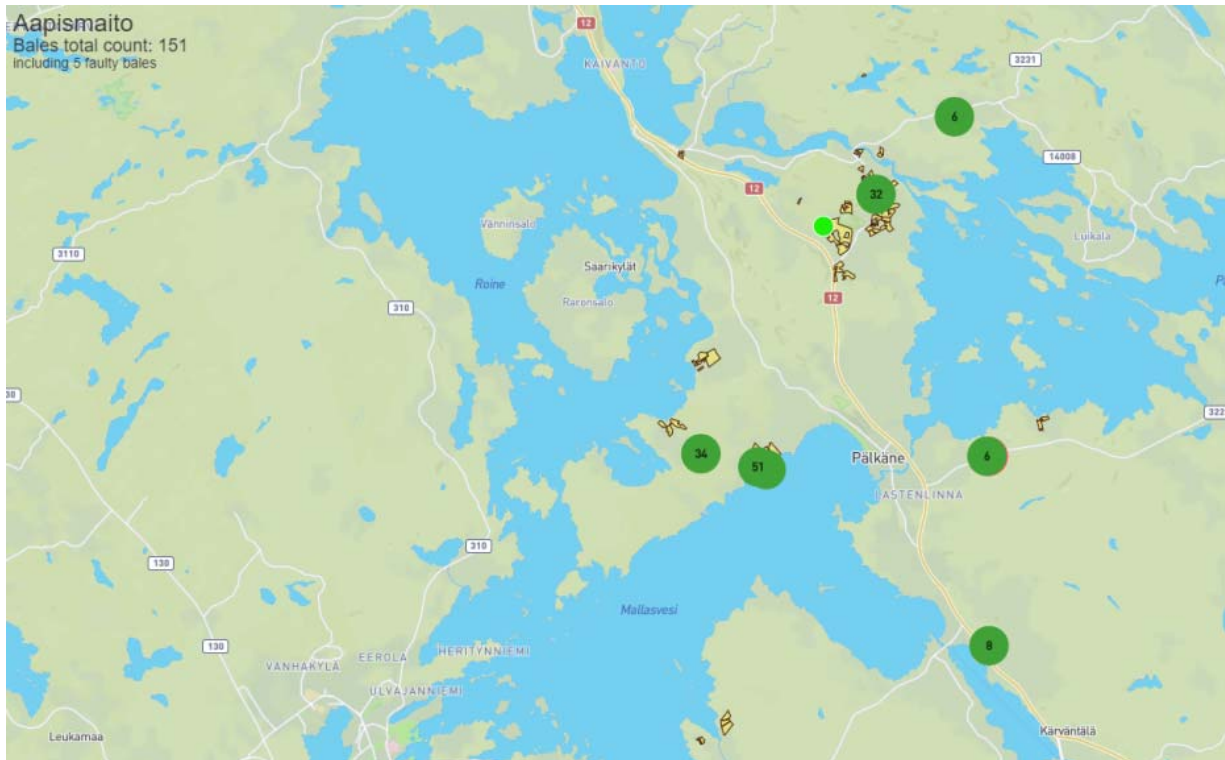


Fig. 10 Overview map of Digibale application/A. Juntunen HAMK.



Fig. 11 Zooming of Digibale map and unique bale information/A. Juntunen HAMK.

3.3 Discussion

The results achieved in this research show that passive RFID technology suits well to the identification of silage bales. Both manual measurements in stationary

environmental conditions and automated field tests in varying environmental conditions were conducted successfully, despite of stationary identification of full 360 degrees. In real application this lack was not seen a problem, as the bale is rotating in baler machine

during the wrapping procedure, enabling continuous transponder identification throughout.

In future work, this lack must be however considered carefully, as in manual treatment of silage bales, e.g., when moving bales from field to cow house, the tractor clamps may both need a reader antenna. The costs for an extra antenna are however rather low, less than €100, making the investment acceptable.

4. Conclusions

The results presented in this paper indicate that passive RFID technology is suitable for unique silage bale identification. Manual application measurements, where the transponders were attached to areal silage bale, between the silage and plastic wrapping, showed sufficient performance over 90 degrees angle, or ¼ of bale, at 1.7 m distance from bale edge. In addition, point-to-point identification, in 0 degree angle, gave maximum of 3.8 m identification distance. In addition, automated field test showed excellent performance with 100% identification certainty, with 151 transponder population. These results give good starting point to upcoming durability testing, where transponders' operation over Finnish winter condition is verified.

As next steps for the Digibale concept development and piloting are durability testing over wintertime, hardware improvement and multiple location stamps addition to database. Passive RFID transponders for challenging applications have been studied for many years, though based on author's best knowledge, silage bale transponder has not yet published or commercialized.

Acknowledgments

Authors would like to express their gratitude to Finnish Countryside Innovation Group (EIP) and Finnish Ministry of Agriculture and Forestry due to funding this project. In addition, authors are thankful to BSc Khoa Dang and Mr. Bao Tran from HAMK for

assisting the practical measurement part of this research.

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