Development of an information system for the traceability of citrus-plant nursery chain related to the Italian National Service for Voluntary Certification

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Abstract: At present, the production of certified plants in Italy, which is obtained by using propagating materials verified in terms of varietal trueness-to-type and phytosanitary condition, is guaranteed by the National Service for Voluntary Certification. The monitoring of productions and activities that are carried out in the centres established by the National Service for Voluntary Certification is crucial for the identification of both possible sources of disease risk and the destination of the propagating materials. In previous studies a methodology was proposed and applied to carry out the requirements analysis and specification for the development of an integrated computer-based information system for certified citrus-plant traceability. This study proposes a methodology for the implementation of the information system suitable to execute the previously designed functionalities. The use of PostgreSQL, a free and open-source object-relational database management system, allowed the implementation of the entity-relation scheme that included the information related to the managed propagating materials and the process activities defined by the certification program. System functionalities were implemented in applications developed on the basis of the client-server paradigm. The proposed methodology was applied to the case study of the Italian citrus-plant nursery chain. Specific information derived from plants and centres of the National Service for Voluntary Certification were included in the database along with the geolocation of both certified citrus plants produced in the nurseries and planted in the field and citrus mother plants. Geographic data acquired by using a GPS system were combined with other information concerning plant health condition and treatments with the aim to find out possible relations between the citrus-plant health status and the territory. The system implemented in this study allows the definition and utilisation of 'track and trace' procedures of propagation materials and plants that are in the certified Italian citrus-plant nursery chain, as well as the evaluation and prevention of the diffusion of the *Citrus Tristeza Virus* which causes one of the most damaging diseases in citrus orchards.

Keywords: citrus, certification, traceability, nursery chain, GIS, information system, plant diseases

Citation: Porto S.M.C., C. Arcidiacono, U. Anguzza, and G. Cascone. 2014. Development of an information system for the traceability of citrus-plant nursery chain related to the Italian National Service for Voluntary Certification. Agric Eng Int: CIGR Journal, 16(2): 208−216.

1 Introduction

The production of healthy and high-quality plants and plant propagating materials is of relevance and constitutes the main purpose of certification programs developed in several countries (Lee, 2004) to protect cultivation from local epidemics or exotic pests and diseases. In this regard, systems able to track and trace plants production have gained importance to improve safety of production and control the diffusion of plant diseases.

Although some authors (Hu et al., 2013) developed a methodology for the implementation of the vegetable supply chain traceability with a systemic approach, other authors adopted very simplified solutions in the design

Received date: 2013-10-18 **Accepted date:** 2014-04-17

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and implementation of the tracking data model (Serrano et al., 2008) or they managed information relating to the distribution of the product rather than to its creation (Li et al., 2010).

To build this kind of systems, as well as to solve technical and management problems arising from precision farming technologies implementation (Cangar et al., 2008; Porto et al., 2013) and computer software applications, specialized knowledge of information and communications technology (ICT) engineering is needed (Arcidiacono and Porto, 2008; Steinberger et al., 2009; Quendler and Boxberger, 2010). Though scientific advances in risk assessment and international warning systems for plant pests have been supported by the use of computer-based information systems, ICT systems that use Global Positioning System (GPS) (Barbari et al., 2006), geographic information systems (GIS) (Provolo, 2005; Nikkilä et al., 2010), and Radio Frequency Identification (RFid) systems (Porto et al., 2012) still have been little utilized in the work field of pest risk management (Rafoss et al., 2010; Luvisi et al., 2010). In this direction, computer-based traceability systems, which make use of different ICT applications, could represent a tool to enhance quality productions and rationalisation of production systems (Bernardi et al., 2008).

In a previous work (Porto et al., 2011a), the importance of designing and implementing integrated computer-based information systems (ICBISs), which incorporate data from different production centres and from existing farm information systems, to obtain supply-chain traceability of each plant by including the plant production process and data related to every sub-product was highlighted. In that study, general guidelines were defined for the design of ICBISs to implement supply-chain traceability procedures regarding certified plants for food, fresh fruit production and agro-processing industries. In another study (Porto et al., 2011b), a methodology was proposed and applied to develop the requirements analysis and specifications (RAS) phase of the ICBIS for the traceability of Italian citrus-plant nursery chain which complies with the National Service of Voluntary Certification (NSVC) established by the Italian Decree of July 24, 2003 (Ministry of Agriculture and Forestry, 2003). In the development of the RAS, product and process information allowed the implementation of the Entity-Relational (E-R) scheme and definition of the functionalities which the system must provide to the users. This information was gathered through interviews conducted at the Research Centre “Centro di ricerca per l’agrumicoltura e le colture mediterranee (CRA-ACM)” located in the municipality of Acireale (Italy), which includes the conservation and pre-multiplication centre (CCP), at the experimental farm “Palazzelli” located in the municipality of Lentini (Italy), which includes the primary source (PS), the pre-multiplication centre (CP) and a multiplication centre (CM), and at some Sicilian nurseries belonging to the NSVC.

To satisfy the requirements of the functionalities defined in the RAS phase it is necessary to develop a database of products and processes and build the software application which uses the database.

The activities described in this paper are part of a wider research aiming at the development of a ICBIS for the traceability of certified plants for food, fresh fruit production, and agro-processing industries. Specifically, this paper reports the methodology that was utilized to build the database of the citrus-plant nursery chain related to the Italian NSVC, the methodology used for the development of the software applications, which satisfy the requirements of the traceability functionalities defined in the RAS phase, and the activities that were needed to build a geographic information system of the citrus-plant nursery chain related to the Italian NSVC. At present, the system architecture is characterized by a centralized database used by centralized applications, whereas the system must be completed with a local database for every NSVC centre that contains a replica of the centralized database regarding activities, plants and materials of the considered NSVC centre, and local applications to manage local data, as described in the system architecture design reported in a previous study (Porto et al., 2011a).

2 Materials and methods

The building of the database and software applications required the use of a number of different software tools which serve the following functions: a) to build and manage a database which is able to store all the information represented in the relational data model (Codd, 1990); b) to provide web server features including the management of HTTP web requests from clients and the execution of server side applications; c) to build and manage a GIS which makes it possible to create static or dynamic maps, view the geographic maps through a desktop program or a web page, perform queries, analyse geospatial data (Arcidiacono et al., 2012), facilitate computation of indices through GIS analysis (Arcidiacono and Porto, 2010), and be often more comprehensible to a large audience.

The software tools used in this research are open-source software solutions that have their source code made available and licensed with an open-source license. In general, these solutions are used for research activities, yet the commercial purpose may be authorized according to the license or by purchasing commercial licenses. The software tools utilized were the following: PostgreSQL with the spatial database extension PostGIS enabled (Ruiz-Garcia et al., 2010), Apache web server and the module PHP used to run server side applications implemented in PHP language, Eclipse, and Quantum GIS (QGIS). These software tools, though they are free of charge, provide efficient solutions for the execution of their functionalities and are supported by worldwide organisations of developers.

2.1 Database design

The addition of the GIS functionality to those considered in the RAS phase required a revision of the conceptual E-R scheme, produced in previous analyses (Porto et al., 2011a). The changes, which were introduced in the scheme of Figure 1 in comparison to the previous work, are the following:

- The E-R diagram is composed of 14 entities, a unique ‘many to many’ relationship that links the entity ‘CENTRES’ with the entity ‘PROPAGATION MATERIALS’, a relation ‘one to one’ between the entity PLANTS and the entity ‘CERTIFICATED CARDS’, and 14 relations ‘one to many’. The two relationships that link the entity PLANTS with the entity ‘PROPAGATION MATERIALS’ make it possible to trace the genealogies of plants and propagation materials
- The previous entities ‘Breeder’, ‘Conservation_ premultiplication_centre’, Premultiplication_centre’, ‘Increase_block’, ‘Multiplication_centre’, and ‘Nursery’ have been replaced with the entities ‘CENTRES’ and ‘CENTRES TYPES’.
- The entity AREAS allowed definition of geographical areas where centres, nurseries, farms and plants belonging to the NSVC are present.
- The entity PLANTS represents both the plants present in the NSVC centres and the certified plants produced in the nurseries.
- The entity ‘PROPAGATION MATERIALS’ represents the propagation material extracted from the plants that are in the centres and utilised for the production of plants in the centres and the nurseries.
- The entity ‘GENETIC PHYTOSANITARY TEST’ represents the visual and genetic verifications performed to guarantee the varietal trueness-to-type as well as the phytosanitary tests carried out to guarantee the absence of known plant diseases.
- The entity CULTIVARS contains information about all the cultivars defined in the Italian national register of the varieties of citrus plant.

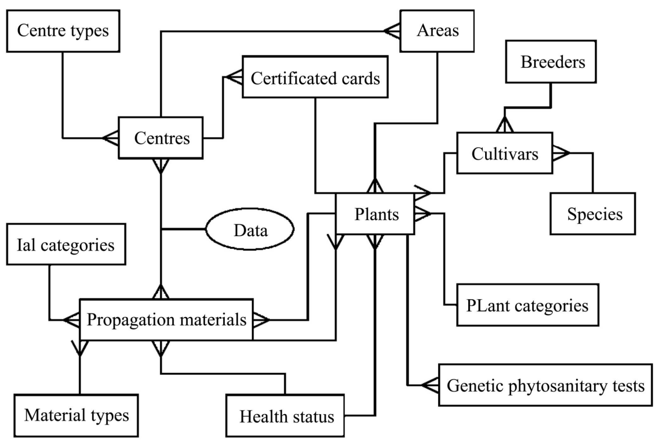

Figure 1 E-R diagram of citrus-plants nursery chain related to the Italian NSVC

To create the database, which was done by using the PostgreSQL database management system (DBMS), it was necessary to derive the relational model, i.e., the logical data structure suitable to represent the data within the DBMS. The relational model was obtained from the E-R scheme by applying the following five conversion rules (Codd, 1990): rule for entities, rule for attributes, rule for relationships 'one to many', rule for relationships 'many to many', rule for identification dependency.

The relational model was then given as input to the application PgAdmin (De Filippis et al., 2010), an open-source administration tool for PostgreSQL, which executed the building of the database and the tables by using the physical structures of the data that were in the PostgreSQL DBMS.

2.2 Applications design

The applications that implement the system functionalities were developed on the basis of the client-server paradigm (De Filippis et al., 2010). According to this paradigm, the 'back-end' logical level, i.e., the management functions and the queries on the data contained in the database, were separated and independent from the 'front-end' logical level, i.e., the user interfaces. These interfaces provided the user with the following services: show and make available the functionalities in a graphical way; activate the back-end functions to receive data; elaborate data deriving from back-end functions; and show the elaborated data. The subdivision of the functionalities into two logical levels simplified the development, optimisation and maintenance of the applications. Furthermore, the functionalities of the back-end can be utilized by different types of front-ends, e.g., stand-alone front-end and web-based front-end. In some research studies a web-based front-end was proposed (Serrano et al., 2008; Ruiz-Garcia et al., 2010; Busato et al., 2013) to build interactive tools that provide decision support, a flexible way of information access, and networking.

The back-end functionalities of the system were built within PostgreSQL through the implementation of stored-procedures by using the structured language PL/pgSQL. The use of this language made it possible to perform complex elaborations on data of the database tables, which could not be carried out by uniquely using SQL queries.

Front-end functionalities were implemented in a web application by using the PHP/Ajax technologies (De Filippis et al., 2010) inside the Apache web server (Serrano et al., 2008).

The GIS functionality was implemented by using the QGIS application. QGIS was connected to the PostgreSQL/PostGIS database and, as a consequence, the GIS is automatically refreshed when any data of the database is modified. To implement GIS functionality, the Regional Technical Map (scale 1:10000), provided in DWG format by the Sicilian Region, was utilized as base cartography (Arcidiacono and Porto, 2012). From this map, the feature classes related to the buildings, the administrative boundaries, the road system and hydrography were obtained and exported in SHP format. The building of the NSVC centres and the nurseries, where the registered plants were bred, were selected from the building feature class to constitute a thematic layer. Each feature attribute was stored into PostgreSQL tables.

Furthermore, another thematic layer was built from the information acquired by means of the GPS described in the following section. This information allowed the localisation of citrus mother plants and certified citrus plants located in other citrus orchards. Also in this case, the attribute data regarding the plants were stored in PostgreSQL tables.

2.3 Data geolocation

The GPS technology makes it possible to obtain the localisation of an object in space with a precision related to the technological level of the acquisition device, the device data elaboration method, e.g., GPS, Differential GPS, and Real-time DGPS, and the survey method, i.e., static method or cinematic method.

A Leica GPS 1200 (Leica Geosystems, USA) was the system utilized for the acquisition of the geographic coordinates of the citrus mother plants and the certified citrus plants located in other citrus orchards. The device, which is composed of a fixed base and a rover that communicate between them by means of two radio modems, makes use of a differential GPS. This system allowed the acquisition of plants' positions with an accuracy of about 10 cm.

By using the software Leica Geo Office the acquired data were exported in vector format and then imported in the GIS.

2.4 Plants and NSVC centres for database population

The population of the database required the census of the plants located in the involved centres and nurseries belonging to the NSVC. Each registered plant belongs to a cultivar among those defined in the national register of the varieties of citrus plant stored and updated at CRA-ACM. The number of cultivars was equal to 91. The structures that are in the NSVC centres, the categories of the bred plants and the categories of the extracted propagation materials are shown in Table 1.

Table 1 Census related to the plants bred in the NSVC centres

NSVC centres	Location	Number of the bred plants	Category of the bred plants	Plant-breeding conditions	Category of the extracted propagation material
PS	Palazzelli	One plant for each cultivar	Primary source	One insect-proof screen house with double doors	
CCP	CRA-ACM	Two plants for each cultivar	Pre-base mother plant	Two insect-proof screen house with double doors	Pre-base
CP	Palazzelli	Two plants for each cultivar	Base mother plant	One insect-proof screen house with double doors	Base
CM	Palazzelli	About 100 plants for each cultivar	Mother plant	Open field	Certified

3 Results

3.1 Database implementation

The relational logical model obtained by the application of the five conversion rules to the new E-R scheme was constituted by 15 tables.

Other three tables were defined to store the system users, the profiles of users' rights related to utilisation of the data contained in the tables, and the languages available for the information system utilisation. In Figure 2 a subset of the relational model is reported. Figure 3 shows some records of the tables PLANTS, AREAS and CENTRES which were obtained by the application of the conversion rules. The attribute 'area id' of the table PLANTS and the attribute 'centre id' of the table AREAS are called external keys and are used to define two logical links between the three tables. For instance, the records of the PLANTS table are logically connected to the records of the AREAS table if the value of the external key is the same as the value of the primary key of the AREAS table, i.e., the attribute 'area id'. Finally, Figure 4 shows the results of a query which joins information contained in the three tables.

Since the PostgreSQL database was extended to manage geographic objects by installing the PostGIS spatial database extender, it was possible to define also geometry attributes, which are spatial representation of geographic features, within the tables.

3.2 Applications implementation

The system back-end provided the system front-end applications with a number of functionalities among which the following ones figure prominently: to provide the characteristics of a plant; to provide the list of the plants located in a centre or a nursery of the NSVC; to provide the list of the infected plants; to identify the plants that provided the propagation material for the production of a considered plant; to identify the plants and the propagating materials involved, in relation to a possible contamination occurrence; to store and provide the flow of plants and propagation materials. These functionalities allow track and trace activities of the system to be performed and represent the fundamental tool for the operators of the chain to automatically control a great number of plants and materials located in different sites.

The system front-end is a web-based application (Figure 5) which provides the user with the following functionalities: the input of attribute values required to execute each of the functions available in the back-end; the execution of a function of the back-end; the visualisation of the results, in table format, including images and maps.

The GIS functionality allowed a number of operations such as the visualisation of the centres, nurseries and geolocated plants on a geographic map and the use of the information contained in the thematic layers to carry out queries aiming at highlighting the relation between the plants and the territory. As an explanation of the traceability function, for each citrus plant of the mother plant field or any certified citrus plant placed in the farm field outside the NSVC, the query "Plant traceability" made it possible to display on a map the localisation of all the plants that provided propagation materials for its production within the nursery chain.

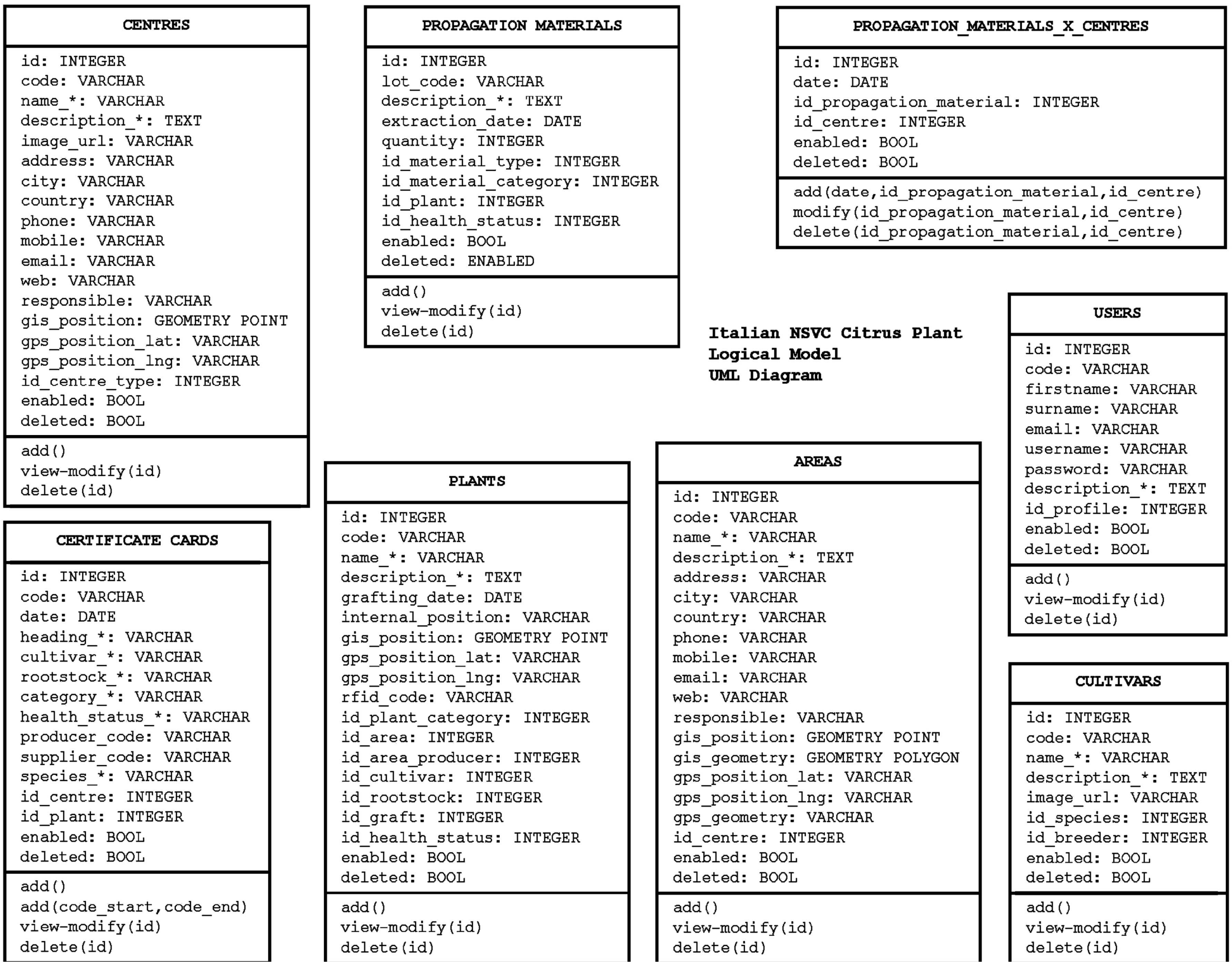

Figure 2 Subset of the relational model related to the information system of the citrus-plant nursery chain of the Italian NSVC

PLANTS table

plant id integer	plant code character varying	plant name character varying	area id integer
1	PLNT0001	A. Valencia S. Marino nuc. 55-1X-6	2
2	PLNT0002	Clementine SRA 89	1
3	PLNT0003	Microcitrus papuana	1
4	PLNT0004	Citrange Carrizo CRC 2863	1
5	PLNT0005	Lima Pursha x Chinotto (LEMOX)	2

AREAS table

area id integer	area code character varying	area name character varying	address character varying	city character varying	area geometry geometry(Polygon,4326)	centre id integer
1	AR0001	Acireale left building	Corso Savoia, 190	Acireale	00002AE5B512BACF42	1
2	AR0002	Acireale right building	Corso Savoia, 190	Acireale	0000ADC3D155BACF42	1

CENTRES table

centre id integer	centre code character varying	centre name character varying	centre description text	centre type character varying
2	CNTR0002	Palazzelli	Palazzelli primary source centre	PS
3	CNTR0003	Palazzelli	Palazzelli premultiplication centre	CP
1	CNTR0001	CRA-ACM Acireale	Research centre for citrus and mediterranean crops	CCP
4	CNTR0004	Palazzelli	Palazzelli multiplication centre	CM

Figure 3 Logical links ‘one to many’ between the records of AREAS and PLANTS tables and between the records of CENTRES and AREAS tables

plant code character varying	plant name character varying	area character varying	centre character varying
PLNT0002	Clementine SRA 89	Acireale left building	CCP (CRA-ACM)
PLNT0003	Microcitrus papuana	Acireale left building	CCP (CRA-ACM)
PLNT0004	Citrange Carrizo CRC 2863	Acireale left building	CCP (CRA-ACM)
PLNT0001	A. Valencia S. Marino nuc. 55-1X-6	Acireale right building	CCP (CRA-ACM)
PLNT0005	Lima Pursha x Chinotto (LEMOX)	Acireale right building	CCP (CRA-ACM)

Figure 4 Results of the JOIN operations performed on PLANTS, AREAS, and CENTRES tables

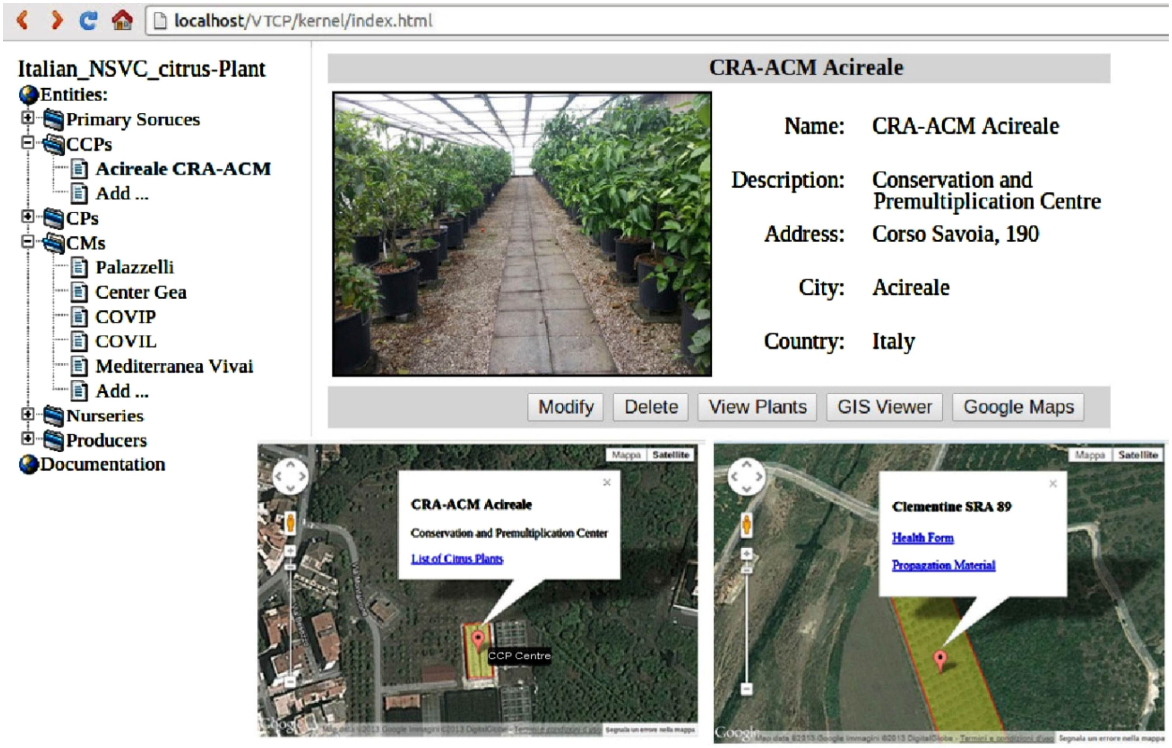

Figure 5 Screenshots of the software applications which implement the 'track and trace' procedures of citrus-plant nursery chain related to the Italian NSVC

4 Discussion

The method adopted to develop the RAS phase of the ICBIS for the traceability of the citrus-plant nursery chain related to the Italian NSVC, which was developed in a previous study (Porto et al., 2011b), yielded a number of valuable technical documents that are related to the flow of information regarding the Italian citrus-plant nursery chain for information exchange among operators of the citrus plant nursery chain and the ICBIS developers. In this regard, the E-R scheme and the system functionalities defined in the RAS phase were crucial to build the database and the applications and, as a consequence, the system implementation was facilitated. The description of the database implementation is a technical document of fundamental importance for the construction of the database. Though this description does not introduce an innovation in the construction of a relational database, it represents a novelty in the management of the Italian citrus-plant nursery chain because it makes it possible to represent the flow of information in the chain in an understandable way for both expert information system designers and experienced operators of the citrus-plant nursery chain.

The choice of using the client-server paradigm for the design of the applications that implement the system functionalities defined in the RAS phase made it possible to obtain a flexible ICBIS. Since the database is independent from the software implementation, it is possible, for instance, to add new functions to the actual applications or to develop a web-based front-end which would require that the final user utilise only a web browser, without the need of modifying the structure of the database.

Furthermore, since the considered open-source software is available on different platforms (i.e., Linux, Microsoft Windows, Apple Mac OS X), it was possible to obtain a multi-platform ICBIS. As a consequence of these choices, system versatility and costs are well balanced.

The system functionalities could be very useful for any operator in the traceability chain, from plant breeder to operators in charge of pathogen control, since they would profit from increased system efficacy against the *Citrus Tristeza Virus* in the territory (Lee and Bar-Joseph, 2000; Moreno et al., 2008).

Moreover, the population of the database at the local level would require an active collaboration of the farmers in keeping updated the information contained in the farm database.

Further improvements of the database population would involve the census of plants and propagation materials related to the other multiplication centres of NSVC. These centres were identified at “Center Gea”, in the municipality of Lamezia Terme (Italy); “COVIP”, in the municipality of Massafra (Italy); “COVIL”, in the municipality of Metaponto (Italy); and “Mediterranea Vivai”, in the municipality of Mazara del Vallo (Italy).

5 Conclusions

In this paper, the implementation and population of the database of the citrus-plant nursery chain as well as the software applications which implement the ‘track and trace’ procedures of propagation materials and plants related to the Italian NSVC were carried out by designing specific methodologies which made use of open-source software solutions and technologies for data geolocation. The application of these ‘track and trace’ procedures could facilitate getting knowledge of severe plant diseases diffusion, like *Citrus Tristeza Virus*, in the territory and support local authorities’ decisions with regard to plant diseases management.

From a technical point of view, a system suitable to collect and share traceability, geographical, plant physiological, and sanitary data as well as official registration was implemented in this work. Compared to other studies, the system achieved a complete data model representation and implementation of the plant nursery chain, allowed the track and trace of the activities related to the certified plant production process and provided detailed traceability information to farmers and operators of the citrus-plant nursery chain.

The system, which is usable with different operating systems (Linux, Microsoft Windows, Apple Mac OS X), is a web-based application that utilizes the open source PHP/Ajax technology inside the Apache web server and the PostgreSQL DBMS.

The efficiency of the system was achieved through the implementation of the client-server paradigm, which allowed the separation of both data management and query functions in the database from the web pages of the user interface.

The use of the structured language PL/pgSQL allowed the implementation of stored-procedures elaborations on data of the database tables that were managed by the PostgreSQL DBMS.

The GPS technology was utilised to get the localisation of citrus mother plants and the certified citrus plants placed in other citrus orchards.

However, when a targeted intervention of the operator in field controls is needed, it is useful to identify each certified plant directly in the field. Therefore, it is necessary to use plant identification devices which assure data security, robustness, and data storage capacity (Luvisi et al., 2010). To this aim, further research already in progress involves the identification of the nursery plants through the use of RFid tags.

Acknowledgements

This research was financed by the Sicilian Region within a project entitled ‘Metodologie innovative per la lotta alla tristeza degli agrumi’. Coordinator of the project: prof. Giovanni Cascone. Responsible of the objective OR3 ‘Realizzazione di un prototipo di sistema informativo informatico integrato di tracciabilità/ rintracciabilità di piante di agrumi certificate prodotte nella filiera vivaistica e successivamente collocate in campo’: Prof. Claudia Arcidiacono.

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