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REVIEW ARTICLE

Electronic identification technology for agriculture, plant, and food. A review

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Abstract Automation in agriculture should improve plant health, product quality, and production efficiency. However the actual use of electronic identification tools in agriculture is limited. Therefore, I review here electronic identification applications to support plant health and production and agricultural sustainability. The major points are as follows: (1) there is a tenfold increase of literature on the application of radio frequency identification in agriculture from 2000–2004 to 2005–2009. (2) Development of quick response code and radio frequency identification solutions are improving automated systems. (3) There is a major advancement in associating thermal sensors to electronic tags to preserve food quality and to manage temperature-controlled supply chain. Whereas tests with biosensors used for biological or chemical alerts are limited. (4) Agrochemical tagging, using radio frequency identification tags, improve plant health management and environmental monitoring. (5) While phytosanitary certifications are mandatory in high-cost cultivation systems and a need for risk management may promote radiofrequency identification (RFID) systems, the lack of specific economic analyses may discourage farmers and investors.

Keywords RFID · QR · Urban farming · Phytosanitary certifications · Food safety

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1 Introduction

The need for information about the origins and qualitative characteristics of food products or plants commercialized worldwide has increased due to consumer demands. This fact is due in part to recent negative events related to food production and has, in turn, led to stricter regulations to safeguard public health and ecosystems from the spread of pathogens. In an essential step to guarantee quality, the former European Economic Community beginning in the 1960s was involved in defining legal regulations regarding the health status of plants such as grapes and their production (European Economic Community 1968). The regulation of plant identity, health, and production continued to develop throughout the last decades in Europe (European Economic Community 1992; European Commission 2005), revealing its importance in the past 50 years. Regulations have followed the general trends in agriculture over the last century: not only with regard to new farming approaches and consequential environmental impact, but also the globalized trade of products, posing new challenges to import/export regulations. Food safety, market protection, property rights, and ecological conservation are common themes for "global" consumers and governmental agencies. These concepts have been reinforced by the EU through "The European White Paper on Food Safety."

Nowadays, many foods and agricultural products have to carry identifying labels or documents, as required by Community regulations (e.g., European Commission 2000), to establish a safe traceability system. In the EU, plants in the certified category must be in line with the most recent directives, and associated labels have to report essential data such as the nursery where they were produced. In Italy, the National Service of Voluntary Certification established guidelines for the traceability of citrus plants, defining technical documents necessary for the Italian citrus plant nursery chain information exchange among operators and integrated computer-based information system developers (Porto et al. 2014). Plant traceability, as in foods, can be supported by information technology and can be considered a useful practice in agriculture, as is the case for livestock. The information technology revolution, exemplified by the Internet, has made traceability and monitoring of food products, through the labyrinth of the agricultural product supply chain, economically feasible. Moreover, the pursuit of sustainable agriculture will also require substantial improvements in knowledge-intensive technologies to support farm decision-making (Byerlee 1996).

The need for knowledge is not limited to the products themselves, but involves also the production and supply chains. Thus, the "item"—foods or plants—can be managed by information technology systems within the "farm-to-fork" paradigm. The introduction of automation in agriculture concerns tools and technologies—many of those belonging to information technology—that can improve product quality and production efficiency. For example, in crop production industries, automated systems may improve efficiency and product quality and also reduce environmental impact, an unwanted side-effect of processing (Lee and Lee 2010). Eventually, these information technology solutions will require the extensive use of sensors or identification devices able to perform tasks (Lee and Lee 2010), leading to the creation of a network of items as conceptualized by the Internet of Things. Identification tools, such as radio frequency identification devices (RFID) or quick response code (QR code), may represent a prerequisite of Internet of Things application and they can be used for plant protection and management (Fig. 1), as well as food production and distribution, thanks to their easy integration within information technology systems. The aim of RFID technology is to acquire information about objects, animals, or people through microprocessors associated with them, as widely described with regard to the technology's basic characteristics (Finkenzeller 2003) (Fig. 2).

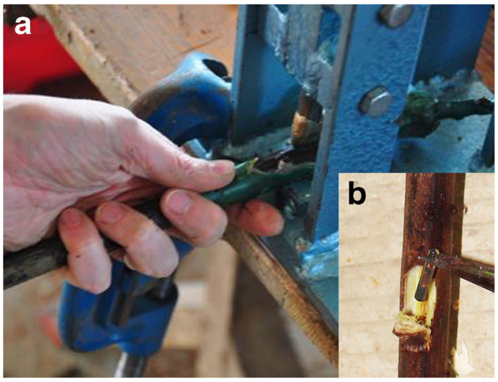

Fig. 1 Application of RFID glass tag to grapevine plant. Note the *U*-shaped blade (*a*) mounted in a lever that cut the rootstock to allow microchip insertion within pith (*b*). The procedure can be easily carried out in nursery by one operator. These tags can represent a safe tool to identify plants and foods that are protected by rights or subjected to specific regulations

The spread of electronic identification tools is outstanding, but applications in agriculture are lagging behind, with the exception of those for livestock in which various animal parameters, input, and output can be verified (Voulodimos et al. 2010). RFID systems permit remote monitoring of animals using dedicated hardware and software. Information related to the organism, item, or environmental factor is accessible via various monitoring stations and operators and can be updated and shared, thus representing a new approach to farm management. As reported by Adhiarna et al. (2013), many theories and approaches to discussing stages of information technology adoption are available, but few conceptual and empirical research studies discuss RFID stages of adoption to maturity. With regard to the agricultural sector, which is characterized by low information technology permeation, comprehension of the adoption phases of electronic identification tools, such as RFID implementation systems, is critical

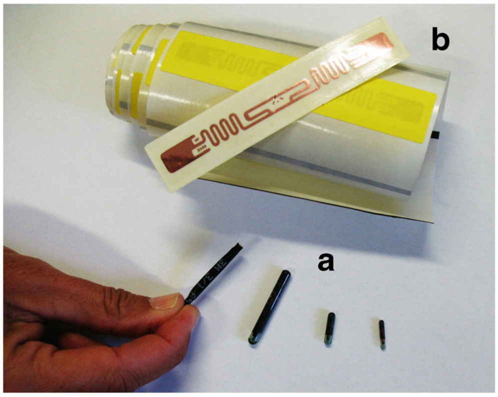

Fig. 2 RFID glass tags (*a*) can be easily implanted within plants and glass capsule is compatible with animal or plant tissue. Anyway, these microchips are quite expensive and few details about economic sustainability of these systems are available. Cheaper ones (*b*) can be difficult to apply due to their shape, dimension, and material composition and they need to be assembled into specific format, as the one handheld in figure

for policy and decision makers. In this way, the impact of electronic identification application in agricultural sustainability plays a major role in the success of its overall adoption.

2 How electronic identification can support food safety

Nowadays one-dimensional codes are printed on food packaging, linking the barcode to a homogeneous plant or food category, or to a certain batch. This traceability method is cheap, easy to carry out, and it can be managed by information technology systems. However, it cannot manage the single plant or food, and barcodes cannot properly work as sensors and have shown a limit for data transmission within Internet of Things application. Thus, other electronic identification tools such as RFID were applied for agri-food supply chain traceability (Costa et al. 2013). A limited number of studies have been conducted on consumers' perception of traceability, commonly of one particular product such as meat (Hobbs et al. 2005; Giraud and Amblard 2003) and not beliefs about traceability in general (van Rijswijk and Frewer 2006). Hobbs et al. (2005) state that although some consumers indicated a willingness to pay for a simple traceability assurance particularly for beef, the results of consumer research suggest that combining traceability with other quality assurances about farm production or processing methods may be a more viable product differentiation strategy in the red meat sector. To be effective as a product differentiation strategy, however, these quality assurances need to be credible. Studies underline that consumers have little notion about what traceability is (Giraud and Amblard 2003) and it seems that people are not very interested in the technical aspects associated with traceability. Moreover, the request for terms linked to traceability shifts from technical to general when skills and household income of consumers decrease. The higher the monthly household income of a consumer, the more that consumer seeks information about breeding conditions and the origin of meat. It is therefore unlikely that emphasizing the technical aspects of traceability is going to boost consumer confidence (Gellynck and Verbeke 2001). However, the widespread diffusion in the last years of electronic identification tools such as QR or near field communication (NFC) applications on mobile devices (i.e., smartphones and tablets) may have changed consumers' perception and confidence of traceability systems.

QRs are associated with plastic labels of mass-market plants and foods, and RFID can offer real options for wine cellar management and bottling (Exposito et al. 2012). Electronic labeling of high-value wine products using RFID systems and to combat forgery are principal areas of application, but they do not involve a cross reference to information about plant health or in-depth traceability. These electronic identification labels are external and are commonly associated with plant or food packaging. External labeling, even if it is easier and cheaper than internal labeling, does not avoid the risk of tag losses or removal. A "direct" labeling—internally or applied on the plant or food surface—may represent a safer method to ensure long-term identification, avoiding tag alterations. An interesting approach was proposed to mark plants and fruits with lasers. Laser marking of horticultural products was authorized in the USA by the Food and Drug Administration in 2012 and is mainly used for tagging citrus fruits with the potential to serve as a paperless marking method in horticultural production (Etxeberria et al. 2006; Sood et al. 2008). An interesting approach of laser marking was proposed by Marx et al. (2013) who marked two-dimensional patterns onto the surface of apple fruits and rhododendron cuttings with different laser systems. This labeling method can be successfully performed on small surfaces (3×3 mm^2) and may represent a rapid and inexpensive tracking method in plants and fruits, even if further studies should examine consumer behavior regarding marketability and possible changes in the taste of laser-marked fruits.

A safer electronic identification approach involved internal tagging, the integration of tags within an item. With regards to food plants, the implementation of information technology solutions to trace the plant-to-food chain by internal tags seems to be possible only in fruit trees, including grapevine, due to the difficulties in labeling and/or tracking herbaceous plants. In contrast to the situation with livestock, where technology plays an important role with electronically labeled and checked animals (Schroeder and Tonsor 2012), farms generally have a low level of computerization, due to both the costs involved and the lack of urgency to shift to a more in-depth traceability system (Luvisi et al. 2012a). However, available technology can satisfy the various needs thank to specially developed computer-based information systems (Porto et al. 2011) that may be integrated with tags and sensors. RFID tags can represent a safe tool to identify plants and foods that are protected by rights or subjected to specific regulations for plant identification (Bowman 2005) or for plant pathology purposes such as viruses or phytoplasma monitoring (Luvisi et al. 2012b, 2014).

The internal implanting of tags within foods was successfully carried out for cheese traceability (Papetti et al. 2012; Barge et al. 2014). Infotracing Web-based systems were designed to acquire basic link information that can be made available to the final consumer or to different food chain players before or after purchasing, using the RFID code to identify the single and specific cheese product. Techniques for fixing tags to the cheese and solutions for automatic identification, adapted to handling procedures as implemented in a dairy farm, were successfully tested, but some concerns need to be evaluated. The main issue is tag ingestion, which can be avoided by increasing the tag's visibility (Papetti et al. 2012). Another essential factor that needs to be investigated is the role of electronic identification tags as "food contact materials." In Europe, these materials are regulated by the Framework Regulation EC 1935/2004 (European Commission 2004) and they must not transfer their components into the foods in unacceptable quantities. Currently, there is a lack of analysis about tag compatibility with this regulation, even if a proper coating of special resins or plastic materials approved for food contact could allow their use (Barge et al. 2014).

The use of biosensors may represent the next step toward electronic identification systems able to guarantee safer foods and actively support their management. Up to now, electronic identification systems in agriculture have rarely been associated with sensors, with the exception of thermal sensors (Costa et al. 2013) (Fig. 3). The main advantage of adopting RFID technology in the traceability of goods is related to quality, especially when processing/storage temperature comes into play. Vergara et al. (2007) integrated, into RFID readers, micro-machined metal oxide gas sensors and showed how they can monitor climacteric conditions during transport and vending. Hertog et al. (2008) monitored tomatoes from growers to the retail chain, using RFID labels with integrated temperature sensors; similar studies were performed by Amador et al. (2009). A captivating approach derives from biosensors able to collect not only environmental data but also to check the quality of foods. Wentworth (2003) conducted a study aimed at inexpensive, disposable RFID biosensor tags used in food products for history checking and contamination, and inventory control. In this test, the biosensor was based on an acoustic wave platform and used antigen-antibody reaction to detect bacteria. Chandler (2003) discussed the potential of RFID tags for "smart packaging," automatic checkout, "smart appliances," "smart recycling," and marketing/promotional opportunities. Nowadays, approaches for modifying conventional RFID tags with chemically sensitive conductive composites were carried out. Fiddes et al. (2014) proposed the use of conductive composite films that can be integrated into the RFID tag circuit. As the film was exposed to selected chemicals, it swelled, increasing its resistance and decreasing the communicating ability of the RFID tag. In this test, using maleic anhydride as the sensing material, the composite was able to detect different biogenic amines associated with food spoilage. Thus, RFID tag response was found to depend on amine concentration and type of biogenic amine.

With regard to RFID literature relative to agriculture, excluding animal applications, the Scopus database reports a tenfold increment in the 2005–2009 period, compared to the previous 5-year interval; literature trends continued from 2010 to 2014, with a doubling of the previous period's increment. "Electronic identification" as a keyword generated similar trends.

In the last 10 years, QR and RFID solutions were developed mainly to improve automated systems, while a significant step was achieved by associating thermal sensors to electronic tags in order to preserve food quality and to manage temperature-controlled supply chains. Conversely, attractive tests with biosensor used for biological or chemical alerts are limited.

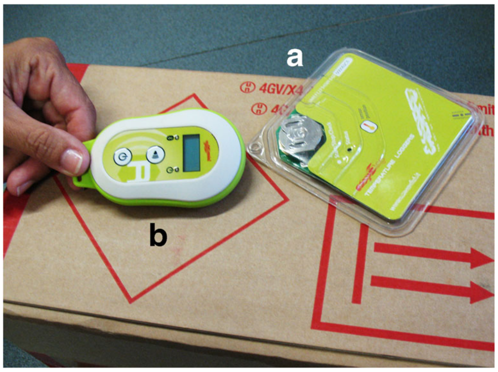

Fig. 3 RFID tags can be associated to sensors such as thermal one (*a*), readable by specific readers (*b*). These devices can be used for "smart packaging" to log temperature data and certificate the right stocking temperature of packages. Their lifetime is limited by battery charge but they can registered data continuously for more than a year

3 Plant protection and environmental monitoring using electronic identification tools

There are few analyses about the use of information technology for field measurements of environment variables, such as weather data and geo-referenced water quality data. In any case, even if at the beginning of this century, data collection still depended on stationary sensors and data loggers and simple pencils and paper notebooks (Vivoni and Camilli 2003), the approach seems to have drastically changed in the last few years, at least at the research level. However, the deployment of wireless sensors and sensor networks in agriculture and the food industry is still in its beginning stages (Wang et al. 2006).

The next generation of monitoring stations for agricultural application using electronic identification has been developed, as well as a tool to manage and share data among researchers. Applications of mobile devices with multi-tag technologies to automatically associate a field location to the relevant database tables or records, and also to access contextual information or services, were developed for vineyard management (Cunha et al. 2010). Systems able to collect land policy information and broadcast it to an office in real time were developed using a number of devices in a smartphone such as GPS or camera (Mesas-Carrascosa et al. 2012).

Electronic identification tools such as RFID can be used for plant health management, in particular for plant health inspection and certification (Luvisi et al. 2012b) (Fig. 4), agrochemical management, or impact assessment. The combination of tagging and hot water treatment against

Fig. 4 Microchips were read electronically by 14-length identification number, and the reading can be performed by mobile devices. According to plant growth rate, readers have to guarantee a sufficient reading range in order to retrieve data after years from tagging. Note that the reader is positioned a few centimeters from the grapevine trunk in proximity to microchip location

phytoplasmas (an increasing practice in Europe) was investigated and RFID tags were found to be useful for data storage regarding this specific treatment (Luvisi et al. 2014). RFID pesticide labels were suggested by Peets et al. (2009) in order to manage and track the use of agrochemicals. They suggested using existing national registration numbers as main product identifiers, store a minimum set of essential information on the label to make it usable independently, and reference existing national pesticide databases. Moreover, authors suggested the use of automatic recording systems can provide an audit trail of actions for an operator.

An interesting approach in agrochemical assessment may derive from in situ assessment of environmental quality carried out using honeybee biomarkers (Badiou-Beneteau et al. 2014). RFID technology is increasingly being used to study the behavior of insects (Robinson et al. 2009) and allows an accurate and automated way of monitoring their activity (Ohashi et al. 2010). An interesting approach is the use of RFID-tagged insects to monitor the impact of agrochemicals (Porrini et al. 2014; Feltham et al. 2014). RFID application for biomonitoring may derive from tags used for real-time data communication. Data from pollution-sensitive plants can be sent via wireless signaling regarding their management or environmental status (Luvisi and Lorenzini 2014). Other applications may derive from collaborative Web 2.0-based workspaces, that can be used to support sampling for health checks, exchange information between users and laboratories, and promote dematerialization (Luvisi et al. 2012c).

Plant health management and environmental monitoring can be efficiently supported by RFID tags, which are able to generate ecological feedback or improve automated systems. Generally, the dematerialization of data represents a common target of plant or agrochemical tagging.

4 Environmental implications of electronic plant identification

According to Hopwood et al. (2005), the usual model for sustainable development includes three separate but connected rings: environment, society, and economy. Among the major trends within sustainable development, a status quo view dominates policy, allowing for trade-offs between environmental and social issues regarding whether some pollution is acceptable to increase growth. The production and protection of plants is strictly linked to economic growth. Supporters of the status quo give priority to this fact and thus, for them, assessment of the economic sustainability of novel technologies in agriculture is of utmost importance. Furthermore, the food safety crisis of 2007–2008 and subsequent trends regarding consumer prices of food commodities (Maetz et al. 2011), as well as the 2008–2009 world economic crisis, have all had major impact on American, European, and Central Asian agriculture (Shane et al. 2009; FAO 2010), decreasing farmers' propensity toward risk.

In any case, even if global policy outlook is dominated by advocates of the status quo—also in agriculture—consumers' demands for safer and more wholesome products can be assimilated into a transformative approach, which embraces both social and environmental questions. Generally, this approach covers a range of viewpoints which, however, share the position that mounting environmental and social crises are interconnected and that there is risk of breakdown if radical changes do not occur (George 1999). Thus, "low impact" technologies to produce and protect plants, and which are able to save time for workers or for traceability, are commonly included among sustainable agricultural practices. Recently, the information technology is transforming societies and economies around the world and agricultural applications, at least from a theoretical point of view, are increasingly more frequent. These applications are often associated with "sustainable agricultural practices," as reported earlier. However, the interaction between information and communication technology and the environment is complex, giving rise to four different types of interaction (Williams 2011). The first considers these technologies as physically embedded in infrastructures and devices, the manufacturing, operation, and disposal of which have environmental impact. The second type of interaction relates to applications used to reduce environmental impact, such as smart buildings, teleworking, and optimized manufacturing. Expanding the boundaries, contributions of information technology to economic growth are both direct, in terms of the economic output of related sectors, and indirect, by promoting growth in other sectors such as agriculture. As Williams (2011) explains, at the broadest system level, these technologies are key to an info–nano–robotics–bio technological convergence that some believe will transform industry and society. Considering these first two interactions, some, although not conclusive, information about the tools necessary for electronic identification systems in plants is available, while there is a lack regarding the third and fourth interaction types which are addressed below.

Electronic identification systems for plants and foodstuffs may be considered an iconic representation of a high-tech solution for tomorrow's agriculture. However, in-depth cost-benefit analyses cannot be avoided before classifying these systems as "sustainable tools." The specific literature cited above is focused on in-depth testing of microchip and tag applications carried out under the general assumption that traceability is synonymous with sustainability. Even if ecological and production feedback represents a significant part of sustainable processes (Campbell 2009), their application must be considered within emerging systems of sustainable production, such as those based on agroecology, in which the role of technology is rigorously defined. Agroecology sets out principles by which rural communities can reach food sovereignty, as well as energy and technological sovereignty, within a context of resiliency (Altieri and Toledo 2011). By following these principles, which include exploiting environmental resources that derive from the biodiversity of the agroecosystem as well as locally available resources, farm production can go forward without external inputs, which in turn can lead to technological sovereignty. Application of such autochthonous technologies allows production of crops and animals able to satisfy household and community demands, thus generating food sovereignty (Altieri and Toledo 2011). Nowadays, it is difficult for developing economies and newly industrialized countries to reach technological sovereignty in terms of information technology tools, and it is not an easy task even for many advanced economies, especially after the 2007–2008 world financial crisis. Thus, the debate about if, and how, electronic identification tools should be considered sustainable tools needs to be carefully contextualized taking into account agricultural policies.

4.1 Economic sustainability

Economic sustainability represents a prerequisite for electronic identification applications in agriculture, particularly due to low capital investments for information technology improvements. Many studies report economic benefits of RFID application in non-agricultural production. In the apparel and fashion supply chain, RFID has proven to provide benefits at the operational level through increased visibility of material flows, labor reduction, and greater accuracy in retail operations, as well as providing new data useful to consistently increase sales and improve customer satisfaction (Bertolini et al. 2012). In inventory management, RFID technology offers possible solutions to the growing cost of inventory inaccuracy. However, different from tangible justification based on shrinkage reduction, adoption of RFID technology has to be justified with improvement in intangible information flow (Dai and Tseng 2012). Food tracking and tracing systems may benefit from RFID systems as they can improve internal logistic efficiency and thus reduce research time for materials and related costs, and define standards concerning the transfer of semi-finished products from cold stores to production halls (Fera et al. 2013). These applications can, theoretically, be transferred to the production of plants. Plant nurseries have to manage great numbers of plants, and visibility of materials, labor reduction, and accuracy of operations are common targets. Similarly, plant inventories require complex management in large nurseries that export their products worldwide.

With regard to the agricultural sector, applications were mainly directed toward product logistics (Amador et al. 2009; Jones et al. 2005; Purvis et al. 2006) and the tagging of living organisms relative to livestock (Reiners et al. 2009; Shanahan et al. 2009). However, few details about economic sustainability of these systems are generally available; even in a study by Heydera et al. (2012), data collected from 234 companies in the German food industry let to interesting results. The authors state that high external pressure to implement tracking and tracing systems (from legislation and retailers) improves the image of these systems in the sense that their use enhances a firm's status, increases the intention to use those systems, and fosters their perceived usefulness in the eyes of agribusiness executives. Unfortunately, the hypothesized negative cost effect on perceived usefulness and intention to invest could not be verified. Conversely, for application of digital farm management systems or plant traceability (Bowman 2005; Luvisi et al. 2012a), economic analyses are totally lacking.

It is necessary to develop methods to evaluate the economic feasibility of electronic identification in the supply chain that may support decision-making. A detailed RFID application was proposed by Irrenhauser and Reinhart (2014). RFID tools may be connected with different obstacles and benefits may not be easy to recognize and assess. More than two thirds of the companies involved in RFID application studies claimed that the integration of RFID in cross-company business is one of the biggest challenges. Further studies indicate that the central reason for the failure of RFID projects is the lack of profitability of RFID. This perception is underlined by the investments of implementation of this technology, especially additional expenses during operation. This hurdle may be particularly difficult to overcome in conventional farming, where investments for management are traditionally low. Moreover, the cost to implement the technology comes from licensing fees for software systems and tags, which need a different approach compared to Information technology investment in agriculture. As an example, the application of RFID glass tags to plants (Fig. 2), even if technologically affordable and biologically sustainable, seems difficult to apply due to the high cost of tags (Luvisi et al. 2012a), while cheap tags may be difficult to implant due to incompatibility in shapes or sizes, and thus they need to be specifically designed and tested. Some prototypes were developed and show good traceability performances (Luvisi et al. 2012b) (Fig. 2); their mass production could help spread this technology among nurseries.

A conceptual model of the farm management information system seems to lead agriculture toward the future (Sørensen et al. 2010) but involves the building of information technology infrastructures for which economic sustainability needs to be analyzed. In addition, benefits (even in non-agricultural sectors) are difficult to identify and economically appraise even considering quantitative-related applications such as logistics (Lee and Lee 2010). By using RFID, stocks can be reduced and the material flows are more efficiently generated beyond resource savings (Reinhart et al. 2011). Furthermore, RFID could reduce harvest costs for fruit producers (Ampatzidis and Vougioukas 2009; Ampatzidis et al. 2013). The proposed labor monitoring system can track and record individual picker's efficiency during manual harvesting of specialty crops, thanks to RFID wristbands and tagged bins. The system is able to record the effective amount of fruit harvested by workers by estimating worker efficiency in order to determine proper wages and promote fair work.

Qualitative influences, such as increased transparency and employee motivation, are the main challenges in quantification and may play significant roles in agricultural applications. Transparency is particularly relevant when considering plants and foods. Nowadays, plant identity—understood as the entire genetic, phenotypic, and health characteristics of the plant—is not only a matter of discussion for plant growers or researchers but it is also of interest, more or less directly, for the whole of society. Genetic and sanitary characterization is the first step to building a detailed and useful information package; however, it is also essential to define all the other relevant input and output factors in order to trace plants and relative products. Traceability may lead to technical difficulties requiring additional efforts to ensure a trouble-free processing of the material flow (Whitaker et al. 2007). In any case, the need of trouble-free processing for plants and foods is a requisite in many countries, even if traceability is not standardized. The United Nations General Assembly (1999), United States Department of Agriculture (2002), and European Union (European Commission 2002) have proposed various strategies, allowing specific regulations in member states, as in the EU. In this context, several manufacturers, retailers, and service companies have already established or are establishing traceability procedures in agriculture with the primary aim of reducing business risks (Regattieri et al. 2007). This voluntary approach to traceability can be standardized, following international standards such as the "Food safety management systems—Requirements for any organization in the food chain" (ISO 22000/2005), with the aim of harmonizing standards concerning food safety, and Hazard Analysis and Critical Control Points (HACCP). Even if this approach is not obligatory and is more oriented toward foods than plants, it represents a point of reference for stakeholders, supporting a virtuous circle of trust: the necessary information for standardizing production is linked to the identification of suppliers, participants in the production line, historic data, and client feedback. All these data have to converge on the product in itself, possibly through an archiving and management platform. But, how does the consumer link traceability to food quality and safety? Gellynck and Verbeke (2001) stated that traceability is usually linked to food risk and safety issues but can potentially be used to ascertain both food safety and food quality, i.e., helping to establish the authenticity of foods. Van Rijswijk and Frewer (2006) estimated consumer perceptions regarding the role and potential impact of traceability in Europe. Their results indicated that traceability, in the mind of consumers, was linked to safety as well as quality, whereas safety was implicated by traceability more often. In the study, quality seemed more important when choosing products because, as respondents indicated, the safety of the products should be guaranteed in any case and therefore it is not a purchase criterion. These types of economic analysis of electronic identification applications that consider these factors in agriculture are desirable in order to correctly evaluate the applications of tools in farms.

Moreover, the implementation of RFID means a complete conversion of data management. Currently, data management in agriculture relies largely on paper-based annotations or poorly integrated Information technology systems that need a complete overhaul toward RFID-compliant data management systems.

In this section, we have seen how in breeding and certified propagation programs, as well as in costly cultivations such as nurseries, the need for risk management can encourage a shift toward RFID systems, while a lack of specific economic analyses may discourage farmers and investors.

4.2 Social and environmental sustainability of cities

Economic reasons and food security may contribute to developing urban agriculture (Ackerman et al. 2014). This innovative approach to agriculture, other than providing a source of healthful sustenance that might otherwise be lacking, can also contribute to a family's income, offset food expenditures, or increase job opportunities. In addition, social aspects need to be evaluated. Gardens or rooftop farms may become places where people come together for socializing. As suggested by Ackerman et al. (2014), the largest urban farms also participate in community enrichment through job training and other educational programs, many of which benefit under-served populations. Finally, the role played by urban agriculture in the environmental sustainability of a city has to be underlined.

Urban farms may be considered a form of green infrastructure able to reduce urban heat islands (defined as higher mean temperatures in an urban area than the surrounding rural area) and mitigate the impact of urban storm water. A great environmental benefit may derive from the reduction of the energy embodied in food transportation thanks to the reduced number of miles that food has to travel from the farm to the table. It has been estimated that food typically travels about 2000 km to reach the table, while urban farming may reduce this distance to about 50 km for some foods (Peters et al. 2009). Thus, besides growing food, urban farming produces a range of benefits that can lead to the adoption of this approach in many contexts because it involves new opportunities for resource efficiency, new farming technologies, specific implementation processes and networks, new patterns of food supply, and new urban spaces (Thomaier et al. 2015).

However, close integration between farms and civilian buildings needs to be supported by a high-tech solution, as proposed in modern cities such as Singapore. To secure reliable vegetable supplies, the city needs to increase local vegetable production to a certain level of self-sufficiency because of erratic climatic conditions that can affect the production via traditional methods (He and Lee 2013). Aeroponics technology to produce fresh vegetables seems to be a good solution for Singapore, even considering its land extension: while it is not possible for arable land to be expanded horizontally, an urban farming system could increase the production area through vertical extensions. However, urban farming or complex growing systems such as aeroponic cultivation need automated systems able to reduce manpower and increase productivity. Thus, the use of smart devices (sensors and actuators), which have been tested through many studied, cannot be avoided (Zhou et al. 2013) and ubiquitous computing may serve as the backbone for management. Ubiquitous computing can be used for storing, retrieving, and updating information from vast skyscraper cultivation with vast amounts of crop production thanks to precise agriculture systems (Sivamani et al. 2014). This approach, based on the large-scale, real-time environment, needs effective monitoring and controlling services that can be achieved through ubiquitous computing in vertical farms. High-tech services such as farm management (Nikkilä et al. 2010), disease diagnosis (Manhire et al. 2012), and production sustainability (Kolhe et al. 2011) can be enriched in remote locations through web applications (Xia et al. 2011) and integration and identification devices may lead to effective Internet of Things applications for vertical farms or urban gardening.

Plants tagged with RFID may represent optimal candidates to be included in tree inventories, thanks to their easy integration within digital environments. Tree inventories can be considered useful tools to protect and enhance urban and rural forests, which help ensure healthy forests for generations to come. These systems help to maintain diversity in urban tree population, assess the health of the urban forest, and communicate with property owners. RFID systems can be used as safe systems for tree identification because city inventories need to be updated regularly in order to determine planting sites, help schedule tree maintenance work, and manage invasive pests (Luvisi and Lorenzini 2014). This environmental sustainability of cities can be supported by remotely controlled, sensor-based tree inventories. Currently, the monitoring of city activity or areas can be achieved using cameras, thanks to increasing resolution and integration with mobile devices. Moreover, the availability of post-processing software for image reading can also lead to the development of desktop or mobile apps able to “scan and read” the city targets, as well as trees or green areas, acting as bioindicator devices. Communication between the item monitored (i.e., the plant) and the monitoring device can be oriented by a long-range electronic identification system, increasing data exchange. The development of small unmanned aerial vehicles (UAVs) can lead to potential applications of this technology in urban farming. Since UAVs fly at low altitudes, they can collect very high resolution images that can be integrated with RFID technology in order to dialogue with tagged plants or data centers. Aerial remote sensing systems, enabling aerial 3D measurements of canopy structure and spectral attributes, are available with red-green-blue spectral attributes for each point, permitting high frequency observations of the tree canopy (Dandois and Ellis 2013). However, integration of unmanned aerial systems (UAS) into the national airspace is challenging for aviation authorities such as the US Federal Aviation Administration. A certificate of waiver or authorization can be requested for public aircrafts, even if the routine operation of UAS over densely populated areas is prohibited in the USA. In Europe, basic national safety rules are applied, but the rules differ across the European Union and a number of key safeguards are not addressed in a coherent way. The European Summit on 19 December 2013 called for action to enable the progressive integration of remotely piloted aircraft systems (RPAS) into civil airspace from 2016 onwards (European Commission 2014).

However, the debate about feeding cities is not only limited to questions of transportation. Analysis of the comparative life cycle inventory of environmental burden and resource use arising from the production of many key food commodities indicates how environmental sustainability is not always associated with local productions (Williams et al. 2006). In this in-depth study, the energy requirement and subsequent greenhouse gas emissions from the production of selected foods in the UK and some other countries was calculated. The authors showed that the global warming potential of food production is reduced when imports come from countries where productivity is greater and/or where refrigerated storage requirements are less, as opposed to the axiomatic preference for local produce.

To summarize, solutions commonly defined as “high-tech” for expected use in urban farming have to be carefully evaluated because they may be associated with even greater resource consumption and environmental impact since transportation reductions do not always compensate for those impacts.

4.3 Direct impact of electronic identification devices used for plants

Cleveland and Ruth (1998) define dematerialization as the idea that technological progress leads to reductions in the amount of materials or energy required to yield goods and services. Microchips can be easily considered a paradigmatic example of dematerialization since value and utility is high while the weight of the product is low. An analysis by Williams et al. (2002) indicate that fossil fuel and chemical inputs to produce one 2-g microchip are estimated as 1600 and 72 g, respectively, while secondary materials used in production total 630 times the mass of the final product. These results indicate the existence of a possible counterforce to dematerialization, a trend that Williams et al. (2002) term secondary materialization. Similarly, the total energy and fossil fuels used to produce a desktop computer including monitor are estimated at 6400 MJ and 260 kg, respectively (Williams et al. 2004). Even if the electronics industry has continuously shown improved performance in both its products and manufacturing processes in recent years, the energy and material impact of devices for electronic identification cannot be neglected (Table 1).

In terms of exposure to hazardous materials, electronic identification devices including tags, readers, and user’s hardware, can be assimilated with conventional information and communication technology items. Williams (2011) reviews a major concern about exposure to ancillary chemicals used in high-tech processing, in particular in the production of semiconductors and brominated flame retardants which are added to casings and circuit boards in electronics ostensibly to improve fire safety. With regards to materials and chemicals, the hardware used for personal computers included in the analysis is similar to that used for electronic identification systems.

Moreover, the widespread use of tags is a requisite to build up an effective Internet of Things network in cities, not only in private areas but in common green areas as well. Thus, the spread of small, almost invisible tags in the open environment, subjected to biotic stress, may lead to their scattering, polluting the areas in which they are deployed. With an increasing number of RFID labels in circulation, the question of end-of-life disposal of RFID labels becomes important, in particular if they are used in green areas. Nowadays, little information about end-of-life issues related to RFID tags is available. The issue of recycling and environmentally safe disposal of RFID devices has been raised for debate in European Commission (2007). According to the case study by Wäger et al. (2005) in which the potential impacts of smart labels on municipal solid waste recycling and disposal have been assessed, specific recycling processes to recover materials used for RFID labels would not be feasible. Unfortunately, most RFID tags are not biodegradable and contain metallic components, plastic, or other petrochemical-based materials, even if the development of completely biodegradable tags is underway for use in medical or food applications. Moreover, as tags become smaller, the different parts of tags are difficult to separate and the recycling procedure is difficult.

Even if end-of-life disposal of RFID labels is a difficult task, no less attention should be given to reading devices (i.e., laptop, mobile devices, identification gates), whose increased use is related to the greater amount of tagged items. Williams’ analysis (2011) included potential exposure following the disposal of information and communication technology devices with regard to three types of material: metals, brominated flame retardants, and compounds generated or used during recycling. Even if the data were collected from personal computers, the differences with electronic identification devices are limited and there is increasing the concern about their disposal. Moreover, as reported for personal computers (Kuehr and Williams 2003), rapid improvements in RFID performance mean to update the electronic identification systems every few years, increasing amount of waste computers. Moreover, different standards such as EPCglobal and ISO for the RFID sector do not promote practices such as the reselling of hardware, which can extend the lifespan of computers (Kuehr and Williams 2003).

Paradoxically, even if RFID is not a green technology itself, it can be used to reduce the carbon footprint in several applications such as refuse management, encouraging the re-use of containers, or reducing equipment by better asset management (Duroc and Kaddour 2012). Sensor-embedded products can be very useful for environmental sustainability of cities because they eliminate most uncertainties involved in product recovery by providing item-based life cycle information. These data are relative to the content of each product and component conditions, and may be useful to estimate the remaining useful life of the components. Once the data regarding the products are read by information systems, it is possible to make optimal recovery decisions (Ondemir and Gupta 2014).

Even if the energy used to fabricate microprocessors or for their use, including the supply chain for the materials used to produce them, has decreased dramatically in the last decades (Deng and Williams 2011), unresolved concerns derive from secondary dematerialization, exposure to hazardous materials, and difficulties to recycle tags.

Table 1 Some example of electronic identification systems applied to plants and derivatives. Traceability is the most recurring scope of applications. Even if ecological and production feedbacks, as well as dematerialization, can represent a significant part of sustainable processes, traceability cannot be considered synonymous of sustainability *tout court*

Technology	Application	Actual/potential benefits for sustainable agriculture	Authors
RFID	Internal implanting of tags in plants	Ecological feedbacks, biocontrol, automated systems, dematerialization	Bowman 2005; Luvisi et al. 2012b; Luvisi and Lorenzini 2014; Luvisi et al. 2014
RFID	Internal implanting of tags in cheese	Ecological feedbacks, automated systems, dematerialization	Papetti et al. 2012; Barge et al. 2014
RFID	Vineyard management	Ecological feedbacks, dematerialization	Cunha et al. 2010
RFID	Pesticide labels	Agrochemical management and impact assessment, dematerialization	Peets et al. 2009
RFID	Honeybee biomarkers	Agrochemical impact assessment	Porrini et al. 2014; Feltham et al. 2014
RFID	Fruit harvester	Fair work	Ampatzidis and Vougioukas 2009; Ampatzidis et al. 2013
Laser/QR	Laser marking of horticultural products and plants	Ecological feedbacks, dematerialization	Etxeberria et al. 2006; Sood et al. 2008; Marx et al. 2013
QR	Wine cellar management and bottling	Ecological feedbacks, dematerialization	Exposito et al. 2012
Thermal sensor	Thermal sensors for food and plant packaging	Automated systems, energy management in temperature-controlled supply chain	Vergara et al. 2007; Hertog et al. 2008; Amador et al. 2009; Costa et al. 2013
Biosensor	Quality check for food and plant packaging	Ecological feedbacks, biocontrol, automated systems	Wentworth 2003
Chemical sensor	Quality check for food and plant packaging	Ecological feedbacks, biocontrol, automated systems	Fiddes et al. 2014

5 Conclusions

Although many of the technologies of precision agriculture are relatively mature (i.e., GPS, GIS, and satellite or airborne remote sensing), there remains ample room for improvement, in particular considering urban areas or automatized contexts. The development of local or proximal sensors that can be used on farm equipment to determine the crop stage, soil conditions and chemistry, weed concentrations, the presence of insects, and other risk factors important for crop growth may be the key for applying high-tech solutions in agriculture (Lee et al. 2010). Electronic identification technology, if appropriately supported by information management systems, can help health controls and be a useful tool for managing risks related to environmental impact of production systems, chemical residues, and the worldwide spread of plant pathogens. However, this potentially positive interaction between information technology tools and the environment, which is increasing rapidly thanks to continuous research and novel applications in agriculture, represents only a part of the cost-benefit balance. As the direct impact of equipment and infrastructures for agricultural purposes has not yet been described in depth, how the term "sustainable" can be applied to RFID systems needs to be examined with further studies.

Even if information technology solutions can support management procedures, much still has to be done in order to create a virtual environment for plants, changing this fragmented agricultural "Internet of Things" into a coherent "Internet of Trees," in which regulations and best practices may converge in harmonized electronic labeling and databases, without losing the link between plants and foods. Indeed, the relationship between plants and foods is not just a simple question of input/output, but rather a complex system in which plant pathogens and their control play an important role. This link is promoted by the European Food Safety Authority (EFSA), the agency that provides scientific advice and communication on existing and emerging risks associated with the food chain and its work covers all matters with a direct or indirect impact on food safety, including plant protection and plant health, as included in the general objective and mission of the EFSA. Moreover, to increase the permeation of information technology in the agriculture sector, the orientation of policies adopted by countries need to change in order to support farmers during the transition from paper processes and management to digital ones. After the 2007–2008 food safety crisis, governments increased their direct interventions in markets and from late 2008 countries started giving more importance to medium/long-term policies by supporting agricultural production (Maetz et al. 2011).

A final consideration should be directed toward the role of traceability as it pertains to sustainability in a corporate food regime. Essentially, the main target of electronic identification systems for plants and foods is traceability with the origin of the product being crucial. Starting from Friedmann's arguments (2005), in which she suggests that certain relationships in emerging food contexts are defined by well-to-do consumer niches, supermarket strategies, environmental rhetoric, new complex forms of audits, inspections and traceability systems, as well as by new emblematic products such as those certified organic, Campbell states that this set of relationships is at the base of risk management systems, food traceability, green/healthy foods, and foods branded as geographically defined, generating a "Food from Somewhere" regime that functions in complete opposition to relationships that are based on the "Food from Nowhere" regime (McMichael 2002). Campbell (2009) states that if the focus is on one set of resilience dynamics, such as the need for ecological feedback and signals to trigger adaptive strategies, then the Food from Somewhere regime is richer in ecological feedbacks than the configurations characteristic of other contemporary and historical regimes. Similarly, the rapidity with which Food from Somewhere regime participants rush to incorporate carbon footprinting and "food miles" criteria in their audits signals that some kind of adaptive response to negative ecological feedback is taking place (Campbell 2009). Surely, the implementation of electronic identification devices can dramatically improve the available information flow and reinforce feedback authority. Moreover, they can be used—indiscriminately—to support different policies within the Food from Somewhere regime: they can be useful to guarantee short food miles for supporters of local productions as well as to certify the authenticity of an imported plant or food. Moreover, privileging supply chains to buy Food from Somewhere may create more ecological feedback but it does not automatically mean, at end of the supply chain, support for more equitable relations for the producer (Lawrence and Burch 2007; Campbell 2009).

Finally, powerful traceability tools such as electronic identification devices could improve forces of incorporation and exclusion. Giving privilege to producers who can meet stringent technological standards—commonly affordable in wealthier countries—and excluding suppliers who do not have the resources, or the cultural possibility to include information technology solutions in their farm management, such as farmers in third world countries, does not ameliorate the highly unequal balance of power between producers and the food industry.

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References

Ackerman K, Conard M, Culligan P, Plunz R, Sutto MP, Whittinghill L (2014) Sustainable food systems for future cities: the potential of urban agriculture. Econ Soc Rev 45:189–206

Adhiarna N, Hwang YM, Park MJ, Rho JJ (2013) An integrated framework for RFID adoption and diffusion with a stage-scale-scope cubicle model: a case of Indonesia. Int J Inf Manag 33:378–389. doi:10.1016/j.ijinfomgt.2012.10.001

Altieri M, Toledo VM (2011) The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. J Peasant Stud 38:587–612. doi:10.1080/03066150.2011.582947

Amador C, Emond JP, Nunes MCN (2009) Application of RFID technologies in the temperature mapping of the pineapple supply chain. Sens Instrum Food Qual 3:26–33. doi:10.1007/s11694-009-9072-6

Ampatzidis YG, Vougioukas SG (2009) Field experiments for evaluating the incorporation of RFID and barcode registration and digital weighing technologies in manual fruit harvesting. Comput Electron Agric 66:166–172. doi:10.1016/j.compag.2009.01.008

Ampatzidis YG, Whiting MD, Liu B, Scharf PA, Pierce FJ (2013) Portable weighing system for monitoring picker efficiency during manual harvest of sweet cherry. Precis Agric 14:162–171. doi:10.1007/s11119-012-9284-3

Badiou-Beneteau A, Benneveau A, Geret F, Delatte H, Becker N, Brunet JL, Reynaud B, Belzunces LP (2014) Honeybee biomarkers as promising tools to monitor environmental quality. Environ Int 60:31–41. doi:10.1016/j.envint.2013.07.002

Barge P, Gay P, Merlino V, Tortia C (2014) Item-level radio-frequency identification for the traceability of food products: application on a dairy product. J Food Eng 125:119–130. doi:10.1016/j.jfoodeng.2013.10.019

Bertolini M, Bottani E, Ferretti G, Rizzi A, Volpi A (2012) Experimental evaluation of business impacts of rfid in apparel and retail supply chain. Int J RF Technol: Res Appl 3:257–282. doi:10.3233/RFT-2012-028

Bowman KD (2005) Identification of woody plants with implanted microchips. HortTechnology 15:352–354, http://horttech.ashspublications.org/

Byerlee D (1996) Modern varieties, productivity, and sustainability—recent experience and emerging challenges. World Dev 24:697–718. doi:10.1016/0305-750X(95)00162-6

Campbell H (2009) Breaking new ground in food regime theory: corporate environmentalism, ecological feedbacks and the 'food from somewhere' regime? Agric Hum Values 26:309–319. doi:10.1007/s10460-009-9215-8

Chandler S (2003) *Vision of the future for smart packaging for brand owners*. Paper presented at the meeting of the International Conference on Smart and Intelligent Packaging, Barcelona, Spain

Cleveland CJ, Ruth M (1998) Indicators of dematerialization and the materials intensity of use. J Ind Ecol 2:15–50

Costa C, Antonucci F, Pallottino F, Aguzzi J, Sarriá D, Menesatti P (2013) A review on agri-food supply chain traceability by means of RFID technology. Food Bioproc Technol 6:353–366. doi:10.1007/s11947-012-0958-7

Cunha CR, Peres E, Morais R, Oliveira AA, Matos SG, Fernandes MA, Ferreira PJSG, Reis MJCS (2010) The use of mobile devices with multi-tag technologies for an overall contextualized vineyard management. Comput Electron Agric 73:154–164. doi:10.1016/j.compag.2010.05.007

Dai H, Tseng MM (2012) The impacts of rfid implementation on reducing inventory inaccuracy in a multi-stage supply chain. Int J Prod Econ 139:634–641. doi:10.1016/j.ijpe.2012.06.005

Dandois JP, Ellis EC (2013) High spatial resolution three-dimensional mapping of vegetation spectral dynamics using computer vision. Remote Sens Environ 136:259–276. doi:10.1016/j.rse.2013.04.005

Deng L, Williams E (2011) Functionality versus "typical product" measures of energy efficiency: case study of semiconductor manufacturing. J Ind Ecol 15:108–121. doi:10.1111/j.1530-9290.2010.00306.x

Duroc Y, Kaddour D (2012) RFID potential impacts and future evolution for green projects. Energy Procedia 18:91–98. doi:10.1016/j.egypro.2012.05.021

Etxeberria E, Miller WM, Achor D (2006) Anatomical and morphological characteristics of laser etching depressions for fruit labeling. HortTechnology 16:527–532, http://horttech.ashspublications.org/

European Commission (2000) *Labelling, presentation and advertising of foodstuffs*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3Al21090

European Commission (2002) Regulation (EC) No 178/2002 of 28 January2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:031:0001:0024:en:PDF

European Commission (2004) Regulation No 1935/2004 of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0004:0017:en:PDF

European Commission (2005) Commission Directive 2005/43/EC of 23 June 2005 amending the Annexes to Council Directive 68/193/EEC on the marketing of material for the vegetative propagation of the vine. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32005L0043

European Commission (2007) *Radio frequency identification (RFID) in Europe: steps towards a policy framework*. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007SC0312:EN:HTML

European Commission (2014) A new era for aviation: opening the aviation market to the civil use of remotely piloted aircraft systems in a safe and sustainable manner. Retrieved from http://ec.europa.eu/transport/modes/air/doc/com%282014%29207_en.pdf

European Economic Community (1968) *Council Directive 68/193/EEC of 9 April 1968 on the marketing of material for the vegetative propagation of the vine*. Retrieved from http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31968L0193

European Economic Community (1992) Council Directive 92/34/EEC of 28 April 1992 on the marketing of fruit plant propagating material and fruit plants intended for fruit production. Retrieved from http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:31992L0034

Exposito I, Cuinas I, Gomez P (2012) *Using radio frequency identification technology to track individual wine bottles*. Paper presented at the International Conference on Signal Processing and Multimedia Applications and Wireless Information Networks and Systems, Rome, Italy

FAO (2010) *The impact of the economic and financial crises on agriculture and food security in Europe and Central Asia: a Compendium*. Retrieved from http://www.fao.org/fileadmin/user_upload/Europe/documents/Publications/REU_TP/Compendium_en.pdf

Feltham H, Park K, Goulson D (2014) Field realistic doses of pesticide imidacloprid reduce bumblebee pollen foraging efficiency. Ecotoxicology 23:317–323. doi:10.1007/s10646

Fera M, Iannone R, Mancini V, Schiraldi MM, Scotti P (2013) Economic evaluation of RFID technology in the production environment. Int J Eng Bus Manag 5:39–52. doi:10.5772/56750

Fiddes LK, Chang J, Yan N (2014) Electrochemical detection of biogenic amines during food spoilage using an integrated sensing RFID tag. Sensors Actuators 202:1298–1304. doi:10.1016/j.snb.2014.05.106

Finkenzeller K (2003) RFID handbook: fundamental and applications in contactless smart cards and identification. Wiley, Munich

Friedmann H (2005) From colonialism to green capitalism: social movements and the emergence of food regimes. In: Buttel F, McMichael P (eds) New directions in the sociology of global development. Elsevier, Amsterdam, pp 227–264

Gellynck X, Verbeke W (2001) Consumer perception of traceability in the meat chain. Agrarwirtschaft 50:368–374, www.gjae-online.de

George S (1999) The Lugano report. Pluto, London

Giraud G, Amblard C (2003) What does traceability mean for beef meat consumer? Food Sci 23:40–64. doi:10.3166/sda.23.40-46

He J, Lee SK (2013) Impact of climate change on food security and proposed solutions for the modern city. Acta Horticult 1004(20):41–52, www.actahort.org/index.htm

Hertog MLATM, Yudhakusuma RF, Snoekx P, De Baerdemaeker J, Nicolaï BM (2008) Smart traceability systems to satisfy consumer expectations. Acta Horticolturae 768:407–415, www.actahort.org/index.htm

Heydera M, Theuvsena L, Hollmann-Hespos T (2012) Investments in tracking and tracing systems in the food industry: a PLS analysis. Food Policy 37:102–113. doi:10.1016/j.foodpol.2011.11.006

Hobbs JE, Bailey BV, Dickinson DL, Haghiri M (2005) Traceability in the Canadian red meat sector: do consumers care? Can J Agric Econ 53:47–65. doi:10.1111/j.1744-7976.2005.00412.x

Hopwood B, Mellor M, O'Brien G (2005) Sustainable development: mapping different approaches. Sustain Dev 13:38–52. doi:10.1002/sd.244

Irrenhauser T, Reinhart G (2014) Evaluation of the economic feasibility of RFID in the supply chain. Prod Eng Res Dev 8:521–533. doi:10.1007/s11740-014-0536-0

Jones P, Clarke-Hill C, Comfort D, Hillier D, Shears P (2005) Radio frequency identification and food retailing in the UK. Br Food J 107:356–360. doi:10.1108/00070700510602156

Kolhe S, Kamal R, Saini HS, Gupta GK (2011) A web-based intelligent disease-diagnosis system using a new fuzzy-logic based approach for drawing the inferences in crops. Comput Electron Agric 76:16–27. doi:10.1016/j.compag.2011.01.002

Kuehr R, Williams E (2003) Computers and the environment. Understanding and managing their impacts. Kluwer Academic Publishers, Dordrecht

Lawrence G, Burch D (2007) Supermarkets and agri-food supply chains: transformations in the production and consumption of foods. Edward Elgar, London

Lee I, Lee BC (2010) An investment evaluation of supply chain RFID technologies: a normative modeling approach. Int J Prod Econ 125:313–323. doi:10.1016/j.ijpe.2010.02.006

Lee WS, Alchanatis V, Yang C, Hirafuji M, Moshou D, Li C (2010) Sensing technologies for precision specialty crop production. Comput Electron Agric 74:2–33. doi:10.1016/j.compag.2010.08.005

Luvisi A, Lorenzini G (2014) RFID-plants in the smart city: applications and outlook for urban green management. Urban For Urban Green 13:630–637. doi:10.1016/j.ufug.2014.07.003

Luvisi A, Panattoni A, Triolo E (2012a) Radio-frequency identification could help reduce the spread of plant pathogens. Calif Agric 66:97–101. doi:10.3733/ca.v066n03p97

Luvisi A, Panattoni A, Bandinelli R, Rinaldelli E, Pagano M, Triolo E (2012b) Ultra-high frequency transponders in grapevine: a tool for traceability of plants and treatments in viticulture. Biosyst Eng 113:129–139. doi:10.1016/j.biosystemseng.2012.06.015

Luvisi A, Panattoni A, Triolo E (2012c) Electronic identification-based Web 2.0 application for plant pathology purposes. Comput Electron Agric 84:7–15. doi:10.1016/j.compag.2012.02.008

Luvisi A, Panattoni A, Rinaldelli E, Pagano M, Mannini F, Gribaudo I, Bandinelli R (2014) Application of tracking implants in grape hybrids: adjustments to production practices and new health-compliant methodologies. Comput Electron Agric 108:130–134. doi:10.1016/j.compag.2014.07.013

Maetz M, Aguirre M, Kim S, Matinroshan Y, Pangrazio G, Pernechele V (2011) *Food and agricultural policy trends after the 2008 food security crisis: renewed attention to agricultural development*. Retrieved from http://www.fao.org/3/a-ap237e.pdf

Manhire J, Moller H, Barber A, Saunders C, MacLeod C, Rosin C, Barr T (2012) *The New Zealand sustainability dashboard: unified monitoring and learning for sustainable agriculture in New Zealand*.

Retrieved from www.nzdashboard.org.nz/uploads/2/3/7/3/23730248/13_01_sustainability_dashboard_final_proposal.pdf

Marx C, Hustedt M, Hoja H, Winkelmann T, Rath T (2013) Investigations on laser marking of plants and fruits. Biosyst Eng 116:436–446. doi:10.1016/j.biosystemseng.2013.10.005

McMichael PD (2002) La restructuration globale des systems agro-alimentaires. Mondes Dev 30:45–54. doi:10.3917/med.117.0045

Mesas-Carrascosa FJ, Castillejo-González IL, de la Orden MS, García-Ferrer A (2012) Real-time mobile phone application to support land policy. Comput Electron Agric 85:109–111. doi:10.1016/j.compag.2012.04.003

Nikkilä R, Seilonen I, Koskinen K (2010) Software architecture for farm management information systems in precision agriculture. Comput Electron Agric 70:328–336. doi:10.1016/j.compag.2009.08.013

Ohashi K, D'Souza D, Thomson JD (2010) An automated system for tracking and identifying individual nectar foragers at multiple feeders. Behav Ecol Sociobiol 64:891–897. doi:10.1007/s00265

Ondemir O, Gupta SM (2014) A multi-criteria decision making model for advanced repair-to-order and disassembly-to-order system. Eur J Oper Res 233:408–419. doi:10.1016/j.ejor.2013.09.003

Papetti P, Costa C, Antonucci F, Figorilli S, Solaini S, Menesatti P (2012) A RFID web-based infotracing system for the artisanal Italian cheese quality traceability. Food Control 27: 234–241. doi:10.1016/j.foodcont.2012.03.025

Peets S, Gasparin CP, Blackburn DWK, Godwin RJ (2009) RFID tags for identifying and verifying agrochemicals in food traceability systems. Precis Agric 10:382–394. doi:10.1007/s11119-009-9106-4

Peters CJ, Bills NL, Lembo AJ, Wilkins JL, Fick GW (2009) Mapping potential foodsheds in New York State: a spatial model for evaluating the capacity to localize food production. Renew Agric Food Syst 24:72–84. doi:10.1017/S1742170508002457

Porrini C, Caprio E, Tesoriero D, Di Prisco G (2014) Using honey bee as bioindicator of chemicals in Campanian agroecosystems (South Italy). Bull Insectology 61:137–146, www.bulletinofinsectology.org/

Porto SMC, Arcidiacono C, Cascone G (2011) Developing integrated computer-based information systems for certified plant traceability: case study of Italian citrus-plant nursery chain. Biosyst Eng 109: 120–129. doi:10.1016/j.biosystemseng.2011.02.008

Porto SMC, Arcidiacono C, Anguzza U, Cascone G (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 16:208–216, www.cigrjournal.org/index.php/Ejounral/article/viewFile/2707/1923

Purvis AC, McGlasson WB, Kanlayanarat S (2006) Progressive challenges in horticultural supply chains: some future challenges. Acta Hortic 712:39–49, www.actahort.org/index.htm

Regattieri A, Gamberi M, Manzini R (2007) Traceability of food products: general framework and experimental evidence. J Food Eng 81: 347–356. doi:10.1016/j.jfoodeng.2006.10.032

Reiners K, Hegger A, Hessel HF, Bock S, Wendl G, Van den Weghe HFA (2009) Application of rfid technology using passive hf transponders for the individual identification of weaned piglets at the feed trough. Comput Electron Agric 68:178–184. doi:10.1016/j.compag.2009.05.010

Reinhart G, Irrenhauser T, Reinhardt S, Reisen K, Schellmann H (2011) Wirtschaftlicher und Ressourceneffizienter durch RFID [Economic and resource efficient RFID]. ZWF 106:225–230, www.zwf-online.de

Robinson EJH, Richardson TO, Sendova-Franks AB, Feinerman O, Franks NR (2009) Radio tagging reveals the roles of corpulence, experience and social information in ant decision making. Behav Ecol Sociobiol 63:627–636. doi:10.1007/s00265-009-0715-8

Schroeder TC, Tonsor GT (2012) International cattle ID and traceability: competitive implications for the US. Food Policy 37:31–40. doi:10.1016/j.foodpol.2011.10.005

Shanahan C, Kernan B, Ayalew G, McDonnell K, Butler F, Ward S (2009) A framework for beef traceability from farm to slaughter using global standards: an Irish perspective. Comput Electron Agric 66:62–69. doi:10.1016/j.compag.2008.12.002

Shane M, Liefert W, Morehart M, Peters M, Dillard J, Torgerson D, Edmondson W (2009) *The 2008/2009 World economic crisis: what it means for U.S. agriculture*. Retrieved from http://www.ers.usda.gov/media/160647/wrs0902.pdf

Sivamani S, Kwak K, Cho Y (2014) A design of web-based services using RESTful API for vertical farm. Life Sci J 11:763–767, www.lifesciencesite.com

Sood P, Ference C, Narciso J, Etxeberria E (2008) Effects of laser labeling on the quality of tangerines during storage. *Proceedings of Florida state horticultural society*, 121, 297–300. www.fcla.edu/fshs/

Sørensen CG, Fountas S, Nash E, Pesonen L, Bochtis D, Pedersen SM, Basso B, Blackmore SB (2010) Conceptual model of a future farm management information system. Comput Electron Agric 72:37–47. doi:10.1016/j.compag.2010.02.003

Thomaier S, Specht K, Henckel D, Dierich A, Siebert R, Freisinger UB, Sawicka M (2015) Farming in and on urban buildings: present practice and specific novelties of zero-acreage farming (ZFarming). Renew Agric Food Syst 30:43–54. doi:10.1017/S1742170514000143

United Nations (1999) *UN guidelines for consumer protection*. General Assembly resolution, 39/248. Retrieved from http://unctad.org/en/docs/poditcclpm21.en.pdf

United States Department of Agriculture (2002) *Traceability for food marketing and food safety: what's the next step?* Retrieved from www2.econ.iastate.edu/classes/econ135/lawrence/Traceability%20ERS.pdf

Van Rijswijk W, Frewer LJ (2006) *How consumers link traceability to food quality and safety: an international investigation*. Retrieved from http://ageconsearch.umn.edu/bitstream/10061/1/sp06va02.pdf

Vergara E, Llobet J, Ramírez L, Ivanov P, Fonseca L, Zampolli S, Scorzoni A, Becker T, Marco S, Wöllenstein J (2007) An RFID reader with onboard sensing capability for monitoring fruit quality. Sensors Actuators B Chem 127:143–149. doi:10.1016/j.snb.2007.07.107

Vivoni ER, Camilli R (2003) Real-time streaming of environmental field data. Comput Geosci 29:457–468. doi:10.1016/S0098-3004(03)00022-0

Voulodimos AS, Patrikakis CZ, Sideridis AB, Ntafis VA, Xylouri EM (2010) A complete farm management system based on animal identification using RFID technology. Comput Electron Agric 70:380–388. doi:10.1016/j.compag.2009.07.009

Wäger PA, Eugster M, Hilty LM, Som C (2005) Smart labels in municipal solid waste— case for the precautionary principle? Environ Impact Assess Rev 25:567–586. doi:10.1016/j.eiar.2005.04.009

Wang N, Zhang N, Wang M (2006) Wireless sensors in agriculture and food industry—recent development and future perspective. Comput Electron Agric 50:1–14. doi:10.1016/j.compag.2005.09.003

Wentworth SM (2003) *Microbial sensor tags*. Paper presented at the meeting of The Institute of Food Engineering, Illinois, USA

Whitaker J, Sunil M, Krishnan M (2007) A field study of RFID deployment and return expectations. Prod Oper Manag 5:599–612. doi:10.1111/j.1937-5956.2007.tb00283.x

Williams E (2011) Environmental effects of information and communications technologies. Nature 479:354–358. doi:10.1038/nature10682

Williams E, Ayres R, Heller M (2002) The 1.7 kilogram microchip: energy and material use in the production of semiconductor devices. Environ Sci Technol 36:5504–5510. doi:10.1021/es025643o

Williams E, Ayres R, Heller M (2004) Energy intensity of computer manufacturing: hybrid assessment combining process and economic input–output methods. Environ Sci Technol 38:6166–6174. doi:10.1021/es035152j

Williams A, Pell E, Webb J, Moorhouse E, Audsley E (2006) *Comparative life cycle assessment of food commodities procured for UK consumption through a diversity of supply chains*. Retrieved from http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=15001

Xia J, Tang Z, Shi X, Fan L, Li H (2011) *An environment monitoring system for precise agriculture based on wireless sensor networks*. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6117391andtag=1

Zhou L, Song L, Xie C, Zhang J (2013) Applications of internet of things in the facility agriculture. Comput Comput Technol Agric 6:297–303. doi:10.1007/978-3-642-36124-1_36